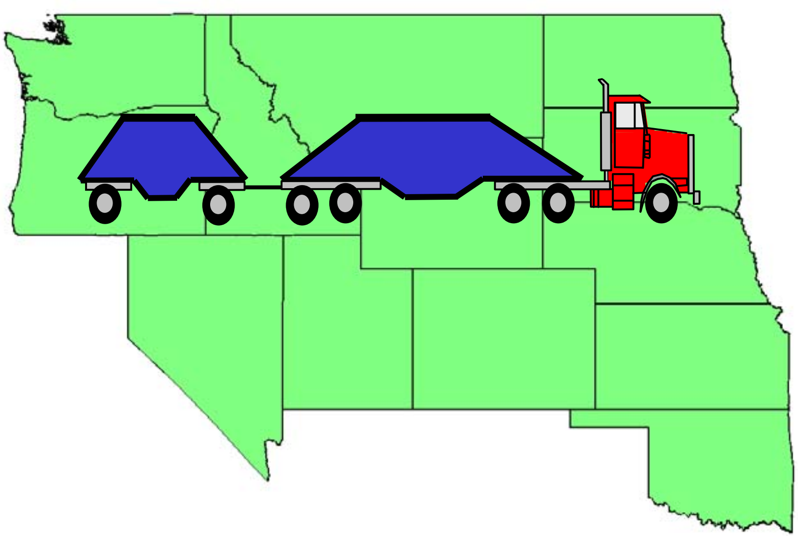
The U.S. Department of Transportation's

Western Uniformity Scenario Analysis



A Regional Truck Size and Weight Scenario Requested by the Western Governors' Association

April 2004

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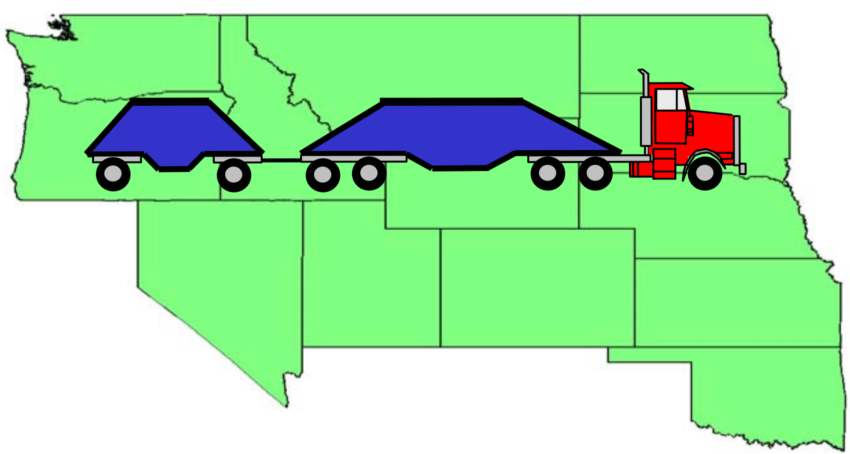
List of Acronyms

AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
BASIC	Bridge Analysis and Structural Improvement Software
BFB	Bridge Formula B
BNSF	Burlington Northern and Santa Fe Railway Company
CSX	
CTS&W Study	Comprehensive Truck Size and Weight Study
CWS	Carload Waybill Sample
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
FAF	Freight Analytical Framework
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
FSE	Freight Service Expense
GVW	Gross Vehicle Weight
HCA Study	Highway Cost Allocation Study
ITIC	Intermodal Transportation and Inventory Costing model
LCV	Longer Combination Vehicle
MPG	Miles per Gallon
MPH	Miles per Hour
NAPCOM	National Pavement Cost Model
NBI	National Bridge Inventory
NN	National Network for Large Trucks
RMD	Rocky Mountain Double
ROI	Return On Investment
STB	Surface Transportation Board
TPD	Turnpike Double
TS&W	Truck Size and Weight
UP	Union Pacific Railroad Company
U.S.	United States of America
WASHTO	Western Association of State Highway and Transportation Officials
WGA	Western Governors' Association

EXECUTIVE SUMMARY



Western Uniformity Scenario Analysis

Introduction

Longer combination vehicles (LCVs) have operated in Western States for many years. Grandfather rights in effect since 1956 have allowed those vehicles to exceed the 80,000-pound federal weight limit on Interstate Highways. Until 1991 States could determine the weights and dimensions allowed under their grandfather rights, but the LCV freeze instituted in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) prohibits States from increasing allowable LCV weights on the Interstate System or allowing longer LCVs on the National Network established in the Surface Transportation Assistance Act of 1982. Because grandfather rights in each of the Western States differ, allowable weights and dimensions for LCVs in most Western States vary.

As the U.S. Department of Transportation's *Comprehensive Truck Size and Weight (CTS&W) Study* was nearing completion, the Western Governors' Association (WGA) asked the U.S. DOT to analyze another illustrative truck size and weight scenario in addition to the scenarios already included in the study. The "Western Uniformity Scenario" requested by WGA would assess impacts of lifting the LCV freeze and allowing harmonized LCV weights, dimensions, and routes among only those Western States that currently allow LCVs. Specifically the WGA requested that DOT analyze impacts of expanded LCV operations assuming that weights would be limited only by federal axle load limits and the federal bridge formula, with a maximum gross vehicle weight of 129,000 pounds.

Scenario Impacts

Scenario impacts are assessed using the same general methods used to analyze impacts of illustrative scenarios in the *CTS&W Study*, although substantial improvements in data and certain analytical methods have been made since that study. Specifically, impacts on safety; pavement, bridge, and other infrastructure costs; shipper costs; energy consumption; environmental quality; traffic operations; and railroad revenues and costs associated with expanded LCV use in Western States are estimated. States included in the analysis are Washington, Oregon, Nevada, Idaho, Utah, Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma. No changes in size and weight limits were assumed for California, Arizona, New Mexico, or Texas. LCVs are not allowed in these States except on a short section of I-15 in Arizona that provides continuity of LCV operations between Nevada and Utah.

Throughout the report impacts are estimated for operations of two different long twin-trailer configurations, one that would have two 48-foot trailers as specified in the WGA request, and one that would have trailer lengths of 45 feet which is consistent with the Western Association of State Highway and Transportation Officials (WASHTO) "Guide for Uniform Laws and Regulations Governing Truck Size and Weight Among the WASHTO States." In this summary, only the impacts of the longer configuration are reported.

Estimated impacts, both positive and negative, of expanded LCV operations in the Western States are substantially smaller than impacts of nationwide LCV operations estimated in the *CTS&W Study*. Several factors account for these smaller impacts including the substantially lower volume of traffic that would be affected by the regional scenario, the lower weights and smaller dimensions assumed for LCVs in the Western Uniformity Scenario compared to the *CTS&W Study*, and the fact that at least some LCV operations already occur in each of the States analyzed in the scenario. This latter factor reduces traffic shifts to the new LCV operations assumed under the scenario and reduces infrastructure costs because the greater weights and dimensions of LCVs have already at least partially been reflected in infrastructure design.

Several types of traffic could be affected by the truck size and weight changes assumed in the scenario. These include short haul truck traffic that moves less than 200 miles, long haul truck traffic that shifts to LCVs from other configurations, rail carload traffic, and rail intermodal traffic. Table ES-1 shows 2010 freight traffic forecasts in the Western States under both current (base case) and scenario size and weight limits. Total truck traffic in the region is estimated to decrease by 25 percent under the scenario assumptions, with the vast majority of that decrease coming from the long-haul trucking sector. Less than one-tenth of one percent of rail traffic in the region is estimated to divert to LCVs under scenario assumptions.

Table ES-1
Forecasts of 2010 Base Case and Scenario Traffic Under Scenario Assumptions

	Base Case Traffic Volume (millions)	**Scenario Traffic**	
		Volume (millions)	**Percent change**
Total truck (VMT)	**18,823**	**14,028**	**-25.5%**
Short haul truck (VMT)	1,844	1,743	-5.5%
Long haul truck (VMT)	16,978	12,285	-27.6%
Rail Carload (ton-miles)	785,399	785,181	-0.03%
Rail Intermodal (ton-miles)	202,168	201,993	-0.09%

The extent to which traffic would actually shift to LCVs depends on relative transportation and other logistics costs for LCVs compared to the current mode of transportation. These relative costs, in turn, depend on specific characteristics of the shippers, the commodities being shipped, and the origins and destinations of the shipments. The Federal Highway Administration has analytical tools that estimate the influence of these various factors on mode and vehicle choice.

While the data may not reflect the actual costs that a specific firm would face when deciding which mode and which type of vehicle to use in transporting specific commodities from one point to another, they are believed to be representative of commodity movements within and through the study region.

Table ES-2 shows 2010 forecasts of truck traffic by major vehicle configuration for the base case and under scenario assumptions. Estimates of base case LCV travel rely on State-reported traffic counts and analyses of vehicle classification and weigh-in-motion data, but these data collection systems are not designed to provide statistically reliable estimates of total LCV travel. Other data sources including the Census Bureau's Vehicle Inventory and Use Survey have been used to supplement the State reported data, but there is considerable uncertainty about the amount of LCV traffic in the scenario States. Previous studies, especially those focusing on LCV safety, have also noted this uncertainty in the extent of LCV use.

Table ES-2
Forecasts of 2010 Base Case VMT by Vehicle Configuration and Western Uniformity VMT Impact for 13 Analyzed States

Vehicle Configuration	Base Case VMT (millions)	Scenario	
		VMT (millions)	Percent Change
5-axle Tractor Semitrailer	14,476	3,442	-76%
6-axle Tractor Semitrailer	1,924	938	-51%
5- or 6-axle Double	1,351	750	-44%
6-axle Truck Trailer	626	607	-3%
7-axle Double	188	2,190	+1,065%
8- or more axle Double	213	5,626	+2,541%
Triples	45	473	+951%
Total	**18,823**	**14,028**	**-25%**

Despite the fact that LCVs are allowed in all States covered by the scenario, conventional tractor-semitrailers and short twin trailers currently are estimated to account for 94 percent of total heavy truck travel in the region. If all Western States covered by the scenario adopted the scenario weight and dimension limits, there would be an estimated 76 percent reduction in travel by conventional 5-axle tractor-semitrailers, a 44 percent reduction of STAA doubles (5 or 6-axle twin trailers with maximum trailer lengths of 28.5 feet) travel, and a 25 percent reduction in total heavy truck travel. Because shipments that would divert to LCVs are longer than shipments that would not divert, the decrease in total travel is greater than the decrease in shipments by tractor-semitrailer. On a tonnage basis less than half of tractor-semitrailer shipments were estimated to divert to LCVs.

Reductions in conventional truck travel would result in large percentage increases in LCV travel. Nearly a twenty-fold increase in LCV travel is estimated if LCVs were allowed to operate in Western States according to assumptions in the Western Uniformity Scenario. Over half of that travel would be expected to occur in twin trailer combinations with 8 or more axles that can carry gross weights up to 129,000 pounds.

Table ES-3 shows how current and projected LCV use varies by the type of shipment. LCVs currently account for about 9 percent of total VMT for shipments entirely within the region. Under scenario assumptions that percentage is projected to grow to 78 percent. Currently LCVs are used very little for shipments where one or both trip ends are outside the region. Under scenario assumptions about half the VMT within the region for such shipments would shift to LCVs. This would require carriers to assemble and disassemble the LCVs for travel in States outside the region that do not allow LCVs. Clearly the ability of various types of carriers to efficiently manage such operations would vary, but the cost savings of operating LCVs throughout the region would make them attractive, even for many shipments with trip ends outside the region.

Table ES-3
Change in LCV Use by Shipment Type

Shipment Type	Percent of VMT in LCVs	
	Base Case	Scenario
Intra-Regional	9.2%	78.0%
Inbound	0.3%	58.3%
Outbound	0.3%	52.1%
Through	0.0%	49.2%
Total	2.4%	59.1%

Changes in the amount and characteristics of truck travel under scenario assumptions would affect long-term pavement and bridge costs, and could necessitate interchange and other geometric improvements to accommodate the larger trucks. Table ES-4 shows estimates of these added infrastructure costs associated with expanded LCV operations under the Western Uniformity Scenario. Despite the fact that more LCVs with higher gross weights could be expected to operate under the scenario assumptions, total pavement costs could actually decrease somewhat. Estimates in this study are that pavement costs in the scenario States could decrease by more than 4 percent under the Western Uniformity Scenario. Several factors account for this decrease including the reduction in total truck VMT, a shift of some traffic from lower-order highway systems to the Interstate System that typically has stronger pavements, and the fact that axle load limits are assumed to continue to control loads on individual axle groups. Incremental pavement costs attributable to the scenario were estimated by calculating the difference between total pavement improvement costs over a 20-year period in the scenario States under current size and weight limits and total pavement costs assuming the estimated VMT and weight distributions under the scenario size and weight limits.

As noted in Chapter V, many factors would affect bridge costs if States were allowed to change size and weight limits in accordance with scenario assumptions. Based on information in FHWA's National Bridge Inventory, many bridges in the Western States are being stressed beyond their design levels by vehicles operating under current State size and weight limits and permitting practices. Since bridges are designed with large safety factors, the overstressed bridges are not in danger of collapsing, but their safety margins are reduced. Based on assumptions discussed in Chapter V about long term needs to replace or strengthen overstressed bridges, base case bridge improvement costs attributable to overstress by vehicles currently operating in the scenario States range from about $1.6 billion to $3.3 billion. Incremental costs to accommodate vehicles assumed to operate under the scenario range from $2.3 billion to $4.1 billion. Thus bridge improvement costs in the region attributable to bridge overstresses are estimated to more than double under the Western Uniformity Scenario. Twenty-year average annual bridge costs to either replace or strengthen overstressed bridges were estimated by simply dividing total estimated costs by 20. In practice, States might not be able to spread bridge improvement costs over a 20 year period, but they would not have to improve or replace all bridges before LCVs could use the bridges.

Table ES-4
Added Infrastructure Costs Attributable to the Western Uniformity Scenario
(millions of 2000 $)

Infrastructure Element	Base Case Improvement Costs	Total Incremental Cost	20-Year Annual Incremental Cost	Percent Change in Base Case Costs
Pavement Improvements	65,934*	-2,769	-138	-4.2
Bridge Improvements	High 3,257	4,125	206	+127
	Low 1,586	2,328	116	+147
Geometric Improvements	864	776	65	+90

* Total estimated pavement preservation cost in scenario States. Base case costs cannot be linked to vehicles with particular weights and dimensions as can bridge and geometric costs

Incremental pavement and bridge costs attributable to the Western Uniformity Scenario are primarily related to the increased weight of vehicles operating in the region. Increases in vehicle length could affect the ability of vehicles to stay within their lanes on curves and to negotiate intersections and freeway interchanges. Like bridges, some highways have geometric design deficiencies to accommodate operations of the current fleet. For instance long vehicles may not be able to avoid running on the shoulders of some interchange ramps or may not be able to stay within their lane when traveling on winding sections of road. Ideally such geometric problems should be corrected, but within the scope of a highway agency's total highway improvement needs, such improvements may be deferred unless they are judged to be a significant safety issue.

Base case costs to improve curves, intersections, and interchanges to accommodate vehicles already operating in the Western States are estimated to be $864 million, $713 million of which is on the Interstate System. Under assumptions of the Western Uniformity Scenario, geometric improvement costs would nearly double to $1,640 million. Like bridge improvements, geometric improvements do not all have to be made before the longer vehicles could operate, but in certain locations safety could be compromised if geometric improvements were delayed. In other locations the primary impact of geometric deficiencies is higher maintenance costs, although when a vehicle cannot stay within the traveled lane there can be a potential safety problem.

In addition to infrastructure costs, there would be several other potential impacts of expanded LCV operations under assumptions in the Western Uniformity Scenario. The most important of those impacts is safety. Other impacts include traffic operations, energy consumption and emissions, and rail competitiveness.

The *CTS&W Study* highlighted many uncertainties that make estimating safety impacts of changes in truck size and weight limits difficult. Data on the number of fatal crashes involving LCVs are available from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System and the University of Michigan Transportation Research Institute's Trucks Involved in Fatal Accidents databases. However, even in States where LCVs currently operate, estimating LCV crash rates is difficult because most States do not collect data on LCV travel. Estimates of LCV travel were available from several States and from some of the larger carriers that operate LCVs, but the data were not complete enough or representative enough to estimate overall LCV crash rates in the Western States. In the *CTS&W Study* the point was made that even if current LCV crash rates were available, those rates might not apply to expanded LCV operations because many companies that had never operated LCVs before would begin using those vehicles, many drivers with little or no previous LCV experience would begin driving LCVs, and large LCVs would be used in places where they have never operated before. Under the Western Scenario some of those uncertainties would be reduced since expanded LCV operations would be in States where LCVs currently are operating. Nevertheless, under the scenario LCVs would be operating in some States at greater weights and larger dimensions than is currently allowed and could be operating on highways they currently are not allowed to use. Even though reductions in overall heavy truck VMT estimated under the scenario would reduce crash exposure, there would still be uncertainties about the safety of expanded LCV operations that would warrant monitoring.

Without data on crash rates it is difficult to quantify safety impacts of allowing more widespread LCV operations in Western States. One set of safety-related factors that can be quantified are stability and control properties of different vehicle configurations. The analysis of vehicle stability and control characteristics conducted for the *CTS&W Study* was updated for this study to reflect the types of trucks currently being operated in Western States and the size and weight limits assumed in this scenario. Three specific performance measures were evaluated, static rollover stability, rearward amplification, and load transfer ratio. Those three measures, which are described in detail in Chapter

VII, indicate the susceptibility of a vehicle to rollover and to rear trailer sway. Stability and control performance of most LCVs currently used in the Western States is as good or better than the performance of STAA doubles (twin 28-foot trailers) that are widely operated in all States. Performance for some configurations is comparable to that of a standard tractor-semitrailer. There are exceptions, however. Conventional triple trailer combinations, in particular, have poorer rearward amplification and load transfer ratios than other vehicles, which makes them more prone to trailer sway and rollover if they have to make a sudden turning movement.

Offsetting the relatively good stability and control properties of LCVs are the greater time required to pass an LCV, the greater offtracking of longer double trailer combinations, the heavier weight of the vehicles which places greater demands on braking systems, and operational problems that longer vehicles create in urban areas where many weaving and merging maneuvers are required.

The Western Association of State Highway and Transportation Officials has developed model regulations for the operation of LCVs, but actual regulations governing LCV operations differ significantly from State to State. Some States have comprehensive regulations covering equipment, drivers and operations while others have no special regulations that apply to LCVs or their drivers. Most States have no program to monitor LCV safety, but in discussions with State officials they did not note particular safety problems with current LCV operations. Some, however, indicated they would not allow operations of LCVs at the weights and dimensions assumed in this study, even if they had the flexibility to do so.

The *CTS&W Study* presented results of focus groups and surveys that indicated a general uneasiness on the part of many motorists in sharing the roads with big trucks. No additional focus group research was conducted for this project and the extent to which these findings reflect attitudes of motorists in Western States is unknown. Many non-technical factors influence truck size and weight policy decisions and public opinion certainly is one of those factors.

The increased use of LCVs estimated under this scenario could also affect traffic operations. Some reductions in congestion and delay could result from the lower truck volumes, but those benefits could be offset by decreased passing opportunities, increased delay if LCVs cannot maintain their speeds on steep grades as well as conventional trucks, increased difficulty merging and weaving in urban areas because of the greater vehicle lengths, and potential delays at intersections and other locations caused by the larger offtracking of LCVs. Many operational problems are directly related to highway geometry. If geometric improvements are made to accommodate LCVs, some operational impacts may be reduced. Adverse impacts on traffic operations affect more than traffic delay. They also can contribute to increased crash risks. A clear demonstration of this is the lower overall crash rates on Interstate highways when compared to other highways.

As shown in Table ES-5, reductions in VMT associated with the Western Uniformity Scenario could reduce fuel consumption associated with freight transportation and could also reduce emissions and highway noise. The 25 percent reduction in truck VMT associated with the scenario is estimated to result in a 12 percent reduction in fuel consumption. Fuel savings are not directly proportional to VMT reductions because fuel economy decreases as vehicle weight increases.

Table ES-5
Energy and Environmental Impacts of Western Uniformity Scenario

Impact Area	Change from Base Case
Energy Consumption	-12 %
Noise Cost	-10 %
Emissions *	-12 %

* Assumes changes in emissions are approximately proportional to changes in fuel consumption.

Reductions in heavy truck travel estimated under the scenario could also reduce noise and emissions. LCVs generally are noisier than conventional trucks, primarily because they have more tires. However the lower volume of truck travel associated with the scenario would result in about a 10 percent reduction in noise-related costs compared to the base case.

Impacts of changes in air quality caused by changes in freight transportation under the Western Uniformity Scenario are difficult to estimate because truck emissions interact with other mobile and stationary sources in complex ways. While a specific change in emissions may not lead to a corresponding change in pollutants in any given area, estimates of changes in emissions would indicate the direction in which air pollution would likely change. There has been little past research on relationships between vehicle size and weight and emissions. Changes in overall truck volumes under the scenario are not likely to cause significant changes in speeds or other traffic characteristics that affect emissions rates. The primary factor that would cause emissions to change is the change in total truck volumes and the change in traffic composition with more LCVs and fewer conventional trucks. Since other environmental, technological, and geographical factors that might affect emissions are assumed to be the same for the base case and the scenario, it is assumed for purposes of this study that total emissions vary directly with changes in fuel consumption. This is consistent with methods used by the Environmental Protection Agency to estimate heavy truck emissions in its Mobile 6 model. Therefore, emissions under the Western Uniformity Scenario are estimated to decrease approximately 12 percent from the base case. The Transportation Research Board's (TRB's) Special Report 267 notes, "basic data on in-use emissions of heavy trucks are extremely limited" and additional research is needed "on how truck traffic volume, the performance characteristics of trucks, and the effect of trucks on the behavior of other drivers affect emissions of all vehicles on a road."

The largest benefits of truck size and weight changes assumed in the Western Uniformity Scenario are shipper cost savings. If more cargo can be moved in each shipment, driver, equipment, and vehicle operating costs will be lower than in the base case. Table ES-6 shows reductions in transport costs that could be realized if all changes in truck size and weight limits assumed in the scenario were adopted. For shipments currently moving by truck, the expanded availability of various types of LCVs could reduce shipper costs by as much as $2 billion per year. This represents a savings of almost 4 percent of total shipper costs for moves by truck in and through the region. Savings would be lower if some States chose not to allow LCVs to operate as widely as is assumed in the scenario. Shippers that currently use railroads also would realize savings. The actual switch from rail to truck is estimated to be small, producing savings of about $3 million annually. A greater savings to rail users would come from rate reductions that railroads would make to keep traffic from switching to trucks. These savings would be about $26 million per year.

Table ES-6
Annual Shipper Cost Savings from Western Uniformity Scenario

Source of Savings	**Amount** (millions of 2000 $)	**Percent Change**
Truck to Truck Diversion	2,036	3.9 %
Rail to Truck Diversion	3	.01 %
Rail Discounts	26	.11 %
Total	2,065	n/a

Conclusions

Longer combination vehicles have been operating in 13 Western States for many years. Size and weight limits in those States vary as does the extent of the highway network on which LCVs can operate. Some of these differences are due to federal truck size and weight limits, especially grandfather rights under which States can allow vehicles exceeding 80,000 pounds to operate on Interstate Highways. But some of these differences also reflect differences among the States in the vehicle weights and dimensions they believe are appropriate for their highway systems. If States were given the flexibility to increase their truck size and weight limits to levels assumed in this scenario, some States immediately would take full advantage of this flexibility, others might change some but not all size and weight limits, and several might not change truck size and weight limits at all.

Like previous studies that have examined the potential impacts of changing truck size and weight limits, this study has estimated substantial shipper benefits from allowing more widespread use of LCVs. Other benefits from the changes in truck size and weight limits assumed in this scenario are reductions in fuel consumption, emissions, and noise-related costs. The full benefits estimated in this study likely would not be realized, however, because all States would not allow LCV to operate as widely as assumed in this scenario.

Infrastructure and related costs would not be as great as has been estimated in previous studies because LCVs already operate on at least some highways in each of the 13 States included in the analysis. Thus to a certain extent States have already considered LCV weights and dimensions in pavement, bridge, and geometric design. Nevertheless improvements costing several billion dollars were estimated to be needed to correct deficiencies in bridges, interchange ramps, and other highway elements just to accommodate existing truck operations. These deficiencies may not be severe enough to require immediate improvements, but in the long run would likely have to be corrected, especially if LCV volumes increased. If LCV operations expanded under assumptions in this scenario, added infrastructure costs could be from about $300 million to more than $2 billion. Several factors would affect the magnitude of these additional infrastructure costs including the extent to which States allowed larger LCVs to operate, the length limits imposed on double trailer combinations, and the extent to which bridges can be strengthened rather than replaced. Some States may continue to defer non-essential costs as they have done under current truck size and weight limits, but doing so ultimately may increase costs and could increase safety risks as well.

Few Western States charge fees that cover the infrastructure costs associated with LCV operations. The significant exception is Oregon that routinely conducts highway cost allocation studies to estimate the cost responsibility of various truck classes and adjusts truck-related fees according to results of those studies. When LCVs and other heavy trucks do not pay the full costs of their operations, other motorists must make up the difference. This is inequitable to the highway users who must subsidize LCV operations and contributes to an uneven playing field for railroads and other competitors. States already are experiencing budgetary problems as they look to improve the condition and performance of their transportation systems, and Federal Highway Trust Fund revenues to support the Federal-aid highway program have been growing more slowly in recent years. Before any action is taken with respect to changes in truck size and weight limits that could increase highway investment needs, plans for financing those improvements should be developed that include how the longer, heavier trucks responsible for additional costs would contribute to paying those costs. This is consistent with recommendations in the TRBs Special Report 267 in which it concluded, “federal legislation creating the (TRB’s recommended) permit program should specify a quantitative test for the revenue adequacy of the permit fees imposed by states that wish to participate….Fees should at least cover estimated administrative and infrastructure costs for the program…”

Safety is always the issue of greatest concern when truck size and weight issues are considered. Data simply are not available upon which to develop reliable estimates of changes in the number of crashes or fatalities that might result from a change in truck size and weight limits such as the Western Uniformity Scenario. While some LCV operators claim the safety experience of LCVs is better than for the conventional vehicles they operate, these claims cannot be borne out for LCV operations as a whole. States in which LCVs operate have not noted particular safety problems with current LCV operations, but they have no formal processes in place to monitor safety. Since there are many uncertainties about the safety of substantially increased use of LCVs as might occur under the Western Uniformity Scenario, it would be prudent to require such processes before any substantial change in federal truck size and weight limits such as the Western Uniformity Scenario was implemented. In addition to monitoring the on-road safety of LCVs, processes might also be considered to ensure that the vehicles to be used meet some minimum thresholds for stability and control, and that companies operating these vehicles have good safety records and vehicle maintenance programs.

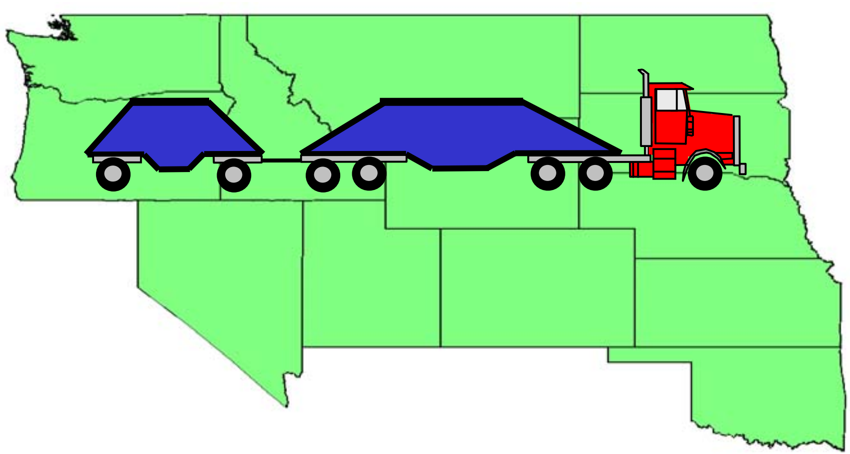
Nationwide, the Department believes that an appropriate balance has been struck on truck size and weight. Western States included in this scenario all can allow LCVs to operate at weights substantially above the 80,000-pound federal limit on Interstate Highways, and a number of other States can allow axle loads exceeding federal limits under grandfather rights. While the widely varying State laws appear to be inefficient, they are the result of political processes that have attempted to balance economic development concerns with concerns for safety and infrastructure protection. This balance has resulted in somewhat different size and weight limits from State to State, but these differences largely reflect factors unique to each State. The pattern of truck size and weight limits that has evolved over the years may not be optimal by any objective measure, but it does allow for some appropriate regional variation without compromising safety, which is the Department's highest priority.

Many proponents of change in truck size and weight limits point to TRB's recommendations in *Special Report 267* as a blueprint for a systematic process to more nearly optimize truck size and weight policy. However, aside from certain segments of the trucking industry and several States interested in truck size and weight increases, strong support for TRB's recommendations has not been evident. The Department has not taken a formal position on the TRB study, in part because it does not favor change in federal truck size and weight policy, but if changes were to be made, the Department believes that the kind of strong monitoring and evaluation that TRB recommends would be essential. Without support for the kind of comprehensive approach to truck size and weight policy and permitting practices recommended by TRB, there would be no mechanism to quickly identify safety or other problems that might arise.

In recent years a number of ad hoc, State-specific exemptions from federal truck size and weight laws have been enacted. For instance, TEA-21 contained special exemptions from federal size and weight limits in four States, Colorado, Louisiana, Maine, and New Hampshire. The Department does not support this kind of piecemeal approach to truck size and weight policy. It makes enforcement and compliance with truck size and weight laws more difficult, it often contributes little to overall productivity, it may have unintended consequences for safety and highway infrastructure, and it reduces the willingness to work for more comprehensive solutions that would have much greater benefits. A regional approach such as the Western Uniformity Scenario could have greater benefits than a series of individual exemptions, but it also could have much more serious adverse consequences unless closely monitored. Unless there were very strong support from State elected officials for a carefully controlled and monitored evaluation of changes in truck size and weight limits such as those in the Western Uniformity Scenario, the risks of adverse impacts from the unmonitored use of LCVs, the divisiveness that might ensue as the current balance in truck size and weight policy is upset, and the further polarization of this very contentious issue would outweigh the benefits that might be realized. Strong support from elected officials of States within the region for a change in truck size and weight limits has not been evident to date, and there is no compelling Federal interest in promoting changes that are not strongly supported by the affected States.

CHAPTER I

Introduction



Introduction

In 2000 the U. S. Department of Transportation (DOT) issued the *Comprehensive Truck Size and Weight (CTS&W) Study*, the first such study by DOT since 1981. The *CTS&W Study* analyzed five truck size and weight scenarios varying from a rollback of size and weight limits to nationwide operations of longer combination vehicles (LCVs). These scenarios were intended only to illustrate the capabilities of the analytical tools. They were not intended to reflect policy options that might be implemented.

The Western Governors' Association (WGA) requested that DOT analyze an additional scenario that would be limited to Western States already allowing LCVs. Specifically the WGA asked the Department to analyze a policy option that would allow 13 Western States (see Figure II-1) to harmonize LCV weights and dimensions at levels that meet existing federal axle load limits, the Federal Bridge Formula and that are in accordance with guidelines established by the Western Association of State Highway and Transportation Officials (WASHTO). Due to time constraints, the scenario could not be included in the *CTS&W Study* Volume III, but the Department agreed to analyze the scenario in a follow-up report.

This analysis draws heavily on work done for the *CTS&W Study*. General background information on the evolution of truck size and weight limits and previous research on potential impacts of truck size and weight policy changes was included in the *CTS&W Study* Volumes I - IV and is not repeated in this report. This report does discuss the many data and analytical improvements since the *CTS&W Study* and included in the Western Uniformity Analysis. This report is not intended as a "stand-alone" report, important background and methodology information is included in Volumes I – IV of the *CTS&W Study.*

Study Purpose

The purpose of this analysis is to use the general analytical framework developed in the *CTS&W Study* to analyze impacts of the Western Uniformity Scenario that the WGA asked DOT to analyze. As with scenarios analyzed in the *CTS&W Study*, there is no detailed discussion of regulatory, enforcement, or other implementation issues that would have to be considered before an option such as the Western Uniformity Scenario could be implemented.

Impact Areas

The impacts of the Western Uniformity Scenario are estimated for 10 impact areas:

Freight Diversion
Shipper Costs
Pavement Costs
Bridge Costs
Roadway Geometry

Safety
Traffic Operations
Environmental Quality
Energy Consumption
Rail Industry Competitiveness

Additional information on each of these impacts can be found in the *CTS&W Study* Volumes II and III.

Updates and Improvements

The Western Uniformity Scenario analysis includes several substantial improvements to data and methods used in the *CTS&W Study* to estimate scenario impacts. Improvements in the truck and rail data and methods used to analyze pavement, bridge, and safety impacts are discussed in the relevant sections of the report.

One of the biggest improvements is the use of the Freight Analysis Framework (FAF) commodity flow data in place of the very limited truck flow data that was available at the time the *CTS&W Study* was undertaken. The FAF is a comprehensive database widely used by the Federal Highway Administration (FHWA) for a variety of freight operations analyses. It includes estimates of county-to-county flows of all manufacturing and agricultural truck shipments. Also the!database for analyzing potential diversion of rail traffic to larger, heavier trucks has been updated to 2000. These new rail data reflect impacts of the 1990's rail mergers.

Outreach

During the course of this study FHWA staff met on several occasions with representatives of State Departments of Transportation to understand current LCV operations, regulations and routes. Although all 13 States in the Scenario have assisted with the project, their participation does not necessarily reflect a State's policy direction toward implementation of the LCV sizes, weights and networks analyzed in this report.

FHWA staff met with LCV operators to understand characteristics of their operations. State officials and regional LCV operators were very helpful in providing a picture of current operations, configurations and the LCV shipping environment.

FHWA staff also met with safety groups to understand their concerns about truck operations and especially LCVs.

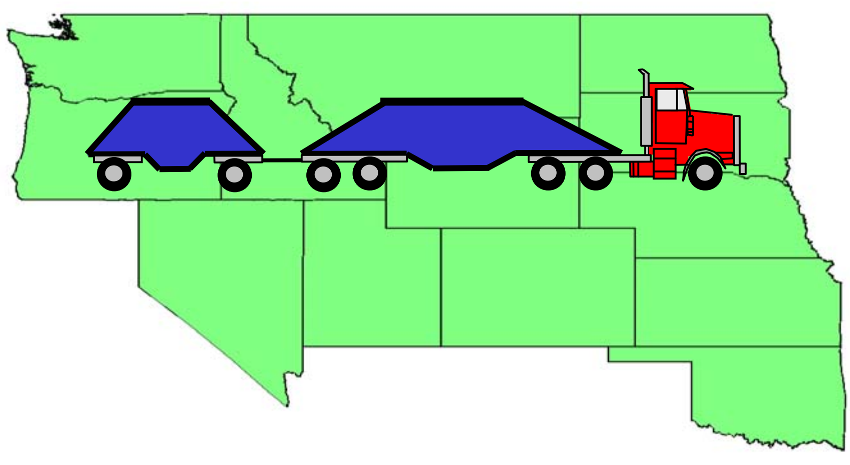
Organization of Analysis

As with the *CTS&W Study's* scenario analysis, there is a broad assessment of potential impacts that might result from the changes in truck size and weight (TS&W) limits assumed in this scenario. Chapter II provides a detailed description of assumptions underlying the Western Uniformity Scenario. Chapter III describes methods used to estimate the shifts in truck traffic that could result from scenario assumptions. These shifts include those rail boxcar and intermodal freight to trucks and from existing truck configurations to larger and heavier configurations that would be allowed under the scenario. Finally Chapter III estimates the impact to shippers' freight bills.

Chapters IV through VI present estimates of scenario impacts on highway agency costs for pavement, bridge, and geometric improvements respectively. Chapters VII through IX estimate external costs (or benefits) that might result under scenario assumptions. The impacts covered in these chapters are safety, traffic operations, and energy consumption and environmental quality respectively. Chapters X estimates reductions in rail traffic and the impacts of the scenario on railroads serving the region. Chapter XI summarizes scenario impacts.

CHAPTER II

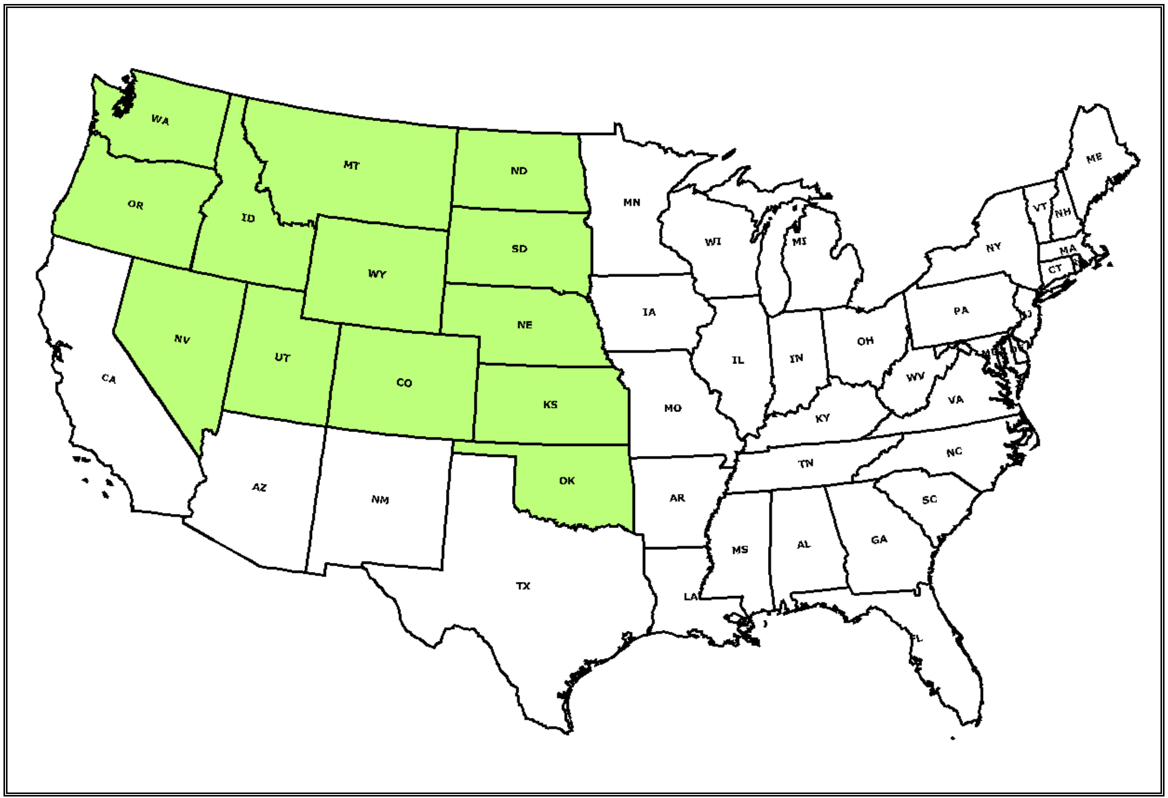
Scenario Description



Introduction

The Western Uniformity Scenario requested by the Western Governors' Association (WGA) from the Department of Transportation (DOT) is different than scenarios examined in the *Comprehensive Truck Size and Weight (CTS&W) Study*. Those scenarios focused on nationwide changes to truck size and weight limits. The Western Uniformity Scenario examines the impact of changes in truck size and weight regulations within a 13-State region in which all the States already allow at least some Longer Combination Vehicles (LCV). The States included in the analysis and shown in Figure II-1 are Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington and Wyoming.

Figure II-1
Analysis States

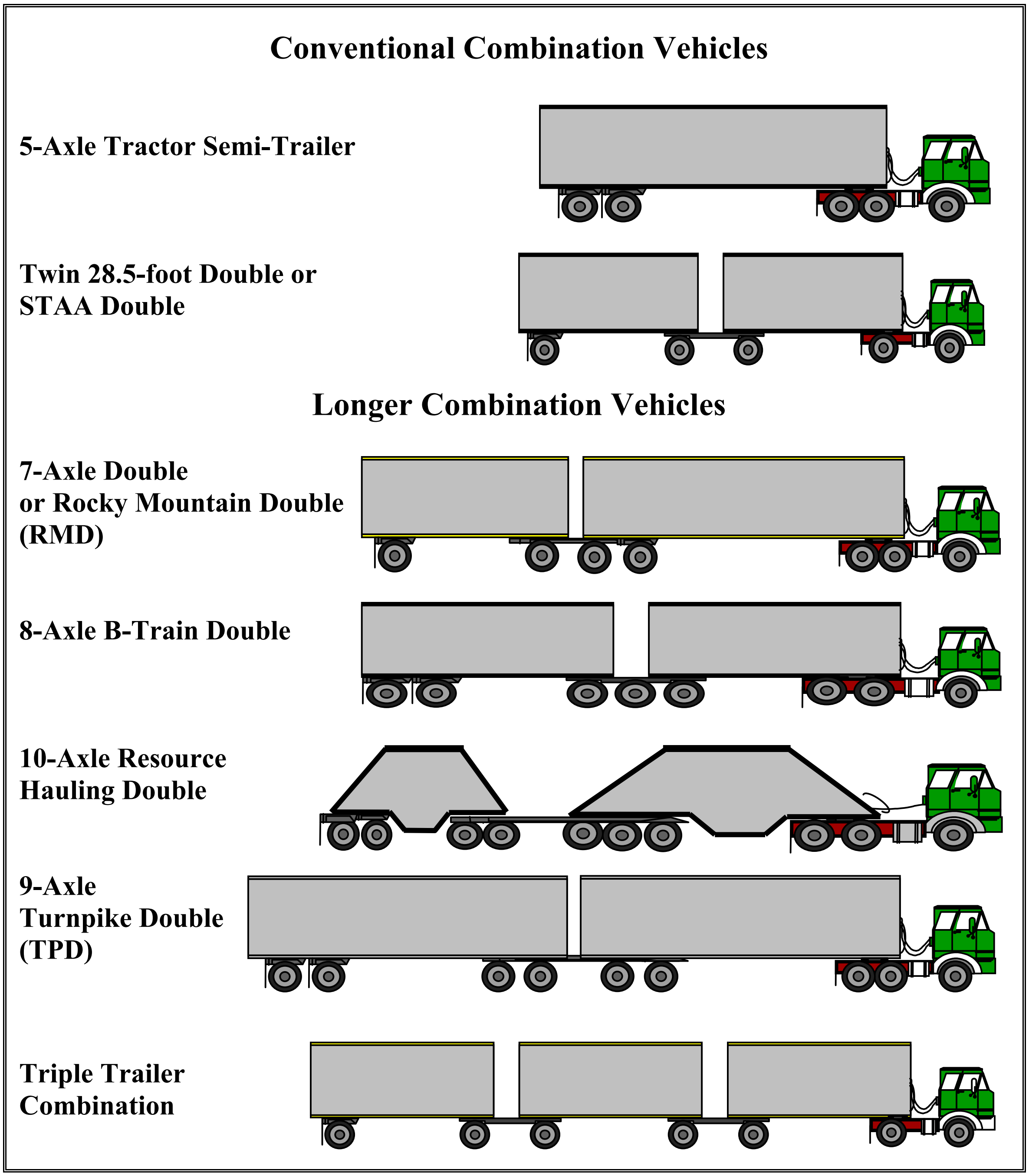


While all the States included in the scenario already allow LCVs, most do not allow the weights and dimensions analyzed in the Scenario. In discussions with State representatives during the course of this analysis, some said that even if given the flexibility to allow heavier weights they would not do so. Thus it must be remembered that, like the scenarios analyzed in the *CTS&W Study*, this scenario is only illustrative of the impacts that could occur if all the States in the region uniformly adopted the size and weight limits assumed in the scenario.

Several Western States currently do not allow LCVs including California, Texas, New Mexico, and Arizona (except for a very small corner of the State). These States were invited to join in the scenario analysis but all declined.

Figure II-2 shows the principal vehicle configurations examined in this analysis.

Figure II-2
Comparison of Longer Combination Vehicles with Conventional Trucks



The analysis includes a broad range of commercial truck configurations: five- and six-or-more - axle tractor-semitrailers, several double-trailer combinations with different weights and dimensions, and triple-trailer combinations. All these configurations are present in both the base case and in the Scenario, although not all States allow all the scenario vehicles in the base case.

The impact analysis in this report focuses on the 13 States in the study region. Table II-1 shows their road networks as a percentage of the national networks. This table shows that these States contain a higher percent of rural roads than urban roads when compared to the whole U.S. Table II-2 shows that within the 13 States more than 80 percent of the public road system is classified as rural.[1]

Table II-1
Miles by Functional System

Functional Class	13 Analyzed States	Total US	Percent of Total
Rural Interstate	8,598	33,048	26%
Rural Other Principal Arterial	29,563	98,911	30%
Rural Minor Arterial	32,788	137,574	24%
Rural Major Collector	123,611	433,121	29%
Rural Minor Collector	77,356	271,815	28%
Rural Local	595,492	2,109,519	28%
Rural Total	**867,408**	**3,083,988**	**28%**
Urban Interstate	1,591	13,379	12%
Urban Other Freeway and Expressways	937	9,140	10%
Urban Other Principal Arterial	5,945	53,312	11%
Urban Minor Arterial	10,662	89,789	12%
Urban Collector	10,155	88,200	12%
Urban Local	68,964	598,421	12%
Urban Total	**98,254**	**852,241**	**12%**
Total	**965,662**	**3,936,229**	**25%**

Source: Highway Statistics Table HM-50.

Analysis Year

The analysis year for this scenario is 2010. Forecasts of traffic by commodity, origin and destination, vehicle configuration, weight, and highway functional class are based on current conditions including current truck size and weight limits. Global Insights, formerly DRI/WEFA, developed economic forecasts and traffic volumes were forecast based on those economic assumptions. Distributions of traffic by vehicle class, operating weight, and highway functional class were assumed to remain the same as estimates developed for 2000, the latest year for which actual traffic volume data are available.

[1] The minor exception is the State of Washington with 78% of the public road system designated as rural.

Table II-2
Rural and Urban Mileage by State

State	Rural		Urban		Total	Percent of Total	
	Interstate	Other	Interstate	Other		Rural	Urban
Colorado	769	70,320	185	14,580	85,854	83%	17%
Idaho	526	41,590	85	4,110	46,311	91%	9%
Kansas	694	123,606	180	10,244	134,724	92%	8%
Montana	1,135	65,764	56	2,546	69,501	96%	4%
Nebraska	437	87,130	45	5,154	92,766	94%	6%
Nevada	480	32,513	80	5,585	38,658	85%	15%
North Dakota	531	84,226	41	1,793	86,591	98%	2%
Oklahoma	721	98,607	209	13,159	112,696	88%	12%
Oregon	581	55,040	146	11,019	66,786	83%	17%
South Dakota	629	80,827	49	2,057	83,562	97%	3%
Utah	771	33,659	167	7,610	42,207	82%	18%
Washington	501	62,293	263	17,929	80,986	78%	22%
Wyoming	826	24,000	87	2,379	27,292	91%	9%

Source: Highway Statistics Table HM-50.

Base Case 2000

The base case for the scenario represents current patterns of truck and rail operations in the scenario States under current truck size and weight laws. It serves as a base line for estimating impacts of changes in truck size and weight limits assumed in the scenario. The Federal size and weight limits for the base case are shown in Figure II-3.

The base case includes the freeze on LCVs imposed by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) that restricts the use of LCVs to the types of operations in effect as of June 1, 1991. The Transportation Equity Act for the 21st Century (TEA-21) continued the LCV freeze. It should be noted that there are two distinct freezes in the ISTEA, one on the weight of LCVs on the Interstate System and the other freeze on the length of the cargo carrying units of combinations with two or more such units on the NN. Table II-3 shows the lengths and weights of twin and triple trailer combinations that each of the 13 States included in the scenario may allow to operate under the LCV freeze.

Figure II-3
Base Case Federal Truck Size and Weight Limits

- 20,000 POUNDS FOR SINGLE AXLES ON THE INTERSTATE SYSTEM;
- 34,000 POUNDS FOR TANDEM AXLES ON THE INTERSTATE SYSTEM;
- APPLICATION OF BRIDGE FORMULA B FOR OTHER AXLE GROUPS, UP TO THE MAXIMUM OF 80,000 POUNDS FOR GROSS VEHICLE WEIGHT (GVW) ON THE INTERSTATE SYSTEM;
- 102 INCHES FOR VEHICLE WIDTH ON THE NATIONAL NETWORK*;
- 48 FOOT (MINIMUM) FOR SEMITRAILERS IN A SEMITRAILER COMBINATION ON THE NATIONAL NETWORK; AND 28 FOOT (MINIMUM) FOR TRAILERS IN A TWIN-TRAILER COMBINATION ON THE NATIONAL NETWORK.
- GRANDFATHER RIGHTS UNDER WHICH CERTAIN LCVS ARE ALLOWED TO OPERATE IN EACH SCENARIO STATE.
- LONGER COMBINATION VEHICLES WHERE PERMITTED BY STATE LAW AND SUBJECT TO THE LCV FREEZE.

* The National Network (NN) is the system of highways designated by the States in cooperation with FHWA on which the 48-foot semitrailers and short twin trailer combinations that States were required to allow under the Surface Transportation Assistance Act of 1982 (STAA) would be allowed to operate. Those highways were judged by the States to be suitable for use by those truck configurations.

Several States allow heavier weights off the Interstate System than are allowed under the LCV freeze on the Interstate System (see Table II-6). For example, Wyoming allows up to 156,000 pounds on a double-trailer, with the appropriate number and spacing of axles, on State designated, non-Interstate roads, but the freeze limits GVW to 117,000 pounds on Wyoming Interstate. The appropriate weight limit is considered for each road segment in both the base case and the scenario analysis. It is also assumed that no change in technology, operating practices, or relative pricing will take place between the base year (2000) and the analysis year (2010). Finally it is assumed that there would be no change in the TS&W regulations and VMT for any States other than those in the study.

Table II-3
Operation of Vehicles Subject to the ISTEA Freeze
Maximum Size and Weight Limits for 13 Analyzed States
(Length in feet (')/Weight in 1,000 Pounds (K))

State	Truck Tractor and Two Trailing Units		Truck Tractor and Three Trailing Units		Other[2]
	Length	Weight	Length	Weight	Length
Colorado	111'	110K	115.5'	110K	78'
Idaho	95'	105.5K	95'	105.5K	78' - 98'
Kansas	109'	120K	109'	120K	No
Montana	93'	137.8K	100'	131.06K	88' - 103'
Nebraska	95'	95K	95'	(1)	68'
Nevada	95'	129K	95'	129K	98'
North Dakota	103'	105.5K	100'	105.5K	103'
Oklahoma	110'	90K	95'	90K	No
Oregon	68'	105.5K	96'	105.5K	70'5"
South Dakota	100'	129K	100'	129K	73' - 78'
Utah	95'	129K	95'	129K	88' - 105'
Washington	68'	105.5K	No		68'
Wyoming	81'	117K	No		78' - 85'

(1) No maximum weight is established as this vehicle combination is not considered an "LCV" per the ISTEA definition because it is only allowed up to 80,000 pounds.
(2) A commercial motor vehicle combination with two or more cargo-carrying units not included in descriptions "truck tractor and two trailer units" or "truck tractor and three trailer units."
Source: *Federal Size Regulations for Commercial Motor Vehicles*, FHWA Publication Number FHWA-MC-96-03, for details on specific vehicle combinations see 23 CFR 658, Appendix C.

Analytical Improvements

Changes since the *CTS&W Study* include (1) updating the truck and rail commodity flow data and the distribution of truck traffic by configuration, highway functional class, and operating weight; (2) a detailed analysis of LCV operations in Western States; and (3) detailed analysis of the road networks on which LCVs currently are allowed.

Updated Base and Forecast Years

The base year for the *CTS&W Study* was 1994 with a forecast year of 2000. For the Western Uniformity Scenario, base year vehicle miles traveled (VMT) was updated to 2000 using the 2000 Highway Performance Monitoring System (HPMS) data. The HPMS data were augmented by State truck weight data to estimate VMT by configuration, highway functional class, and operating weight, following the same methodology as was used in the 1997 Highway Cost Allocation Study. Table II-4 summarizes the VMT by configuration for the 13 States in the present analysis.

The truck commodity flow database is significantly improved compared with that which was available for the *CTS&W Study*. In the *CTS&W Study* the truck flow data was based on a national survey of 24,000 truck drivers, but could not be calibrated to national totals and the relevant sample for a regional analysis was very small.

The truck commodity flow data for the scenario analysis is now based on the Freight Analytical Framework (FAF) developed by FHWA.[2] The FAF truck data was created from a synthesis of the 1994 Commodity Flow Survey, 5-year Census and Annual Survey of Manufacturers, county population data, Motor Carrier Industry Financial & Operating Statistics, trade association production and shipment reports, and private data sources. The FAF truck database is calibrated to national totals[3] and is geographically specific. County-to-county flows of nearly 400 different commodities groups are estimated.[4] The database of both private and for-hire trucking comes close to capturing the universe of truck shipments and can be broken apart into regional and State subsets.

The rail shipment database was also updated using the 2000 Rail Waybill. This is an improvement over the 1994 data used in the CTS&W Study since this data reflects rail traffic flows following the round of rail mergers in the mid and late 90's.

Global Insight, a nationally recognized economic forecasting company, (formerly DRI/WEFA) developed the 2010 forecasts of commodity flows using demand-based forecasting to estimate the consumption growth from which truck and rail commodity flows are derived. Table II-5 summarizes forecasts of domestic tons to be hauled by trucks and railroads.

Scenario Specifications

Only those trucks likely to be impacted by changes in TS&W limits were explicitly modeled in the analysis. Figure II-4 shows the commercial vehicles included in the analysis and characteristics of how those vehicles are currently used in the Western States. Changes to their operations under the Western Uniformity Scenario are discussed in Chapter III. Specifically the turnpike double would become utilized for more general freight shipments.

Single unit trucks are not included in this analysis since the scenario hypothesizes no changes to their weights or operating conditions and operators are unlikely to switch from single unit trucks to combination trucks.

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[2] More information on the Freight Analytical Framework (FAF) data is available at www.ops.fhwa.dot.gov/freight.

[3] There was additional calibration for the 13 scenario States to State VMT control totals.

[4] Data utilized the four digit Standard Transportation Commodity Codes (STCC) codes created by the American Association of Railroads.

Table II-4
Base Year and Forecast Commercial Vehicle Travel
(million VMT)

State	Single Unit Truck		Tractor Semi-trailer with 3 to 4 axles		Tractor Semitrailer with 5 axles		Tractor Semi-trailer with 6 or more axles		Truck Trailer with 3 to 4 axles		Truck Trailer with 5 axles		Truck Trailer with 6 or more axles		Double trailer with 5 or 6 axles		Double trailer with 7 axles		Double trailer with 8 axles or more axles		Triple Trailer	
Year	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**
Colorado	1,263	1,716	155	209	1,096	1,452	82	112	16	21	27	37	6	8	37	50	21	28	3	5	2	2
Idaho	341	453	49	66	482	635	110	147	2	2	14	19	26	37	30	39	22	30	7	10	7	10
Kansas	933	985	126	138	1,151	1,280	132	144	11	13	11	13	22	27	47	54	3	4	1	1	1	1
Montana	240	255	28	30	396	422	95	104	6	7	9	10	45	53	41	45	14	15	11	13	0	0
Nebraska	454	300	126	76	2,051	318	97	133	6	8	3	8	21	40	9	14	-	-	-	-	1	0
Nevada	520	429	79	119	656	1,954	31	92	0	6	40	3	30	21	32	9	20	-	4	-	2	1
North Dakota	265	646	65	107	272	887	115	42	7	0	6	55	32	43	12	43	-	27	-	6	0	3
Oklahoma	1,410	1,710	389	467	2,639	3,153	169	203	21	25	28	35	3	4	54	65	1	2	-	-	1	1
Oregon	1,044	1,176	234	260	1,078	1,217	291	327	0	0	21	24	29	34	705	820	12	14	35	42	22	26
South Dakota	262	282	36	39	389	417	77	83	4	4	5	5	16	19	19	20	10	11	21	25	0	0
Utah	482	651	89	121	753	991	65	87	6	8	20	28	92	132	49	66	25	33	13	19	1	2
Washington	1,510	1,472	120	116	856	829	385	383	18	18	73	74	145	152	72	71	22	21	81	84	-	-
Wyoming	149	166	62	73	731	921	56	65	6	8	22	30	44	57	40	54	3	4	6	8	-	-
Total	**8,873**	**10,240**	**1,558**	**1,821**	**12,551**	**14,476**	**1,706**	**1,924**	**102**	**120**	**279**	**341**	**511**	**626**	**1,147**	**1,351**	**154**	**188**	**183**	**213**	**37**	**45**
Percent of Fleet	**31.8%**	**32.7%**	**5.6%**	**5.8%**	**45.0%**	**46.2%**	**6.1%**	**6.1%**	**0.4%**	**0.4%**	**1.0%**	**1.1%**	**1.8%**	**2.0%**	**4.1%**	**4.3%**	**0.6%**	**0.6%**	**0.7%**	**0.7%**	**0.1%**	**0.1%**

Table II-5
Domestic Tons (millions) by Mode for Base and Forecast Years

Mode	1998	2010
Air	9	18
Highway	10,439	14,929
Rail	1,953	2,527
Water	1,082	1,344
Grand Total	13,484	18,820

*Source: Freight Analytical Framework, FHWA

Figure II-4
Current Use of Scenario Vehicles

Configuration Type	Number of Axles	Common Maximum Weight (pounds)	Current Use
Semitrailer	5	80,000 - 99,000	Most used combination vehicle. It is used for long and short hauls in all urban and rural areas to carry and distribute all types of materials, commodities, and goods
	6 or more	80,000 - 100,000	Used to haul heavier materials, commodities, and goods for hauls longer than those of the four-axle single-unit truck.
STAA Double	5, 6	80,000	Most common multi-trailer combination. Used for less-than-truckload (LTL) freight mostly on rural freeways between LTL terminals.
B-train Double	8	105,500 - 137,800	Mostly used in flatbed trailer operations and for liquid bulk hauls
Rocky Mountain Double (RMD)	7	105,500 - 129,000	In the Western States used as a resource hauling vehicle, usually open hopper, tank, or flat.
Turnpike Double (TPD)	9	105,500 - 147,000	Some truckload operations similar to a 5 or 6 axle Semitrailer but mostly a western State resource-hauling vehicle.
Triple Trailer Combination	7	90,000 – 129,000	Similar to an STAA Double, used for less-than-truckload (LTL) freight mostly on rural freeways between LTL terminals.

The Vehicles

The truck configurations analyzed in this study conform to the State and Federal regulations and current operations. All of the 13 States analyzed allow variations from Federal truck size and weight limits, but all[5] utilize the Federal Bridge Formula B to control loads placed on bridges. The formula gives the allowable weight on any group of two or more axles in terms of the number and spacing of the axles,

$$W=500[LN/(N-1) + 12N +36]$$

Where

W = allowable weight on the collection of axles under consideration
L = length between extreme axles in collection of axles under consideration
N = number of axles under consideration

In most States (10 out of 13), the Bridge Formula is capped at a fixed value tied to that State's grandfather rights. The States that don't have a fixed cap use the bridge formula as their practical limit. Table II-6 lists the LCV length and gross vehicle weight (GVW) limit for the States analyzed in this study. Figures II-5 and II-6 show the geographical significance of the GVW and length variations on Interstate transportation.

Some States regulate the overall length of the vehicle from front to rear bumper, other States regulate the combined length of the trailers, and still others regulate the length of the individual trailers.

Interviews with shippers provided useful insight into impacts on Interstate operations where no two States have the same truck size and weight limits. Often shippers must study each State's regulations and then design a vehicle to match the State with the most restrictive truck size and weight rules to avoid costly re-configuration at the borders. This sometimes precludes an out-of-state truck operator from bidding on a job since in-state operators already own the most economically efficient configurations.

The wide variety of size and weight rules in the Western States has given rise to uniquely-designed, jurisdictionally-specific vehicles. Figure II-7 provides examples of specific vehicles designed for the unique jurisdictional rules in the Western States. In Figure II-7 the "Montana Truck 2 Sugar Beets GVW 123,000," with 9-axles, 81-feet combined trailer length and a tare weight of 38,100 has a competitive disadvantage in Washington, Idaho or Oregon since resource haulers in those States employ a truck with 7-axles, 68-foot combined trailer length and a lower tare weight of 34,300 pounds (see Figure II-7, "Washington/Idaho/Oregon GVW 105,500"). The heavier tare weight of the Montana truck, due to additional axles and trailer length, translates into a lower payload given Washington, Idaho and Oregon's maximum GVW of 105,500 pounds and higher cost per payload ton mile.

[5] Colorado uses Bridge Formula B in conjunction with its own State formula.

Table II-6
Current Maximum Weight and Length for Scenario States[1]

STATE	DOUBLES MAXIMUM LENGTH (FEET)		DOUBLES MAXIMUM GROSS VEHICLE WEIGHT (POUNDS)	TRIPLES MAXIMUM LENGTH PER TRAILER (FEET)	TRIPLES MAXIMUM GROSS VEHICLE WEIGHT (POUNDS)
	Rocky Mountain Double	Turnpike Double			
Colorado[5]	48 + 28.5	48 + 48	110,000	28.5 each	110,000
Idaho	105 overall	105 overall	105,500	28.5 each	105,500
Kansas	48 + 28.5	48 + 48	120,000	28.5 each	120,000
Montana	95 overall or 81 CTL[3]	95 overall or 81 CTL[3]	Uncapped BFB[2]	95' overall	Uncapped BFB[2]
North Dakota	110 overall	110 overall	105,500	110' overall	105,500
Nebraska	105 CTL[3]	105 CTL[3]	95,000	28.5 each	empty
Nevada	105 CTL[3] up to 48 + 42	105 CTL[3] up to 48 + 42	129,000	28.5 each	129,000[4]
Oklahoma	110 CTL[3] up to 53 + 53	110 CTL[3] up to 53 + 53	90,000	29 each, up to 95' CTL[3]	90,000
Oregon[5]	68 CTL[3] 40 + 20	Not allowed	105,500	28.5 each, up to 96' CTL[3]	105,500
South Dakota	110 CTL[3]	110 CTL[3]	129,000	28.5 each	129,000[4]
Utah	95' CTL[3]	95' CTL[3]	129,000	95' CTL[3]	129,000[4]
Washington	68 CTL[3]	Not allowed	105,500	Not allowed	Not allowed
Wyoming	81 CTL[3]	81 CTL[3]	117,000 (Interstate), Uncapped BFB[2] (off-interstate)	Not allowed	Not allowed

1. Limitations on routings, time-of-day, and/or day-of-week apply within each State.
2. Uncapped Federal Bridge Formula B.
3. Combined Trailer Length.
4. In practice, Bridge Formula B limits the triples to around 123,000 pounds depending on axle spread.
5. State has a variation to the Federal Bridge Formula B for computing axle spread and weights.

The Networks

The scenario impacts are evaluated based on assumptions concerning the networks that would be available for various types of LCVs. Several networks are considered in the analysis -- the National Network (NN) for large trucks designated pursuant to the STAA of 1982; networks on which the three general types of LCVs (RMD, TPD, and Triples) currently are allowed to operate; and the networks assumed in the scenario to be available for each type of LCV. Under the scenario, routes currently available for LCVs in particular States are assumed to remain available to those vehicles, even if they are beyond the networks assumed in the scenario to be available to particular configurations.

County-to-county mileages were developed for all 7 networks using the National Highway Planning Network (NHPN)[6] and the 3 current and 3 scenario LCV networks. The NHPN is a comprehensive network database geographically coding for over 400,000 roadway miles including Rural Arterials, Urban Principal Arterials, and all the National Highway System routes. The NHPN is used as a surrogate for the NN since most 53-foot tractor semi-trailers and STAA Doubles have broad access in the analyzed States.

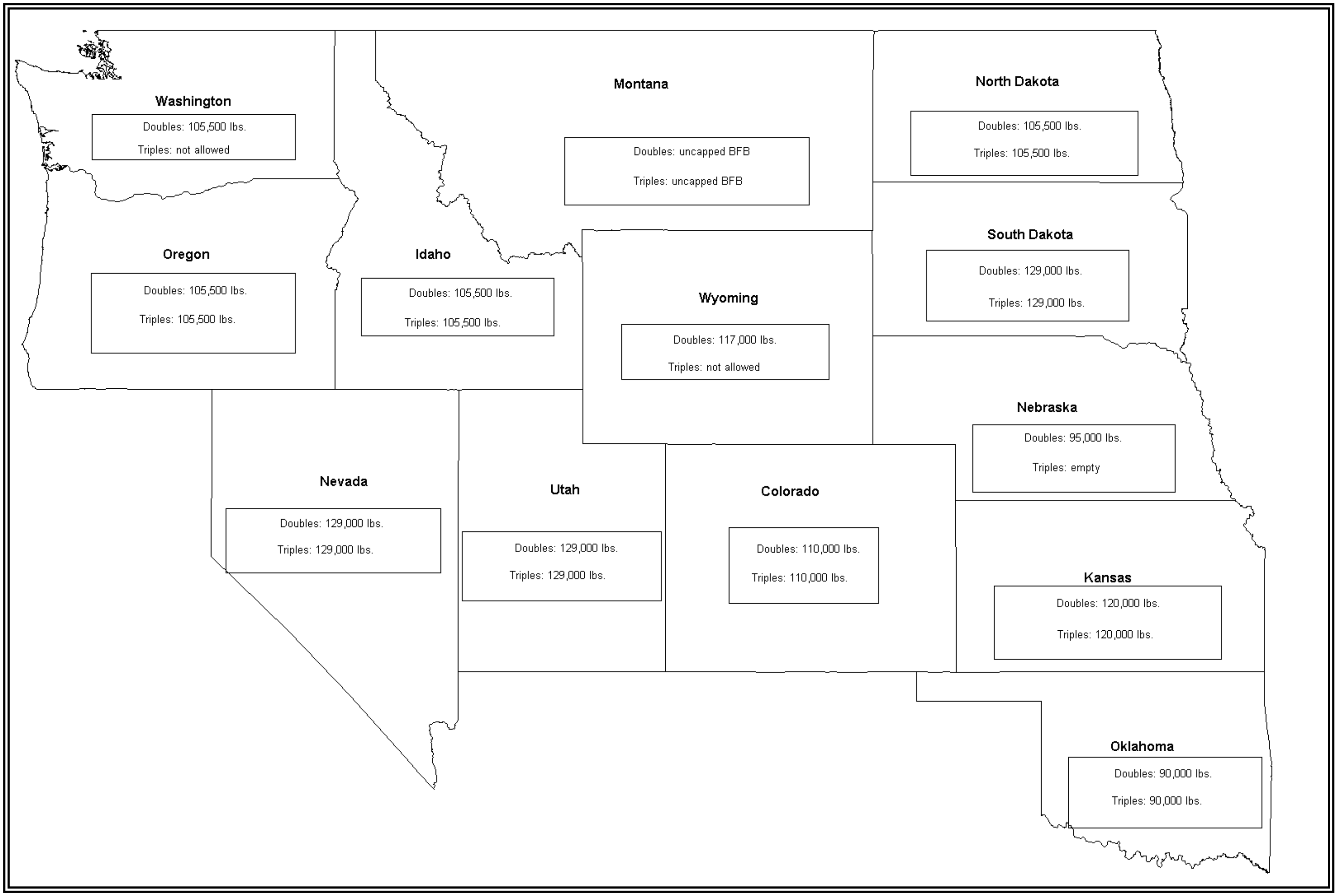
The use of specific highway networks allows the proposed changes in the truck size and weight limits to be measured on specific highway functional classes within each State. For each network, the mileage to and from each county population center was determined. For each origin-destination pair the following information was derived: (1) travel distance based on shortest travel time; (2) estimated travel time; (3) mileage on each highway functional class; and (4) non-network miles between origin/destination to the road network (i.e. drayage distance).

The network routings attempted to include all roads with current operations, but some additional restrictions were beyond the modeling capabilities, including "time of day" restrictions (for example, LCVs are not allowed in Denver, Colorado during rush hour) or "day of the week" restrictions (for example, no LCVs are allowed on Oregon's coastal roads on the weekends).

Combinations with 48-foot semitrailers and "STAA" double trailers operate on a 200,000-mile network designated under the Surface Transportation Assistance Act of 1982 (STAA). Combinations with semi-trailers longer than 48 feet generally must comply with State routing requirements and provisions to minimize vehicle off-tracking. Figure II-8 shows the current permit requirements and route restrictions for LCVs in each scenario State.

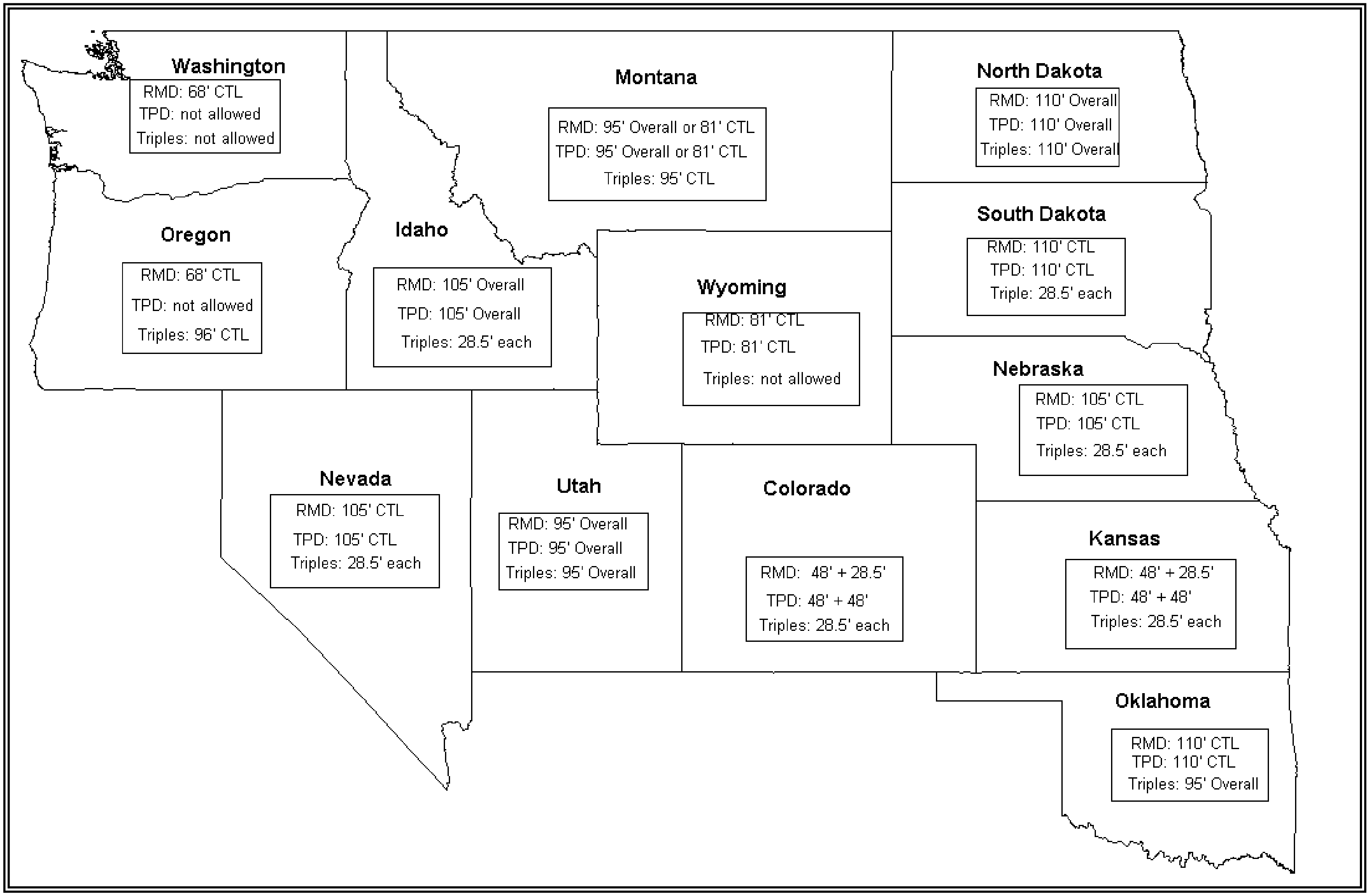
[6] The analysis utilized NHPN Version 3.0, 2000. For more information please refer to www.transtats.bts.gov.

Figure II-5
Current LCV Gross Vehicle Weights
(pounds)



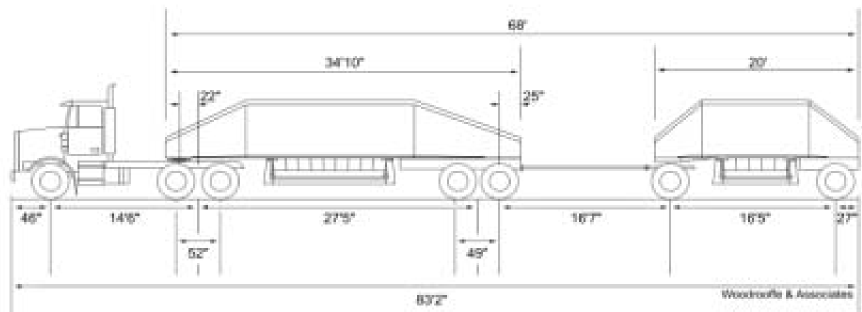
Notes: RMD is Rocky Mountain Double, TPD is Turnpike Double and BFB is Bridge Formula B

Figure II-6
Current LCV Lengths
(feet)



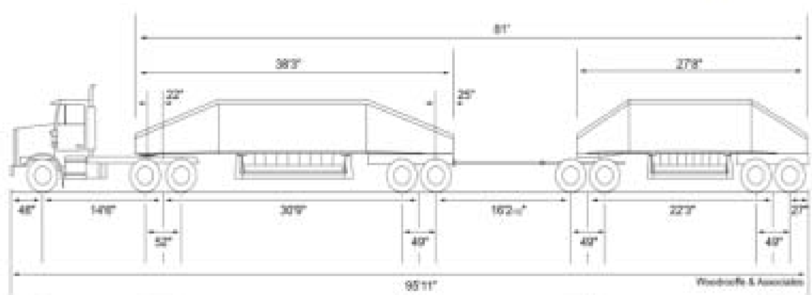
Notes: RMD is Rocky Mountain Double, TPD is Turnpike Double and CTL is Combined Trailer Length

Figure II-7
Vehicles Operating in the Western Study States



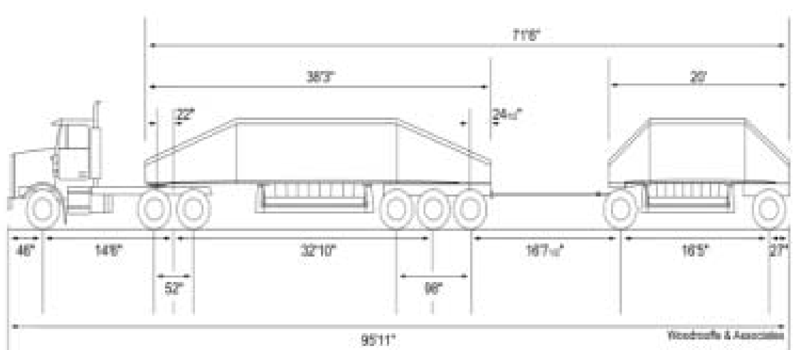
TARE:	7,500 lbs	10,400 lbs	7,600 lbs	4,500 lbs	4,300 lbs	Total: 34,300 lbs
TARE:	12,000 lbs	30,000 lbs	30,000 lbs	16,300 lbs	16,700 lbs	Total: 105,000 lbs

Washington / Idaho / Oregon Truck GVW 105,500 pounds



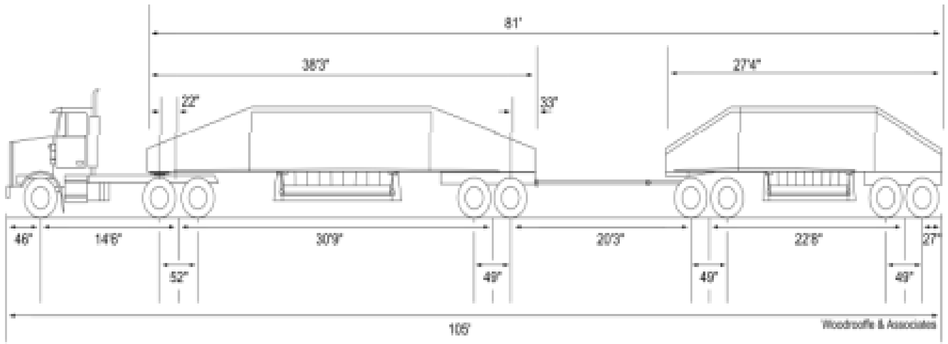
TARE:	7,500 lbs	10,400 lbs	7,600 lbs	6,400 lbs	6,200 lbs	Total: 38,100 lbs
TARE:	11,900 lbs	32,800 lbs	32,800 lbs	21,600 lbs	23,900 lbs	Total: 123,000 lbs

Montana Truck 2 Sugar Beets GVW 123,000 pounds



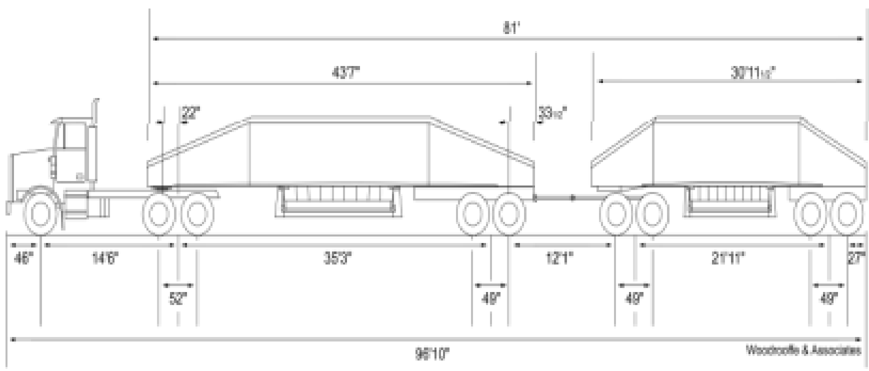
TARE:	7,500 lbs	10,600 lbs	9,300 lbs	4,500 lbs	4,300 lbs	Total: 36,200 lbs
TARE:	11,900 lbs	32,800 lbs	37,200 lbs	13,700 lbs	13,650 lbs	Total: 109,250 lbs

Nebraska Truck GVW 109,250 pounds



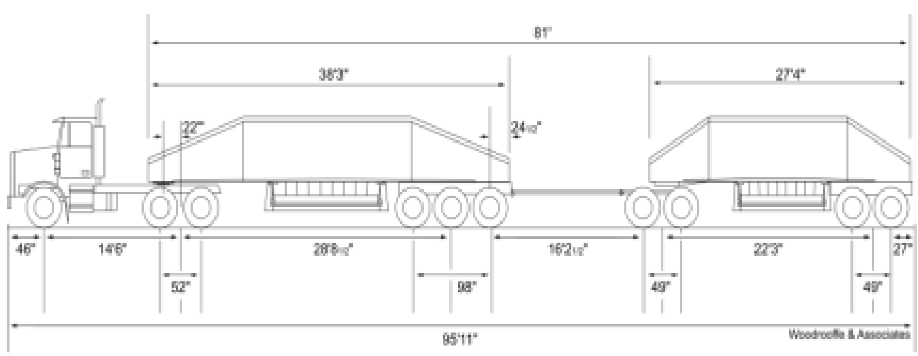
TARE:	7,500 lbs	10,600 lbs	7,600 lbs	6,400 lbs	6,200 lbs	Total: 38,300 lbs
TARE:	12,000 lbs	34,000 lbs	34,000 lbs	21,800 lbs	25,700 lbs	Total: 127,500 lbs

Nevada Truck GVW 127,500 pounds



TARE:	7,500 lbs.	10,900 lbs.	7,900 lbs.	6,600 lbs.	6,400 lbs.	Total: 39,300 lbs
LOADED:	11,900 lbs.	32,800 lbs.	32,800 lbs.	21,600 lbs.	23,900 lbs.	Total: 123,000 lbs

Montana Truck GVW 123,000 pounds



TARE:	7,500 lbs	10,600 lbs	9,300 lbs	6,400 lbs	6,200 lbs	Total: 40,000 lbs
TARE:	11,000 lbs	32,200 lbs	37,200 lbs	22,400 lbs	25,200 lbs	Total: 128,000 lbs

Wyoming Truck 128,000 pounds

Figure II-8
Longer Combination Vehicle State Permit and Route Restrictions

State	Permit Required	Route Restrictions
Colorado	Annual permit required	Restricted to designated Interstate and state highway segments
Idaho	Required; good for 1 year from date of issuance	Allowed on National Network (NN) routes and access routes to breakdown areas via interchanges designated for LCVs
Kansas	Access permits, valid for 6 months required for access between Kansas Turnpike & terminals located within a 10-mile radius of each tollbooth except at NE end of Turnpike where 20-mile radius allowed. Special Vehicle Combination (SVC) permits, good for 1 year, are required for operation on I-70 between Colorado state line and Exit 19	Allowed only on Kansas Turnpike, Special Vehicle Combination (SVC) triples allowed only on I-70 from Colorado state line to Exit 19
Montana	Required for double trailer combinations if either trailer exceeds 28.5'. Annual or trip permits available; require continuous travel. Special triple vehicle annual or single trip permit required	Allowed on NN routes except US 87 from milepost 79.3 to milepost 82.5. Doubles have length and access limits. Triples allowed only on Interstate System and granted a 2-mile access off Interstate System for loading or service
North Dakota	Required if combination has gross vehicle weight of 80,000 pounds or more	Allowed on all NN routes with 10-mile access from National Network
Nebraska	Annual length permit required for cargo-carrying combinations greater than 65'	Triples can only travel empty. LCVs allowed on I-80 from Wyoming state line to Exit 440 (NE50); only doubles allowed a 6-mile access to designated staging areas
Nevada	Required	Allowed on all NN routes except US 93 from NV 500 to Arizona state line
Oklahoma	Required for all combinations	Allowed on NN and legally-available routes. 5-mile access from legal routes

State	Permit Required	Route Restrictions
Oregon	Permit required if gross vehicle weight is 80,000 pounds or more	Oregon Doubles allowed on all NN routes. Triples allowed only on routes approved by Oregon DOT. Access determined by Oregon DOT
South Dakota	Required if combination has gross vehicle weight of 80,000 pounds or more	Doubles with cargo-carrying length of 81.5 feet or less are allowed on all NN routes with statewide access unless restricted by South Dakota DOT. Doubles over 81.5 feet and triples are allowed on the Interstate System and selected state routes. Access must be approved by South Dakota DOT
Utah	Required	All NN routes with access routes approved by Utah DOT for combinations of less than 85'. Combinations 85' and over may operate only on NN routes: I-15, I70 from JCT. I15 to Colorado state line, I-80, I-84 from JCT. I80 to Idaho state line, I-215, and UT 201 from I80 Exit 102 to 300 West St. Salt Lake City
Washington	Required for cargo-carrying units over 60' but not exceeding 68'	Allowed on all NN and state routes except WA 410 and WA 123 in Mt. Rainier N.P. May be restricted by local ordinances
Wyoming	No	Allowed on all NN routes and unlimited access off NN to terminals

As part of the study's outreach effort, extensive routing maps were created showing the truck size and weight regulations in each State. Figures II-9 through II-11 show the current networks available for RMD (maximum 68-feet combined trailer length), TPD (82-feet combined trailer length and up) and triple trailer combinations. Most States do not prescribe a difference between Rocky Mountain Doubles and Turnpike Doubles; they specify routes for different combined trailer lengths. The distinction between Rocky Mountain Doubles and Turnpike Doubles is made in the maps below to facilitate comparisons in the Western Uniformity Scenario. In general a RMD has a combined trailer length between 68 and 81 feet and a TPD has a combined trailer length between 82 and 101 feet.

Figure II-9
Rocky Mountain Doubles Base Case Network

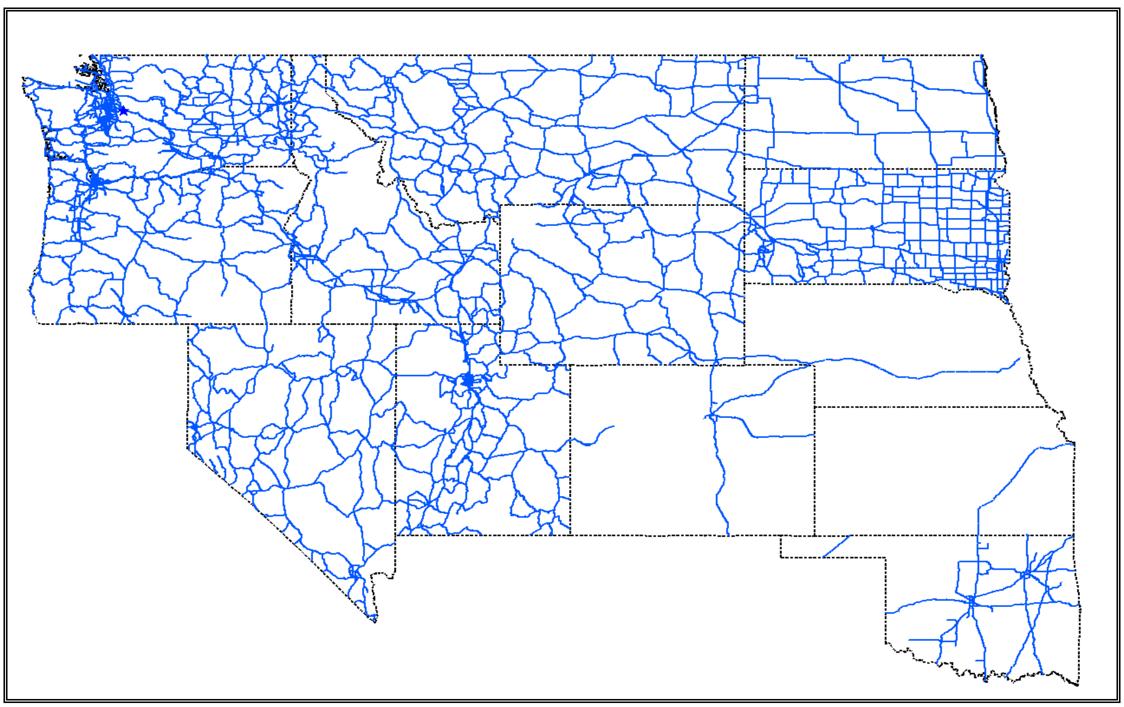


Figure II-10
Turnpike Doubles Base Case Network

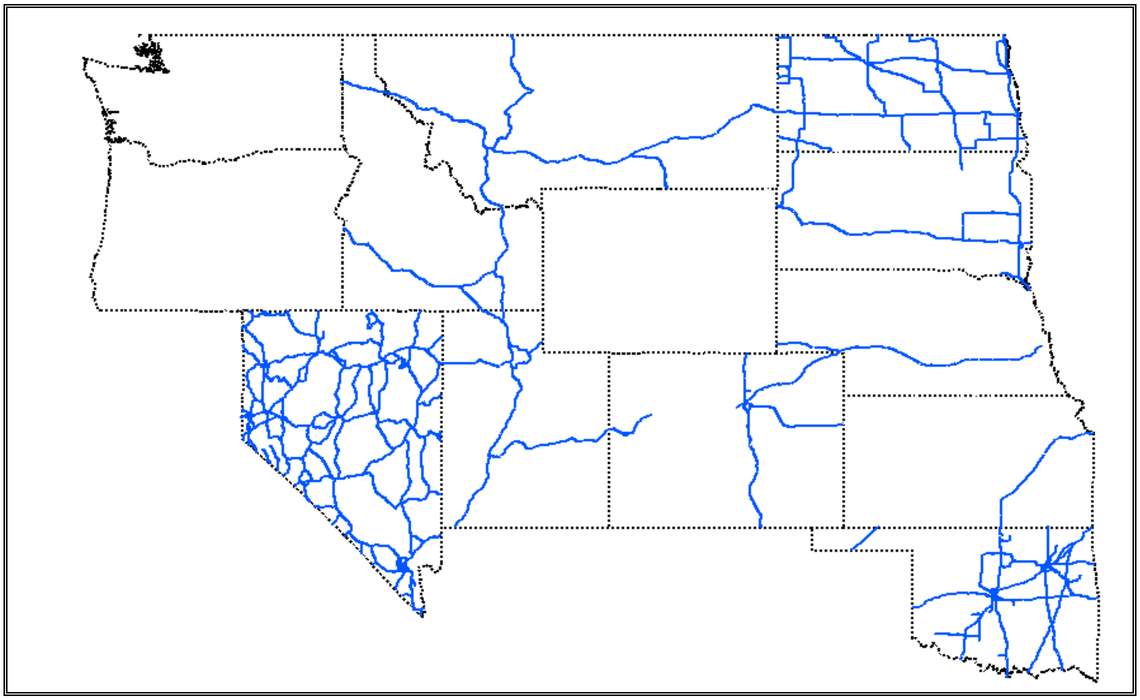
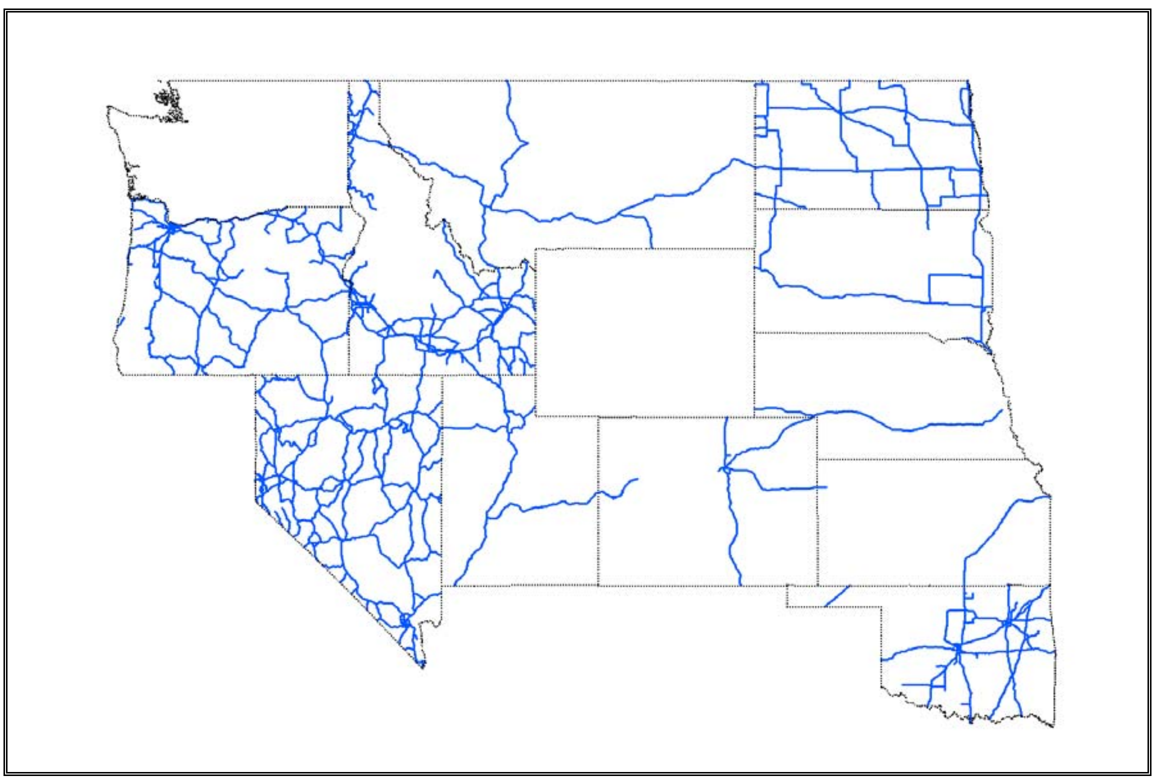


Figure II-11
Triples Base Case Network



Western Uniformity Scenario

The LCV freeze imposed by the ISTEA of 1991 responded to public concerns regarding the safety of LCVs as well as concerns regarding rail competitiveness. This freeze prevents the States from changing the weights, lengths, and routes of LCVs. For purposes of the freeze, LCVs are defined as commercial motor vehicles having two or more cargo units and gross weights above 80,000 pounds. Figure II-12 provides additional details on the LCV freeze.

The Western Uniformity Scenario explores the impact of lifting the LCV freeze for 13 Western States and allowing States to set weight limits for LCVs that would be controlled only by federal axle load limits and the Federal Bridge Formula. Trailer lengths would be limited to 48 feet for twin trailer combinations and 28.5 feet for triple trailer combinations. Operations would generally conform to the *Guide for Uniform Laws and Regulations Governing Truck Size and Weight Among the WASHTO States* (January, 2000) that was adopted by the Western Association of State Highway and Transportation Officials (WASHTO).

Several States belonging to WASHTO chose not to participate in the analysis – Arizona, California, New Mexico, and Texas.[7] The non-participating States do not currently have LCV operations. As noted above, a number of States included in the analysis indicated they would not adopt the size and weight limits assumed in the scenario, even if given the flexibility to do so. Thus, like the other *CTS&W Study* Scenarios, this scenario is merely illustrative of the impacts that might occur if assumptions in the scenario were fully implemented.

Figure II-12
The ISTEA Longer Combination Vehicle Freeze

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 imposed a freeze on States to restrict the operation of Longer Combination Vehicles (LCVs) on the Interstate System to the type of vehicles in use on or before June 1, 1991. The ISTEA defined an LCV as a combination of a tractor and two or more trailing units weighing more than 80,000 pounds that operates on the Interstate. This freeze was continued with the Transportation Equity Act for the 21st Century.

In addition to freezing the weights, lengths and routes of LCVs on the Interstate System, ISTEA froze the lengths and routes of commercial motor vehicles having two or more cargo units on the National Network for Large Trucks. A commercial motor vehicle is a motor vehicle designed or regularly used for carrying freight whether loaded or empty.

Because of the freeze, States that did not allow LCV operations prior to June 1, 1991 are precluded from allowing them. States that did allow LCVs are precluded from lifting restrictions that governed LCV operations as of that date. Such restrictions may include route-, vehicle- and driver- specific requirements.

[7] Hawaii and Alaska are members of WASHTO but were not approached to participate since the analysis focuses on LCV operations on a continuous network.

Scenario Description

The Western Uniformity Scenario estimates the impact of lifting the LCV freeze (see Figure II-1) for 13 contiguous States: Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington and Wyoming. These States would be allowed to increase the size and weights of their LCVs to match the WASHTO guidelines. Four of the participating States, Montana, Nevada, South Dakota and Utah would experience little change since they currently operate vehicles at, or above, the scenario limits. The scenario assumes that all States would uniformly adopt the new limits, and therefore captures the maximum impact.

The Vehicles

The scenario focuses on three LCVs, Rocky Mountain Doubles (RMD), Turnpike Doubles (TPD) and Triple-Trailer Combinations (Triples). All lengths and weights are subject ot the BFB limits. All the participating States currently allow RMDs, although combined trailer length limits vary from 68- to 81-feet and weight limits vary from 105,500 to 129,000 pounds. A typical RMD consists of a three-axle truck-tractor with a long front trailer (40- to 48-foot) and a shorter (20- to 28.5-foot) rear trailer. RMDs are used for general freight and resource hauls. The scenario assumes that all 13 States would allow RMDs a combined trailer length of 81-feet and a GVW of 129,000 pounds. The trailers would be allowed up to a 48-foot lead trailer with a 28.5-foot rear trailer.

The scenario also includes the triple-trailer combination. A typical triple consists of a two- or three-axle truck-tractor towing three trailers. Each trailer is usually 28- to 28.5-feet in length. Of the 13 States in the study, only Washington and Wyoming do not currently allow triples. Nebraska allows only empty triples on a very limited network.[8] Triples are mostly utilized by the less-than-truckload industry to move relatively small shipments among their terminal network. The scenario would allow triples to operate up to three 28.5-foot trailers with a GVW of 110,000 pounds.

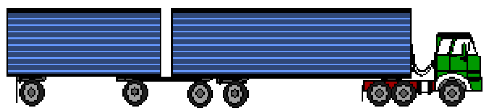
The longest and heaviest configuration tested in the scenario is the Turnpike Double (TPD). It would be allowed to 129,000 pounds GVW and have either maximum twin 48-foot trailers (101 feet combined trailer length) or maximum twin 45-foot trailers (95 feet combined trailer length). Both cases are tested since the WASHTO guide recommends twin 45-foot trailers, but five of the participating States currently allow the longer TPD, and 48-foot trailers are more common in the general truck fleet.[9] For discussion purposes this breaks the scenario into two cases: (1) the High-Cube Case that includes the twin 48-foot trailers; and (2) the Low-Cube Case that includes the twin 45-foot trailers. Both the High- and Low-Cube Cases include the RMD up to 81-feet combined trailer length and the triple-trailer configurations.

[8] Nebraska allowed a trailer manufacturer to haul empty trailers but they are no longer in business so Nebraska has no triples currently operating in their State.

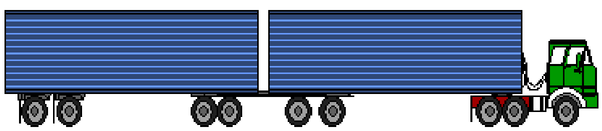
[9] Also the twin 48-foot TPD was explicitly requested for analysis in the letter from the Western Governor's Association.

Figure II-13 summarizes the main features of the Western Uniformity Scenario.

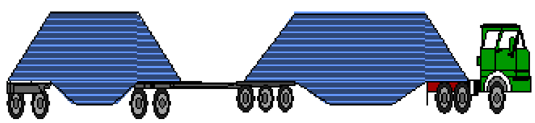
Figure II-13
Western Uniformity Scenario



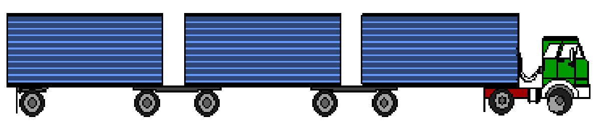
7-axle Rocky Mountain Double Maximum weight 111,000 lbs.



9-axle Turnpike Double Maximum weight 129,000 lbs



10-axle Resource Hauler Maximum weight 129,000 lbs.,



7-axle Triple Maximum weight 110,000 lbs

- **Main Feature**
  - Broad LCV Operations in 13 Western States
- **Available Highway:**
  - TPDs and Triples on Interstate;
  - RMDs and 8-axle B-train on National Network for STAA.
- **Access Provisions:**
  - TPDs and Triples State issues permits;
  - RMDs and 8-axle B-train current Federal and State provisions.
- **Bridge Formula B controls Axles and Allowable Weight up to 129,000 pounds for double and 110,000 pounds for a triple**

<u>The Networks</u>

Highway networks on which various LCVs were assumed to operate under the scenario are as follows: (1) RMDs would be allowed on the NN System and (2) TPDs and triples would be allowed only on the Interstate Highway System. As in the CTS&W Study, a larger network is assumed for RMDs because of their superior ability to negotiate curves and grades. The scenario networks are shown in Figures II-14 through II-16. In creating the scenario networks, it was assumed that States would continue to allow LCVs on all the current routes where LCVs now operate.

Figure II-14
Rocky Mountain Double Western Uniformity Scenario Network

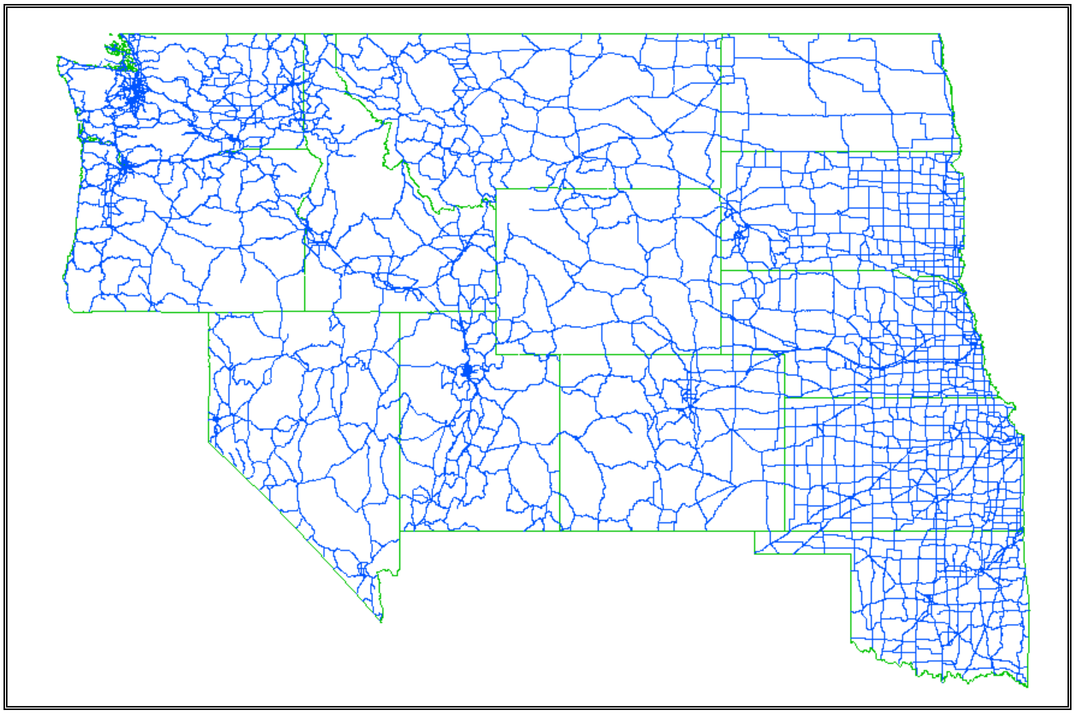


Figure II-15
Turnpike Doubles Western Uniformity Scenario Network

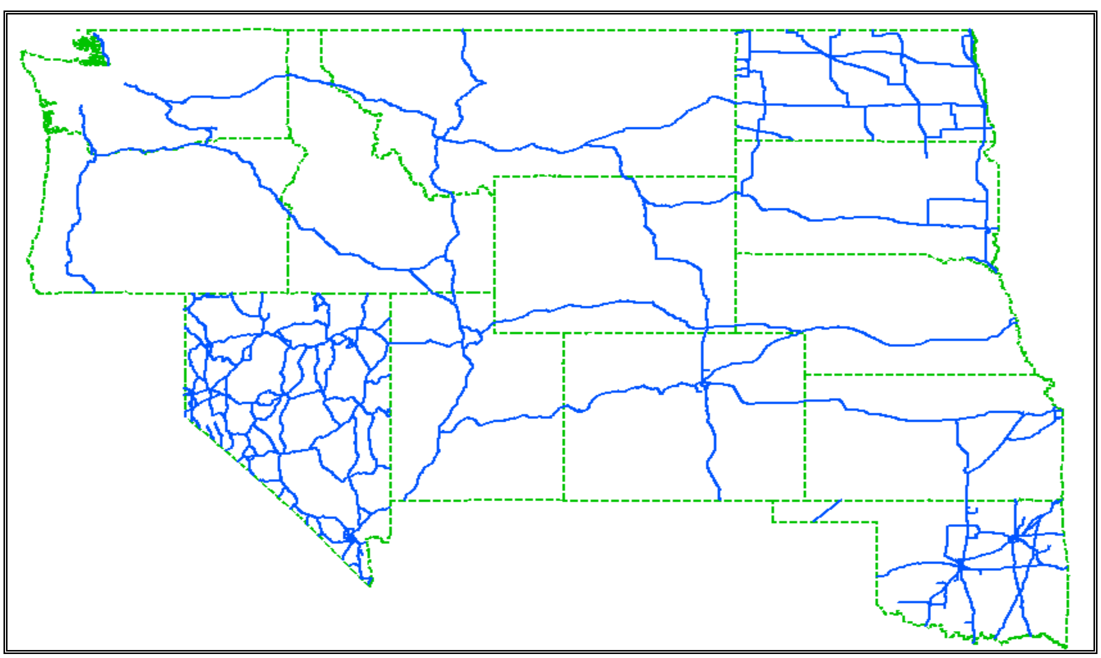
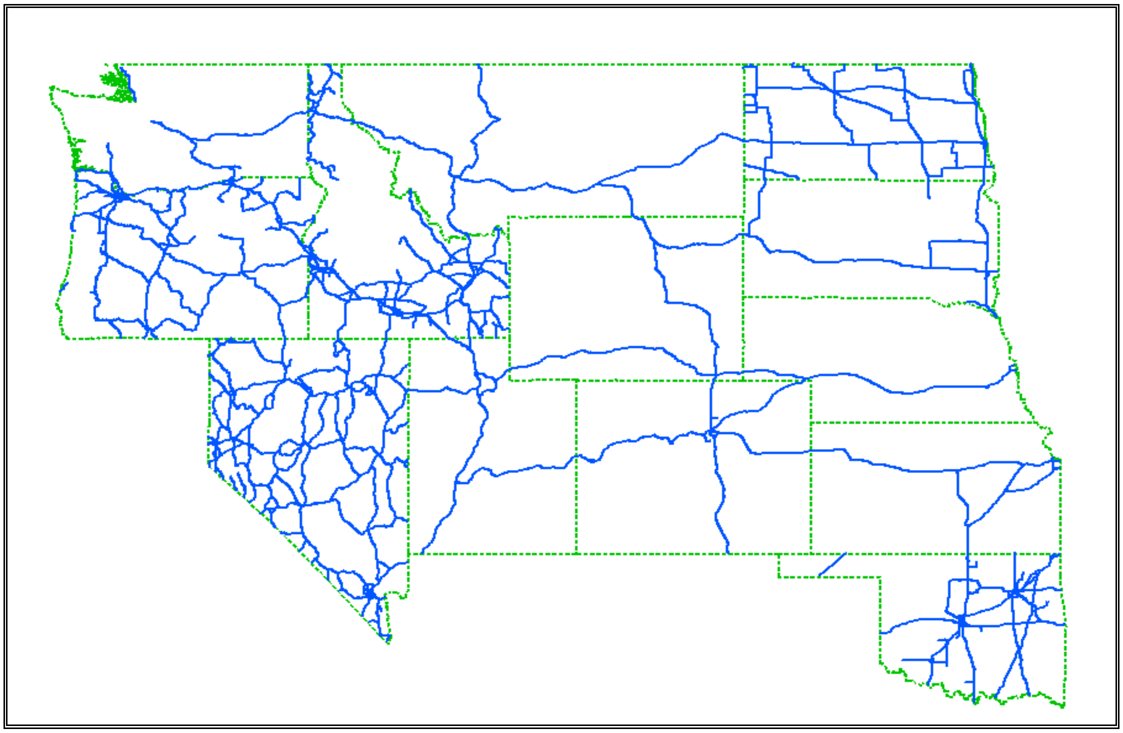


Figure II-16
Triples Western Uniformity Scenario Network



Access Provisions

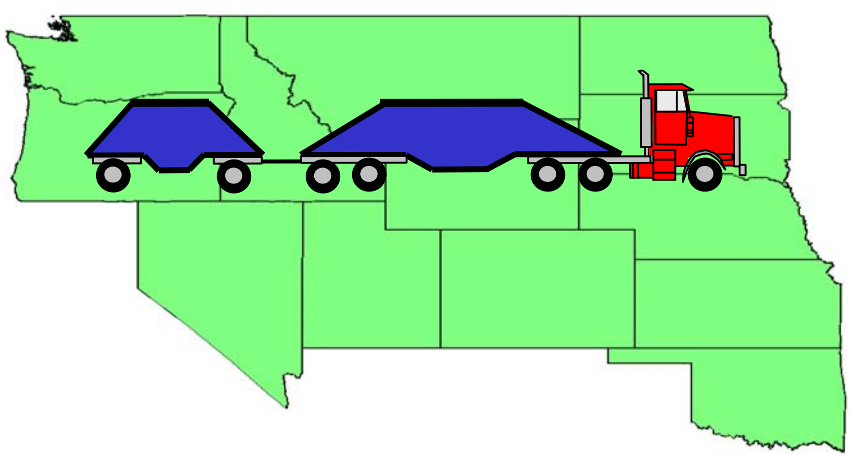
Current rules in the Western States control access to and from the road networks, see Figure II-8. The scenario assumes that States would continue to control access to and from the networks to mitigate LCV impacts on bridges, pavement, roadway geometry and congestion.

Because of poor off-tracking, or cornering, performance, the scenario assumes that TPDs would be restricted to the designated TPDs network. It is assumed that drivers of these vehicles will use staging areas—large parking lots—to disconnect the extra trailer and attach that trailer to another tractor for delivery to its final destination. Drayage is assumed to be along the most direct route off the network between the shipper or receiver and the network.

Triple-trailer combinations are allowed direct access, under a State-issued permit, to and from the network without disconnecting the trailers for up to 2 miles for loading or service.

CHAPTER III

Freight Distribution and Shipper Costs



Introduction

Changes in truck sizes and weights impact the relative costs of utilizing different truck configurations and modal choice between truck and rail. These cost changes translate into changes in mode choice, changes in shipper costs and changes in the distribution of freight to truck configurations. The changes in the distribution of freight to truck configurations impacts truck vehicle miles traveled (VMT) and the weight distribution of that VMT. The shifts in freight between truck configurations and from rail to truck directly impact shipper costs, highway pavements, safety, energy consumption, air quality, and noise levels.

Analytical Approach

The analytical approach used in the *CTS&W Study* is essentially unchanged but has been updated to include the newest data sources and expanded modeling of over 1 million truck shipments and explicit modeling of existing LCV shipments. Similar to the *CTS&W Study's* analysis the data is examined with explicit user-controlled assumptions concerning the mode and configuration costs. The discussion in this chapter focuses on the differences between the current analysis and the *CTS&W Study's* analysis. The reader is referenced back to Chapter IV of the *CTS&W Study* for a more general discussion of truck and rail analysis.

Model and Data Updates

The analysis year for this scenario is 2010 and the base year is 2000. Using the methodology developed for the Department of Transportation's (DOT's) *1997 Federal Highway Cost Allocation (HCA) Study*, year 2000 VMT were developed for the study vehicles disaggregated by weight group, highway functional class and State. The base year data for the rail car mile traffic comes from the Surface Transportation Board's 2000 Waybill Sample.

The 2000 VMT and car mile estimates are forecast to 2010 using commodity-by-commodity demand based forecasting. The forecasts were developed by Global Insight (formerly DRI/WEFA) using their U.S. macroeconomic model. This improves upon the single percentage truck and rail growth rates that were used in the *CTS&W Study*.

<u>Truck Analysis</u>

For purposes of analysis truck traffic is divided into short-haul, long-haul and triples. The short-haul truck analysis focuses on combination trucks that operate less than 200 miles, on a typical haul. In the 13 scenario States this is primarily resource and construction hauls. Operations in four States that currently have double-trailer combinations operating at the scenario's weight limits were used to develop proportional weight distributions and utilization rates for the 9 States that would experience an expansion of their size and weight rules for double-trailer combinations.

The triple-trailer analysis similarly developed weight distributions and utilization rates for the 3 States that currently do not allow triple-trailer operations. Triple-trailer combinations are primarily operated by less-than-truckload carriers who use them to facilitate the movement of small packages between and among their terminals.

Long-haul truck analysis explicitly accounts for changes in transportation costs and the impact of expanded roadway networks. The analysis used the Intermodal Transportation and Inventory Cost Model (ITIC) developed for the *CTS&W Study* and further discussed in Chapter IV of that study. This analysis significantly updates the truck database by using the Freight Analytical Framework (FAF) database. The FAF data provides truck-freight-tonnage flows by commodity type at the county level of detail. FAF freight volumes are assigned to cargo body types using commodity and vehicle data from the *1997 Vehicle Inventory and Use Survey (VIUS)*. The assignment of truck tonnage totals to individual truck movements and configurations is estimated from the application of market freight-rate data to the truck flows routed over the available highway networks. The traffic is assigned to the configuration with the lowest cost as determined by the load size, which is based on commodity density (pounds per cubic foot) and market rates. The configuration's size and weight limit was set to the lowest maximum size and weight allowed in the States traveled in-route from origin to destination. Figure III-1 describes the development of motor carrier origination-destination specific market rates that used Signpost Solutions' *North American Truckload Rate Index.*

Figure III-1
Development of Motor Carrier Market Rates

- Year 2000 dry van tractor-semitrailer market rate-per-mile data covering 120 market areas and 14,400 origin/destination pairs.
- Rate differentials for non-dry van body types reflect differences from dry van in percent-empty rates, annual-mileage rates and trailer ownership cost.
- Rate differentials for other configurations reflect differences from tractor-semitrailer in engine size, fuel mileage, and cost of 2^{nd} trailer based on length and number of axles.

<u>Rail Analysis</u>

The rail analysis, both intermodal and carload, followed the methodology used in the *CTS&W Study*. The data was updated to the 2000 Carload Waybill Sample and movements that did not travel within or through the 13 analyzed States were excluded.

Shipper Cost Analysis

A change in truck size and weight regulations will alter a shipper's logistic costs. "Logistic cost" includes the whole cost of receiving raw inputs and shipping final outputs. Transportation and inventory costs are two of the largest components of a shipper’s logistic costs. This section updates transportation and inventory totals to 2000; Chapter XII of the *CTS&W Study* contains a more detailed explanation of the trade-off between transportation and inventory costs.

Transportation cost is the cost of moving a shipment from its origin to its destination. In 2000 rail shippers paid $36 billion in transportation expenses and shippers using commercial trucks paid $481 billion of which $158 billion was intercity shipments (ENO Foundation). Total logistics costs for all modes, including inventory, administration and carrying costs topped $1.006 trillion or 10.1 percent of year 2000 nominal gross domestic product (GDP).

Changes in truck size and weight also affect inventory costs. Inventory costs include warehousing, depreciation, taxes obsolescence, insurance, ordering and interest expenses. Total national inventory carrying cost was estimated to be $1.485 trillion in 2000 (Cass Logistics).

The impact on shipper transportation costs is derived from the ITIC model. As was true with the *CTS&W Study*, estimation of the aggregate changes in inventory cost associated with the illustrative scenario could not be completed within the scope of this study. Shipper costs for truck transportation are computed by multiplying the VMT for each shipment by that shipment’s transportation cost, which depends upon the configuration, gross vehicle weight, and the market rate for that origination-destination pair.

Rail shipper transportation cost is computed from revenues reported in the Surface Transportation Board’s (STB) Carload Waybill Sample, a sample of rail freight movements. The Waybill Sample includes expansion factors to allow estimation of total impacts. The cost of the truck alternative movement of rail traffic traversing the 13 study States is generated for base case and scenario truck configurations to compare with the cost of the move by rail. Where the scenario’s truck cost is below rail variable cost as reported in the Waybill, the traffic diverts to truck. Where the scenario truck cost is above rail variable cost, but below rail revenue, rail retains the traffic by lowering the rate to match the truck cost. As a result of the rate reductions made by rail to retain the freight, some shippers who remain on rail benefit from lower rates as well as those shippers who switch from rail to truck.

Scenario Impacts

The Western Uniformity Scenario is analyzed with two alternative maximum lengths for the longest double trailers. The two cases both include shorter double-trailer RMDs and triple-trailer combinations but the low-cube case constrains the longest double to 95-feet combined trailer length (this allows up to a twin 45-foot TPD), where as the high-cube case allows the longest double to reach 101-feet combined trailer length (this allows up to a twin 48-foot TPD). The analysis assumes that the regulations governing the sizes and weights analyzed have been in place long enough to be fully adopted by industry. Figure III-2 outlines assumptions regarding how freight currently traveling in the affected configurations would respond to the new LCVs.

Figure III-2
Likely Truck Configuration Impacts of the Western Uniformity Scenario

Original Truck Configuration		Likely Reaction to the Scenario
Five-axle tractor semitrailer	→	Change to Rocky Mountain Double
	→	Change to Turnpike Double
Five- or Six-axle double-trailer combination (LTL freight)	→	Change to triple-trailer combination (LTL freight)
Rocky-Mountain (or short) double-trailer combination	→	More payload
Turnpike (or long) double-trailer combination	→	More payload
Triple-trailer combination	→	No change

As Table III-1 shows, total scenario VMT declines from base case levels for all of the highway classifications. The share of VMT on non-Interstate declines in each of the scenario cases as well. The largest decline in non-Interstate truck VMT occurs in the High Cube Case due to the utilization of the longer TPD that is restricted to the Interstate System.

Table III-1
2010 VMT by Highway Type
(in millions)

Functional Class	Base Case VMT	Low Cube Case VMT	High Cube Case VMT
Rural			
Interstate	8,329	7,850	7,791
Other Principal Arterial	3,457	2,810	1,942
Other	3,127	3,098	1,906
Urban			
Interstate	2,001	1,631	1,360
Freeways/Expressways	316	179	107
Other	1,592	1,460	922
Rural and Urban			
Interstate	10,330	9,482	9,151
Other	8,493	7,547	4,877
Total	18,823	17,029	14,028

The extent of LCV use will depend on the types of commodities moving within and through the region, as well as whether the traffic originates and/or terminates within the region. Tables III-2 and III-4 show the LCV share of VMT for specialized freight, dry freight, and in total for the Base Case and the Western Uniformity Scenario Cases. Intra-regional traffic has the largest penetration of LCVs in the Base Case and both of the scenario cases. This is expected, as these traffic flows do not have the costly operational disadvantage of separating the configuration for travel outside the region.

Low-Cube Case

Table III-3 and Figure III-3 summarize the VMT analysis results for the low-cube case. In this case the 2010 VMT within the analyzed region[10] declines 9.5 percent. It is interesting to examine the impact of the scenario on truck traffic that flows within the 13 analyzed States, through the analyzed States (either across or with an origination or destination with in the analyzed States) and on rail traffic. Within the study region 69 percent of the base case VMT is impacted, 65 percent by shifts from tractor-semitrailer configurations to LCVs and 4 percent by increased weight on existing LCVs. Only 8 percent of the truck travel across the region is impacted (these are moves that have an origination and destination outside the 13 analyzed States). Table III-2 indicates that through-traffic VMT in the 13 States would actually increase from the use of more productive LCVs. This is because the best routing for much of the through-traffic between the Southeast and California in the base case is across Texas, New Mexico and Arizona. With the introduction of more productive LCVs in the west, the scenario routing shifts north to take advantage of the LCV network.[11]

Compared to the "Longer Combination Vehicles Nationwide Scenario" in the *CTS&W Study*, the impact of the regional permit system is very small. As a percent of the rail traffic moving within or through the 13 States, only 0.22 percent of the rail carload miles divert and only 0.07 percent of the intermodal rail miles divert to truck. The restriction of the 45-foot trailers on the turnpike double and the limited 13 State involvement coupled together create a small impact on the railroads. In contrast, the LCVs Nationwide Scenario predicted 9 percent of rail carload miles and 31 percent of rail intermodal miles diverted.

[10] Although it is implicitly assumed that VMT outside the analyzed region would not change there would probably be some small increase in VMT attributable to delivery of single trailers that travel as LCVs within the permitted States.

[11] This potentially overstates the diversion of truck traffic using I-40 in the base case since the shift-up to I-70 would force the trucks to travel through mountain passes where they would encounter steep grades and weather related issues.

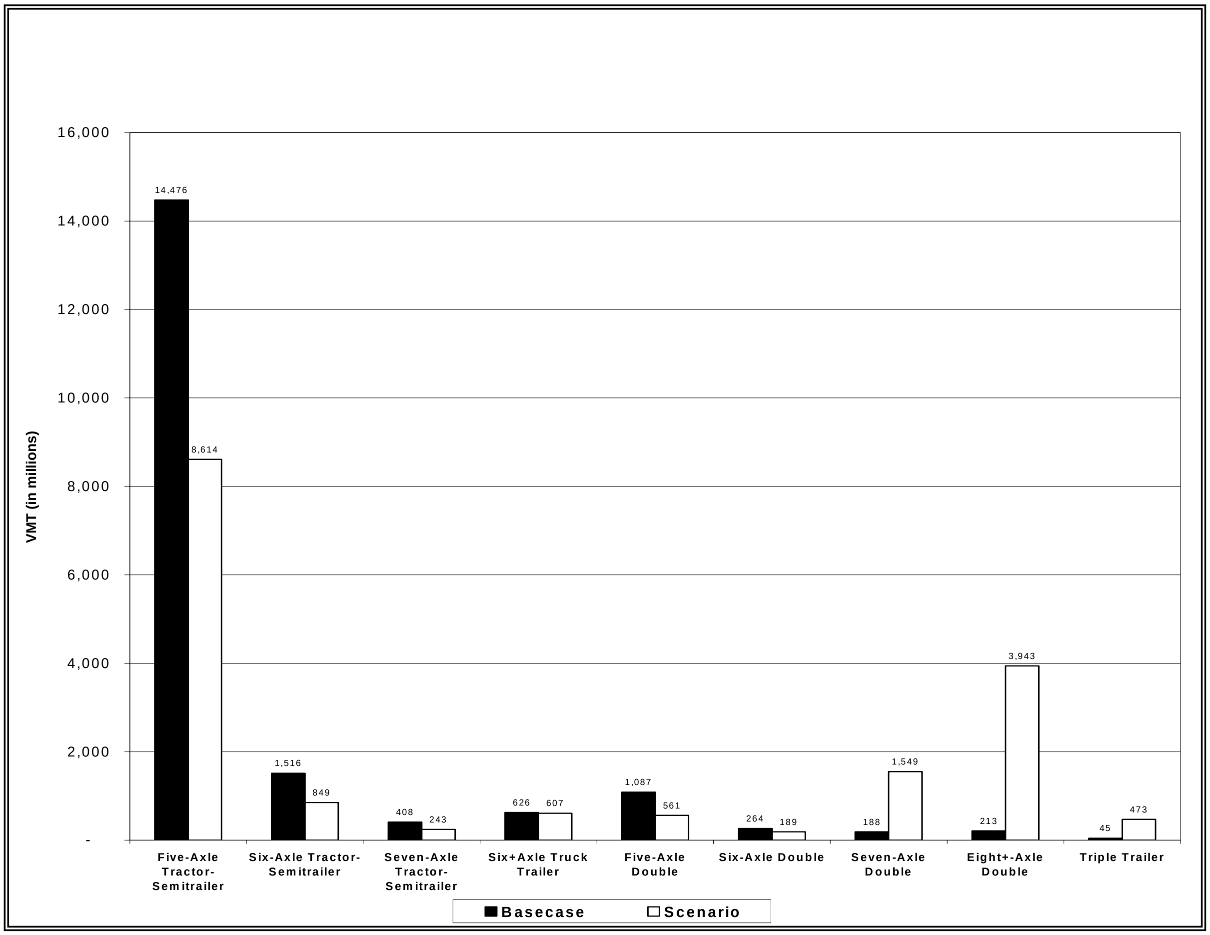
Table III-2
Base Case and Low Cube Western Uniformity Scenario
2010 LCV Vehicle Miles of Travel in the Analyzed Region
by Commodity Group and Flow Type

Commodity Group	Flow	VMT By Flow and Commodity Group			
		Base Case		Low Cube	
		Total VMT (millions)	Percent in LCVs	Total VMT (millions)	Percent in LCVs
Bulk, Tank, Flatbed (Specialized Freight)	Intra-Regional	2,101	12.7%	1,713	88.8%
	Inbound	1,098	0.8%	958	40.5%
	Outbound	2,285	0.8%	2,150	23.8%
	Through	887	0.0%	895	7.1%
	Total	6,370	4.6%	5,716	43.5%
Dryvan, Reefer (General Freight)	Intra-Regional	2,406	6.2%	2,063	53.9%
	Inbound	2,700	0.1%	2,382	35.7%
	Outbound	4,589	0.0%	4,041	34.1%
	Through	2,758	0.0%	2,827	5.0%
	Total	12,452	1.2%	11,313	30.8%
All Traffic	Intra-Regional	4,506	9.2%	3,775	69.7%
	Inbound	3,798	0.3%	3,341	37.1%
	Outbound	6,874	0.3%	6,191	30.5%
	Through	3,645	0.0%	3,722	5.5%
	Total	18,823	2.4%	17,029	35.0%

Table III-3
Total VMT for Base Case and Western Uniformity,
Low-Cube Case

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	18,823
Low-Cube Case	17,029
Percent Change	-9.5%

Figure III-3
Impact of Western Uniformity Scenario on VMT by Different Vehicles, Low-Cube Case



High-Cube Case

Table III-5 and Figure III-4 summarize the analysis results for the high-cube case. The longer turnpike double (up to twin 48-foot trailers) reduces VMT 25.5 percent among the 13 analyzed States. As with the low-cube case, it is interesting to examine the impact of the scenario on truck traffic that flows within the 13 analyzed States, through the analyzed States (either across or with an origination or destination with in the analyzed States) and on rail traffic. Within the study region 76 percent of the base case VMT is impacted, 71 percent by shifts from tractor-semitrailer configurations to LCVs and 5 percent by increased weight on existing LCVs. As compared to the low-cube case, there is a much larger impact on the through-traffic. In the high-cube case 60 percent of the through-traffic tractor-semitrailers divert to LCVs. These truck movements would originate as two single 48-foot tractor-semitrailers but would join as a twin 48-foot TPD for the move across the region and then split apart for delivery outside the region. Such operations could yield substantial benefits for logistics management and large fleet operations. Small single truck owner-operators could be at a competitive disadvantage.

Table III-4 shows that the different types of truck traffic are not impacted equally. The intra-regional traffic has the greatest cost per ton-mile gains since there is no penalty for staging trailers for moves outside the region. The Table also shows that the heavier bulk, tank and flatbed commodities are more likely to divert since they will experience strong gains in the amount of freight each truck can accept. Comparing Tables III-2 and III-4 shows that the longer trailers allowed in the High-Cube Case translate into more diversion for all traffic segments. The High-Cube Case exhibits a substantial jump in the inbound, outbound and through traffic that diverts when compared to the Low-Cube Case. This is because the "penalty" of delivering the trailers outside the 13 State region is less when operating 48-foot trailers than for 45-foot trailers.

As a percent of the rail traffic moving within or through the 13 States, only 0.24 percent of the rail carload miles divert and only 0.10 percent of the intermodal rail miles divert to truck. The restriction of the 48-foot trailers on the turnpike double and the limited 13 State involvement coupled together create a small impact on the railroads.

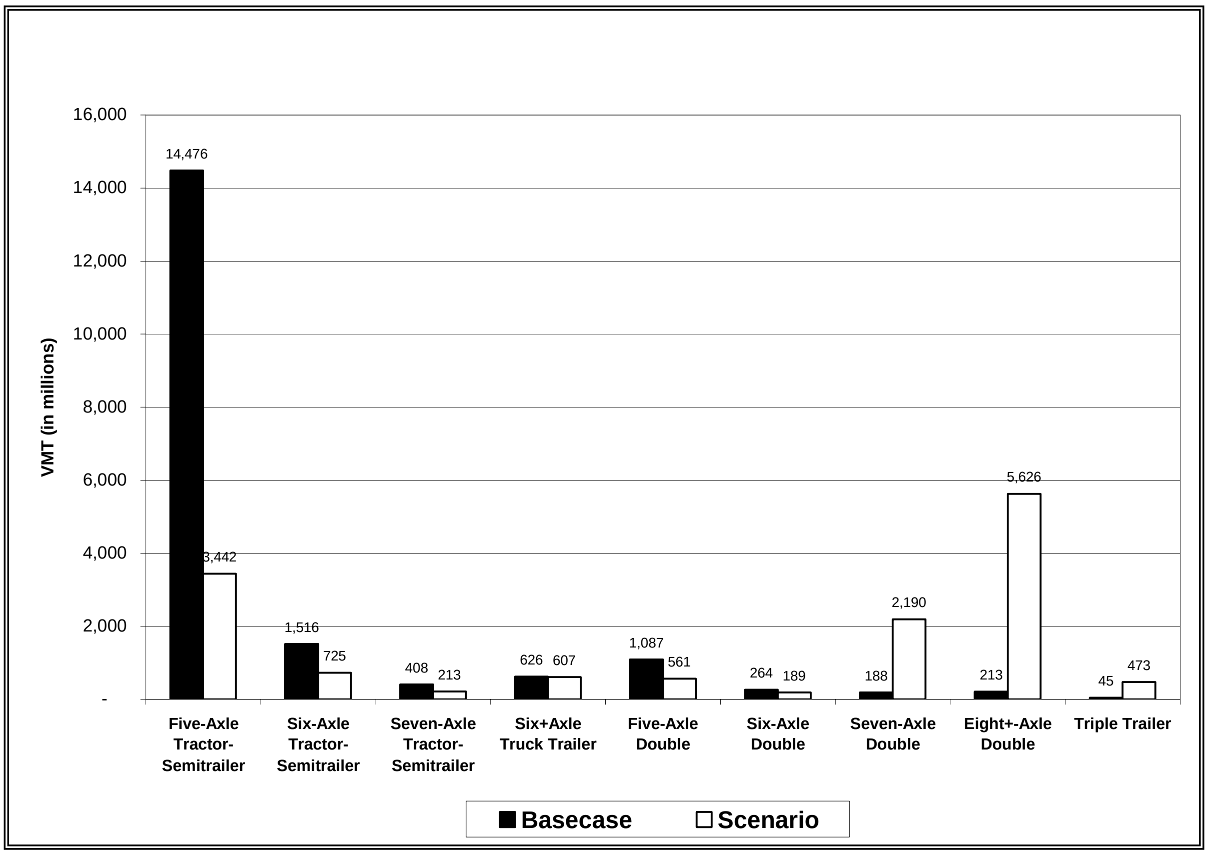
Table III-4
Base Case and High Cube Western Uniformity Scenario
2010 LCV Vehicle Miles of Travel in the Analyzed Region
by Commodity Group and Flow Type

Commodity Group	Flow	VMT By Flow and Commodity Group			
		Base Case		High Cube	
		Total VMT (millions)	Percent in LCVs	Total VMT (millions)	Percent in LCVs
Bulk, Tank, Flatbed (Specialized Freight)	Intra-Regional	2,101	12.7%	1,566	96.1%
	Inbound	1,098	0.8%	827	56.9%
	Outbound	2,285	0.8%	1,804	41.5%
	Through	887	0.0%	664	45.8%
	Total	6,370	4.6%	4,861	62.3%
Dryvan, Reefer (General Freight)	Intra-Regional	2,406	6.2%	1,853	62.7%
	Inbound	2,700	0.1%	1,966	58.8%
	Outbound	4,589	0.0%	3,302	58.0%
	Through	2,758	0.0%	2,047	50.3%
	Total	12,452	1.2%	9,167	57.4%
All Traffic	Intra-Regional	4,506	9.2%	3,419	78.0%
	Inbound	3,798	0.3%	2,792	58.3%
	Outbound	6,874	0.3%	5,105	52.1%
	Through	3,645	0.0%	2,711	49.2%
	Total	18,823	2.4%	14,028	59.1%

Table III-5
Total VMT for Base Case and Western Uniformity, High-Cube Case

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	18,823
High-Cube Case	14,028
Percent Change	-25.5 %

Figure III-4
Impact of Western Uniformity Scenario on VMT by Different Vehicles, High-Cube Case



Shipper Cost Impacts

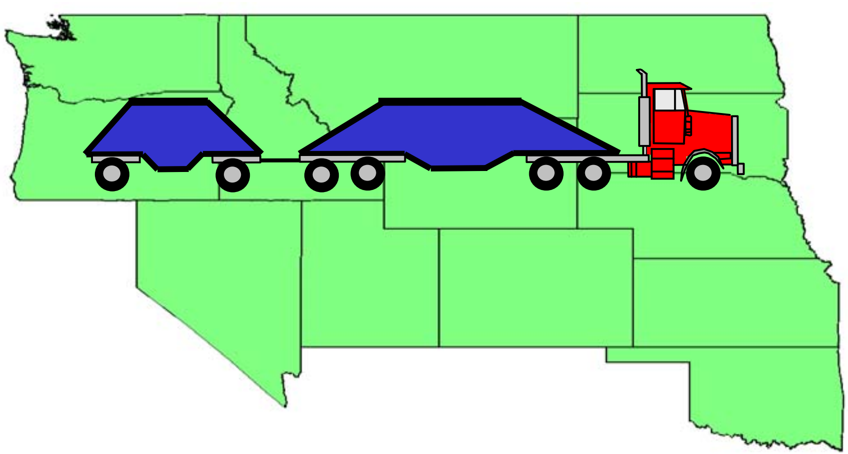
Table III-6 shows that shippers who use the LCVs at heavier weights and sizes experience transportation savings. Truck shippers who change configurations would save $1,190 million in the low-cube case and $2,036 million in the high-cube case. Rail shippers who change from rail to truck save $2.3 million in the low-cube case and $3.2 million in the high-cube case. Rail shippers who continue to use the railroad obtain competitive rate reductions of $26 million in the low-cube case and $48 million in the high-cube case. The impact of the lower rail revenues is presented in Chapter X.

Table III-6
Annual Transportation Cost Savings for Truck Shipments

	Western Uniformity Scenario	
	Low-Cube Case	**High-Cube Case**
Truck-to-Truck		
Dollars (millions)	$1,190	$2,036
Percent Change	2.3%	3.9%
Rail-to-Truck		
Dollars (millions)	$2.3	$3.2
Percent Change	0.01%	0.01%
Rail Discount		
Dollars (millions)	$26	$48
Percent Change	0.06%	0.11%

CHAPTER IV

Pavement



Introduction

The *2002 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance Report to Congress* indicates that $594 billion in highway expenditures, exclusive of those related to bridges, will be required nationwide between 2001 and 2020 just to preserve the physical condition of the existing highway system. Changes in truck size and weight (TS&W) policy could have a major impact on pavement quality and performance characteristics and, therefore, future investment requirements.

As discussed in Chapter 3, uniform TS&W regulations in the Western States would change the distribution of freight to the more productive LCVs, and thus change the configuration characteristics of trucks traveling over the region's roadway pavements. Pavement wear occurs from load related, as well as non-load related factors. Non-load related factors include current pavement condition and environmental factors such as climate, subsoil type, and drainage.

Load related factors include axle weight, number, and width of tires on the axle, and spacing between axles. Because pavement deterioration increases with axle weight, the number of axle loadings and the spacing within axle groups, changes to the distribution of truck configurations traveling in the region could affect pavement wear.

Truck-Pavement Interaction

The primary determinant of vehicle induced pavement wear severity is the load carried on axles and axle groups. Gross vehicle weight (GVW), in and of itself, has little impact on how much pavement wear a vehicle will cause. The number of axles and spacings between axles on the vehicle, and how the GVW is distributed over those axles, are the key determinants of the amount of stress a vehicle applies to the pavement.

Axle groups, such as tandems or tridems, distribute the load along the pavement, allowing greater weights to be carried and resulting in the same or less pavement distress than that occasioned by a single axle at a lower weight. The spread between two consecutive axles also affects pavement life or performance – the greater the spread, the more each axle in a group acts as a single axle. For example, a spread of 9 to 10 feet results in no apparent interaction of one axle with another, and each axle is considered a separate loading for pavement impact analysis or design purposes. Conversely, the closer the axles in a group are, the greater the weight they may carry without increasing pavement deterioration beyond that occasioned by the same number of single axles.

A common metric used to measure the amount of stress an axle or group of axles applies to pavement is the Equivalent Single Axle Load (ESAL). The ESAL unit expresses the amount of pavement stress occasioned by an 18,000 pound axle. Although ESALs were not used as the basis for estimating pavement impacts for this Study,[12] they are widely understood by those concerned with the pavement impacts of TS&W scenarios, and

[12] Pavement impacts in this study were estimated by Load Equivalency Factors (LEFs) for six pavement distresses. LEFs are similar to ESALs in that they standardize pavement distresses to an 18,000-pound axle equivalent, but the ESAL measure does not differentiate between distresses, such as fatigue, rutting and cracking.

provide a convenient metric for comparisons of pavement stresses between vehicles of different weights and axle configurations.

Table IV-1 shows payload tons per ESAL for study configurations at key weights, indexed to a 5-axle tractor-semitrailer weighing 80,000 pounds. Configurations at weights with an index number over 100 carry more payload per unit of pavement damage than the 5-axle tractor semitrailer, those with an index under 100 carry less.

Table IV-1
Net Tons per ESAL –Study Configurations at Key Weights
(indexed: 80,000 pound CS-5=100)

Configuration – Axles[1]	**GVW**	**Payload Tons Per ESAL** (indexed: 80,000 pound CS-5=100)	
		Rigid Pavement (10 inch thickness)	**Flexible Pavement** (structural number 5, terminal PSI 2.5)
5-axle Tractor Semitrailer	80,000 [1]	100	100
	85,500 [2]	81	83
6-axle Tractor Semitrailer	85,000	145	160
	97,000	98	119
7-axle Tractor Semitrailer	85,000 [1]	238	290
	101,000 [2]	142	189
5-axle Double-Trailer Combination	80,000 [1]	126	72
	94,000 [2]	73	45
6-axle Double-Trailer Combination	80,000	221	148
	97,000	120	86
7-axle Double-Trailer Combination	95,000 [1]	202	158
	114,000 [3]	114	95
	121,500 [2]	93	79
8-axle Double-Trailer Combination	95,000[1]	255	263
	124,000 [3]	115	127
	126,000 [2]	111	124
9-axle Double-Trailer Combination	95,000 [1]	380	333
	129,000 [2,3]	139	139
7-axle Triple-Trailer Combination	90,000 [1]	261	142
	110,000 [3]	143	81
	121,500 [2]	104	61
8-axle Triple-Trailer Combination	90,000 [1]	369	229
	110,000 [3]	213	136
	126,000 [2]	140	93

[1] Minimum Current WGA Limit for Configuration
[2] Maximum Current WGA Limit for Configuration
[3] Uniformity WGA Limit for Configuration

The ESAL calculations are based on hypothetical highway sections – rigid pavement of 10 inch thickness and flexible pavement with a structural number of 5 and terminal pavement serviceability index value of 2.5.[13] Actual ESALs (and LEFs) vary by several factors including pavement type, thickness and sub-grade type, as well as the distribution of GVW over the vehicle's axle groups. These theoretical values show relative relationships among axle load, axle type, pavement type, and pavement characteristics, but they do not show the influence of environmental factors and thus should not be used in specific applications.

The payload per ESAL measure reflects the volume of freight that can be moved per unit of pavement distress relative to the distress occasioned by a 5-axle tractor semitrailer at the Federal weight limit of 80,000 pounds. As the table shows, all of the configurations considered for uniform size and weight throughout the region, with the exceptions of the 7-axle double and 7-axle triple on flexible pavement, are less damaging than the 5-axle tractor semitrailer comparison vehicle. In the case of the 7-axle triple, it is important to note that this configuration is expected to divert traffic from the 5-axle double configuration, which is more damaging at 80,000 pounds than the 7-axle triple is at 110,000.

Estimates of Pavement Cost – The National Pavement Cost Model

The National Pavement Cost Model (NAPCOM) was used to estimate potential pavement impacts resulting from changes in vehicle size and weight limits in the region.[14] NAPCOM is a complex simulation model initially developed in 1992 and subsequently improved for use in the 1997 *Highway Cost Allocation Study (HCA Study)* and 2000 *CTS&W Studies*. The key output of NAPCOM for truck size and weight analysis is the change in overall pavement improvement needs under alternative size and weight policy scenarios. The model is sensitive to different weight policies, depending on truck configuration, including the number of axles. Changes in pavement rehabilitation costs between successive runs of NAPCOM with changed assumptions about the distribution of freight among truck configurations and operating weights are attributed to specific groups of vehicles.

Axle load and frequency information have been estimated based on vehicle-miles-of-travel (VMT) information for various classes of highway vehicles from the 1997 *HCA Study*. *HCA Study's* VMT estimates by vehicle class and weight group have been updated and modified according to the policy options evaluated in this Study as analyzed in the freight distribution phase of the study described in Chapter III.

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[13] Flexible pavement structural number is a measure of pavement strength determined from materials, thickness and drainage characteristics of the pavement subbase, base and surface layers. Pavement serviceability index is a ride quality measure scaled from 1 to 5. The terminal index value indicates the point where ride quality is unacceptable and requires resurfacing or rehabilitation.

[14] *NAPHCAS Users Guide*, R.D. Mingo, 1998. Unpublished.

Scenario Impacts

Scenario pavement impacts are measured by comparing NAPCOM results from a scenario run of the model against those from a base case run of the model. A base case run of the model uses the distribution of VMT by vehicle class and operating weight under existing TS&W regulations to estimate the level of pavement damage under the assumption of no change to TS&W policy. A scenario run of the model uses the VMT distribution estimated in the freight distribution phase of the study to estimate the level of pavement damage under the assumed change to TS&W policy. The difference between the scenario result and the base case result is the impact of the policy change.

Table IV-2 shows the impacts for the two scenarios analyzed in this study. Neither scenario changed pavement cost nor the cost share attributable to the study vehicles significantly over the 20-year time horizon modeled by NAPCOM. The low cube scenario's 9.5 percent decline of study vehicle VMT decreases pavement cost by $258 million, 0.4 percent, over the 20-year period. The 25.5 percent decline in vehicle VMT in the high cube scenario decreases pavement cost by $2,787 million, or 4.2 percent.

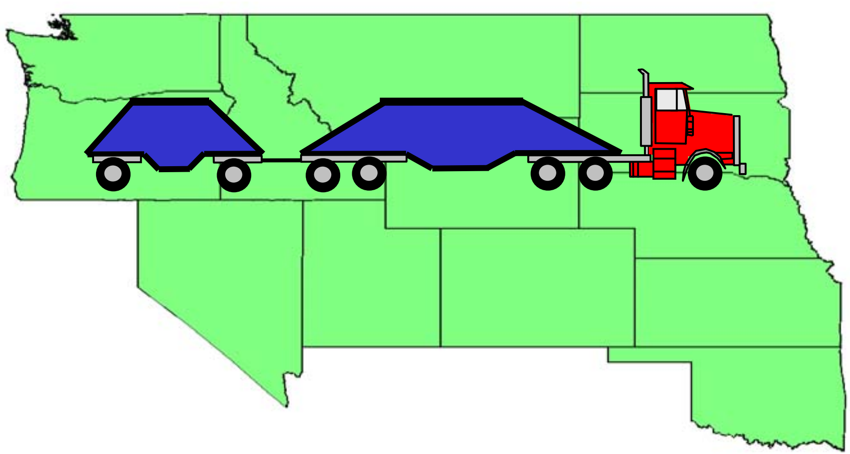
The relatively small percent change in pavement cost seen in the two scenarios is not surprising. Neither scenario proposes changes to axle weight limits, the primary driver in pavement damage. Overall, the increased size and weight of each scenario moves the same amount of freight ton-miles generating essentially the same axle load equivalents as the base case, but with fewer VMT.

Table IV-2
Scenario Pavement Impacts

Analytical Case	**VMT in Region (millions)**		**Impacts** (millions of 2000 $)			
	All Highway Vehicles	**Study Vehicles**	**Annual Pavement Cost**	**20-Year Pavement Cost**	**Change from Base Case**	**Study Vehicles' Share**
2010 Base Case	381,801	18,823	$3,297	$65,934	--	76.0%
Low Cube Scenario	380,008	17,029	$3,284	$65,676	-0.4%	75.4%
High Cube Scenario	377,006	14,028	$3,157	$63,147	-4.2%	73.0%

CHAPTER V

Bridge



Introduction

Damage to highway structures represents the most critical infrastructure cost of allowing larger and heavier trucks on the nation's highways. All of the studies performed by the Federal Highway Administration (FHWA), the Transportation Research Board (TRB), and several universities in the last ten years that examined potential impacts of truck size and weight (TS&W) increases have found that the estimated damage to bridges would be the greatest single infrastructure cost caused by larger, heavier trucks.

Impacts of Truck Loads

Bridges must be strong enough to safely accommodate all vehicular traffic. This accommodation of truck loads is the critical element in the design of highway bridges, except for the few very large bridges where the weight of the bridge itself is so much greater than the traffic loads that the bridge weight is the critical element. The analysis described below examines and compares the bending moments (and therefore the bending stresses) produced by the set of scenario trucks and the base case trucks with the moments caused by the bridge rating vehicle. Before documenting this analysis, bridge behavior when subjected to truck loads is briefly discussed.

Stresses

In general, bridges must accommodate three forms of stress: bending stress, shear stress and fatigue stress. If a weight were placed at the center of a beam that is supported at each end, the beam would bend, or deflect. Material at the bottom center of the beam would stretch and at the top of the beam it would compress. Truck loads produce a bending moment, which inflicts this stress. A bending moment is a load times a distance; in bridges it is a point or equivalent point load (in cases of uniform or non-point loads) times the distance of that load to the nearest support. There is a direct one-to-one relationship between bending moment and bending stress.

Shear stresses can be thought of as those stresses caused by a force that cuts (i.e., shears) rather than bends the beam. For example, if a very large load were applied very close to the support, there would be no significant bending action (since the distance to the support is very small), however, the beam would resist the "cutting" action, that is, the shear stresses. Fatigue stresses are, most simply, repeated bending stresses. Everyone who has repeatedly bent a paperclip back and forth until it breaks has caused fatigue stresses to the metal of the clip. Although bridge engineers consider and design for all three stresses, in most cases, the bending moment stresses are the critical factor in the design.

Types of Loads

Trucks affect bridges in several ways. When moving across a bridge, they produce static live loads and dynamic live loads. These loads result in the bridge experiencing bending, shear and fatigue stresses. The weight of the vehicle causes the live load stresses; its movement across the bridge, in conjunction with its weight, causes the dynamic stresses; and the movement, weight and the number of repetitions cause the fatigue stresses. When designing bridges, engineers typically increase the static load by a fixed percentage (about 10 to 30 percent) to account for the dynamic load.

Additionally, the bridge must withstand dead loads (the weight of the bridge itself, including the weight of future overlays), wind, thermal, earthquake, and other loads. The AASHTO bridge design manuals provide procedures to account for all these stresses.

Critical Stresses for Analysis

This analysis concentrates on bending moment stresses for several reasons. Generally a bridge designed to accommodate the bending moment stresses caused by the live, dead and dynamic loads, will also accommodate the fatigue and shear stresses. Thermal, wind and seismic stresses are not a function of vehicle weights and dimensions. If the bending stress is excessive, the other stresses usually are excessive as well. This is one reason that bridge replacement often is the best solution for an overstressed bridge. Another important reason is that highway agencies often must improve safety features, alignment, lighting, utilities, and other level of service characteristics if they strengthen a bridge. When costs of these other improvements is added to the cost of strengthening, total bridge replacement often is found to be more cost effective. Strengthening is possible for only some bridge types. Steel girder, some truss and even some prestressed concrete beam bridges can be economically strengthened if they meet all other stress and level of service criteria, but reinforced concrete slab and several other bridge types cannot be easily strengthened.

Bridge analysis for nationwide policy studies must rely on readily available nationwide data. The FHWA's National Bridge Inventory (NBI) is the only such dataset that meets this objective. Unfortunately, the NBI does not contain any detailed data describing the bridge geometry, location of details and the like which effectively rules out the analysis of fatigue, shear or other stresses that require this level of detailed data on the individual bridge design elements. However, the NBI does contain sufficient data describing the bridge length, support type, design type, material, etc., that permits the accurate estimation and computation of the live load and total bending moments. This is an additional reason why previous studies of national TS&W policy issues have either ignored fatigue and other less critical stresses or have handled them in a very simplified manner. But, as noted above, little is gained by considering fatigue or other stresses, since the bending stress is a reasonable proxy for all stresses.

Design Vehicles, Ratings and the Federal Bridge Formula B

An examination of design vehicles, ratings, and the Federal Bridge Formula B (BFB) is necessary in any study of the impacts of TS&W changes, because these three concepts are interrelated with the concept of bridge overstress, which is the measure used to identify bridges that might require improvement if size and weight limits were changed.

Design Vehicles

Bridge engineers developed the concept of design vehicles prior to World War II. They are hypothetical vehicles intended to represent the entire truck fleet in the vehicle stream. Use of the design vehicle allows the engineer to design bridges to safely withstand live load stresses caused by a single envelop vehicle rather than having to estimate stresses for each of the many different types of trucks on the road. Most States use one type of design vehicle, the HS vehicle. The HS vehicle is a three-axle vehicle with the load on the steering axle of X tons, a load on the second axle of 4X tons 14 feet behind the steering axle, and a load on the third axle also of 4X tons spaced 14 to 30 feet from the other non-steering axle. The engineer tests several axle spacings for the distance between the second and third axles to determine which axle spacing produces the maximum stresses. In most cases, the HS vehicle with the short 28-foot wheelbase is most critical. The number immediately following the HS is the total weight of the vehicle in tons divided by 1.8. Consequently, the HS vehicle weighing 72,000 pounds would be the HS20 vehicle, since 36 tons (72,000 pounds) divided by 1.8 is 20. This vehicle would have a 4-ton load on the steering axle and loads of 16 tons on each of the other two other axles.

Bridge Ratings

States report two bridge ratings to the FHWA for inclusion in the NBI, the inventory rating and the operating rating. The inventory rating is effectively 55 percent of the yield[15] stress of the bridge and the operating rating is 75 percent of the yield stress. The design stress level for new bridges is effectively the same as the inventory rating, 55 percent of the yield stress. The FHWA requires that states report these ratings in terms of the hypothetical HS vehicle.

To determine the inventory rating of a bridge the analyst will compute the heaviest HS vehicle that can traverse the bridge such that the weakest structural member is effectively at 55 percent of its yield stress. In a well-designed bridge, once loaded, all the designed members will be at or near 55 percent of their yield stress. Generally, that produces a safety factor of 1.8 (1÷0.55). Most States allow full and legal operation of trucks that produce bending moments on a particular bridge less than or equal to the moment caused by this Inventory Rating Vehicle

The operating rating is computed in a fashion similar to the inventory rating except that the maximum stress is set at 75 percent of the yield stress of the weakest structural bridge member. Generally, this produces a safety factor of 1.33 (1÷0.75). Most States do not allow vehicles with or without a permit to travel on bridges that would be stressed beyond their operating rating. The only exception may be for special non-divisible loads for which a detailed engineering analysis of the bridge confirms that a single passage will not measurable harm the bridge.

The FHWA requires States to use a consistent analysis methodology to compute the rating and to report this rating in the HS rating system. This provides consistency across all States. For example, if the heaviest HS design vehicle that can traverse a bridge without exceeding the bridge inventory rating weighs 62,000 pounds, the bridge is rated at HS17.2, since 62,000 pounds is 31 tons, and 31 divided by 1.8 yields 17.2.

Federal Bridge Formula B

Every truck has a different HS rating, and that rating is different for every bridge. Consequently, a standard had to be developed that would provide an easily enforceable method to regulate the weight of all types of trucks to protect the nation’s bridges. Consequently, the current standard,

[15] The limiting or yield stress is defined as the stress at which steel will undergo permanent deformation.

which is used in virtually all States for all highways, is the Federal Bridge Formula B (BFB). While most States provide some exceptions, usually for a few "grandfathered" trucks or for some economically important truck type (log carriers, grain carriers, etc.), the vast majority of States require trucks to meet BFB. A detailed discussion of BFB is in Appendix V-A.

Description of Bridges in Western Uniformity Scenario States

Table V-1, in columns 2 through 4, shows the number of records in the NBI and the number and percent of "actual truck-relevant" bridges for each of the Western Uniformity Scenario States. Not all records in the NBI are bridges that would be affected by TS&W policy changes. There are a number of duplicate records, especially bridges over an Interstate Highway that appear twice in the NBI, once for the Interstate highway and once for the route traveling over the highway. Also there are bicycle and pedestrian bridges, railroad bridges, culverts, tunnels, and some structures less than 20 feet long that generally are not considered bridges.

Of the almost 92,000 actual truck-relevant bridges in the 13 States, almost 25 percent are on the National Truck Network for Large Trucks (NN)[16] on which it is assumed scenario vehicles would operate. The numbers of bridges, actual truck-relevant bridges, and the percent of actual truck-relevant bridges on Interstate and other NN highways for each State are shown in columns 5 through 7 in Table V-1.

Analysis Methodology

The methodology used to estimate bridge costs for this scenario is similar to the method used to estimate bridge costs in the *Comprehensive Truck Size and Weight (CTS&W) Study*. It compares the bridges "overstressed" by the scenario vehicles with the bridges overstressed by the current fleet. Costs of improving or replacing bridges in the former set that are not in the latter set represent the incremental costs associated with the scenario.

Analysis Tool

The model used in this analysis is the Bridge Analysis and Structural Improvement Software (BASIC) model. The model computes the live load and total load bending moment for any truck configuration, for any span length, for most bridge types, and for both continuous and simple span bridges. Additionally it computes the ratio of those moments to the NBI-reported inventory or operating rating. The model computes live load moments directly for each truck configuration and weight and representative dead loads for each bridge type (reinforced concrete, steel girder, prestressed concrete T beams, etc.) and span length. It assumes a vehicle in every lane of the bridge; lane loadings "kick in" according to AASHTO procedures. Although the model can handle the most prevalent bridge types, it cannot analyze suspension, movable, and timber bridges. BASIC applies State-specific unit construction costs to estimate replacement costs. It computes the square footage of the replacement bridge and then applies the unit cost to estimate the replacement cost.

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[16] The National Network for Large Trucks is a 260,000 mile network of highways designated in 23 CFR 658. It includes virtually all the Interstate systems and other arterials that are used relatively extensively by trucks.

Table V-1
Numbers of Bridges on Various Systems by State

State	Entire Highway System			Interstate and National Network Highways		
	Number of Records	Number of "Actual" Bridges	Percent of Records that are Actual Bridges	Number of Records	Number of "Actual" Bridges	Percent of Records that are "Actual" Bridges
Colorado	8,933	6,435	72.0%	2,861	1,774	62.0%
Idaho	4,557	3,872	85.0%	999	747	74.8%
Kansas	27,276	18,602	68.2%	5,699	2,967	52.1%
Montana	6,042	4,836	80.0%	2,164	1,682	77.7%
North Dakota	4,823	3,788	78.5%	670	321	47.9%
Nebraska	16,293	12,920	79.3%	3,006	1,622	54.0%
Nevada	1,635	843	51.6%	784	444	56.6%
Oklahoma	24,748	16,290	65.8%	2,119	1,069	50.4%
Oregon	8,037	6,971	86.7%	2,136	1,496	70.0%
South Dakota	6,502	5,123	78.8%	5,136	4,241	82.6%
Utah	3,584	2,232	62.3%	1,272	852	67.0%
Washington	9,228	7,279	78.9%	4,095	2,766	67.5%
Wyoming	3,331	2,620	78.7%	1,573	1,270	80.7%
TOTAL	124,989	91,811	73.5%	32,514	21,251	65.4%

Overstress Identification Criterion

The stress level that should be used to estimate bridge replacement or major rehabilitation needs has been controversial. The U.S. Department of Transportation, in all of its TS&W studies, has used the inventory rating as the basis for determining whether bridge improvements would be needed if larger, heavier trucks were allowed to operate. The Transportation Research Board, on the other hand, has used the operating rating to identify bridge replacement needs.[17] This has resulted in much lower estimates of bridge improvement needs, but many analysts and bridge engineers believe the use of the operating rating underestimates bridge improvement needs. While States may allow vehicles that would stress bridges up to the operating rating to travel on a limited basis under special permits, many would not allow those vehicles to travel routinely at weights that would stress bridges to their operating rating.

[17] The TRB *Special Reports 225, Truck Weight Limits: Issues and Options* and *227, New Trucks for Greater Productivity and Less Road Wear: an Evaluation of the Turner Proposal* estimated the bridge costs of the TS&W changes under study based on the operating rating of 75 percent of yield stress, whereas reviewers of those reports found much higher bridge costs resulting from the use of the inventory rating of 55 percent of yield stress.

Significant cost differences result from the choice of rating. To test the sensitivity of bridge investment needs to assumptions about the level of stress at which bridge improvements would be made, this study estimates investment needs for several stress levels between the inventory and operating ratings.

Use of the lower stress level (inventory rating) results in many more bridges being identified as needing to be upgraded to accommodate increased weights. This is as expected, since the design rating is effectively the same as the inventory rating on a new bridge. Bridge designers have used the HS20 vehicle as the design standard for most bridges built in the last 50 years, although some States have begun to use the HS25 design vehicle so that the new bridges better accommodate heavier trucks. Use of the HS20 design vehicle resulted in bridges being over-designed for the truck fleet of 50 years ago. However, over time, as trucks were allowed to become heavier, this extra factor of safety has evaporated.

Today, while the HS20 vehicle still envelops most of the current truck fleet (except for LCVs and a few other very heavy trucks in States with “grandfather” rights), it does so with little margin of error. Consequently, small increases in truck weight will result in trucks having stresses greater than the HS20 design vehicle for most bridges. However, since the operating rating stresses are 36 percent greater than the inventory rating stresses, only large increases in truck weight and length will overstress bridges when the operating rating is used as the threshold in defining “overstress.”

Overstress

The term “overstress” is figurative and does not necessarily mean that a bridge is in danger of failure. The NBI contains an inventory rating for each bridge that represents a stress effectively equivalent to 55 percent of the lowest yield stress of the primary bridge members. The rating is expressed in terms of a standardized vehicle, e.g., the HS20 vehicle. If a bridge has an HS20 inventory rating as reported in the NBI, it means that an HS20 vehicle on each lane produces an acceptable stress for the bridge; any vehicle that creates a greater moment than the HS20 vehicle “overstresses” the bridge. States regularly allow small overstresses, but large overstresses could cause premature deterioration or, if truly excessive, failure of key bridge members.

There are several factors that allow some bridge overstress without compromising safety. First, using the inventory rating as the basis for determining the level of overstress, provides a large measure of safety since it represents stresses of only 55 percent of the yield stress a bridge can withstand. Secondly, bridges have some unmodeled redundancy. The method used by the States to compute the bridge ratings reported to the FHWA do not consider the strength contributed by unmodeled members of the bridge superstructure; consequently, ratings are inherently conservative. Third, the rating methodology considers a truck with a moment equivalent to the rating vehicle in each lane of the bridge. This rarely occurs, especially on low volume roads, and thereby contributes to a considerable factor of safety.

Except in unusual cases, the dead load and the truck live load (times a multiple to account for dynamic stresses) are the prevailing factors in the design of the bridge, and in decisions concerning whether bridge loadings associated with particular vehicle configurations would necessitate bridge replacement or repairs.

Base Case Vehicles

The first step in the analysis of the base case was to identify the vehicles in the current fleet and the highway systems on which they operate. Determining the vehicles currently operating in each study State is difficult because most State permit practices allow widespread use of vehicles that are heavier than Federal weight limits. Base case vehicles include not only vehicles operating at Federal and State weight limits without special permits, but also vehicles operated under monthly or annual permits that allow unlimited trips. In many cases these vehicles operate almost as freely as legal vehicles.

Motor vehicle laws and regulations were examined to discover what the legal and permitted loads and vehicle lengths were in each State. Although every State in the study uses Federal Bridge Formula B to determine truck axle loads and spacings, most States eliminate the 80,000 pound cap for grandfathered trucks, the multi-trip permit trucks, and for trucks operating on most of the non-Interstate highways. In addition, each State had unique overall length and trailer length restrictions.

The next step was to identify a small group of the critical vehicles from the current fleet for actual analysis. The objective was not simply to identify the heaviest trucks, but rather, to identify those trucks that would produce the greatest bending moment, and therefore the greatest bending stresses, on all types of bridges and spans lengths. It was not necessary to analyze every truck in the current fleet, but only the heaviest set of trucks representative of the current fleet. This usually means the heaviest of both short and long trucks. The base case trucks for each State are described in Table V-2.

The specific highway systems on which each set of trucks can operate were identified so that bridges subjected to overstress by the current vehicle fleet could be identified. Since not all overstresses are cause for immediate action, the number of bridges subjected to various levels of overstress was estimated. Bridges on the Interstate System and other parts of the NN were separated from those on other highway systems since the majority of LCV travel is on those higher-order systems.

Table V-2
Base Case and Uniformity Vehicles

State	System	SU2		SU3		SU4-5		CS5		CS6		CS6-7		DB5-7		DB5-7		DB8		DB8		DB9		DB9		DB10		DB11		TRP	
		WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)	WB (ft)	GVW (kips)
CO	**All**					22	54			36	74.5	67	80	72	80																
	Non-Int					22	54			36	85	67	85	72	80																
	Some Int													75	94	97	110	109	126	121	110										
ID	**All**	9	38			26	59.5	67	80	55	80			70	80																
	Arterials	13	42	13	55.8	20	59.5	67	80	55	91.5			72	80																
	Special Arterials									55	91.5																			105	105.5
	Special Arterials									55	91.5							61	105.5			83	105.5								
	Special Arterials									55	91.5											103	105.5								
KS	**All**	9	38			26	59.5	80	80	43	80			65	80	80	80														
	Except Interstate									53	85.5	67	85.5	65	85.5	80	85.5														
	Turnpike													65	92							115	120					70	120	98	120
MT	**All**					26	59.5			43	80	43	90.6	65	89.6			43	90.6	77	108.4	91	123.2	99	127.6						
ND	**All**					26	59.5	69	80	43	80			56	80	75	80														
	All, less Interstate	10	40			19	60							86	105.5							60	105.5								
NE	**All**					25	58.5	69	80	43	80			56	80	65	80														
	All, less Interstate	10	40			19	60					70	95	85	95	60	95														
	Harvest, non-Int					19	65					60	109	93	109																
NV	**All**					25	58.5	69	80	43	80			56	80	75	80														
	Int and arterials	10	44.5			19	54					74	103.7			86	114							60	91	101	115			101	128
OK	**All**					25	58.5	69	80	43	80			56	80	65	80														
	All, less Interstate									68	90	52	90					49	90			111	90								
	Toll roads RINT ROPA																							111	108	54	108			117	108
OR	**All**	10	40			19	60	51	80.5			74	101	86	105							60	105							117	[illegible]
SD	**All**	10	40			19	60					74	101													65	113	96	127.5		
UT	**All**	10	40			26	59.5	67	80	43	80			65	80	80	80	80	80												
	Inter & Arterials					19	60					74	101													65	113	96	127.5	102	126
	Specific Arterials					19	60					74	101													65	113	114	136		
WA	**All**	10	40			27	65			43	80			63	80																
	All, less Interstate					23	62	48	83			73	107.5									88	117								
WY	**All**					23	64	48	83			73	105.5									88	117								
UNIFORMITY																															
National Network																		58	99	92	117					92	127				
Interstate																							108	129						106	110

Truck Descriptions: SU = Single Unit; CS = Combination Truck with Semi-Trailer; DB = Combination Truck with One Semi-Trailer and One Full Trailer; TRP = Combination Truck with One Semi Trailer and Two Full Trailers. The number after the letter designation is the number of axles.

Analysis Results

Sensitivity Analysis

The BASIC program computes and compares bending moments of different vehicles. For this study bending moments of scenario vehicles are compared to moments produced by the inventory-rating vehicle. As noted above, this vehicle was chosen because bridges typically are designed based on the inventory rating and the Bridge Formula weight limits for different axle groups are derived from the inventory rating. Since States typically would not replace most bridges subjected to stresses that just exceed the inventory rating, a sensitivity analysis was performed to estimate the number of bridges that would be overstressed at various stress levels. Specifically, the number of bridges that would be overstressed by stresses 5 percent, 10 percent, 15 percent, 20 percent, 25 percent, 30 percent, and 36.4 percent greater than the inventory-rating vehicle was estimated. State responses to the various levels of overstress would vary depending on the particular bridge and the traffic volumes it carries, but this sensitivity analysis provides a basis for estimating the likely range of impacts rather than simply assuming that States would take actions at a single overstress level.

Analysis Results – Base Case

Table V-3 shows the aggregate number and percent of bridges on the Interstate System and other NN highways that are estimated to be subjected by vehicles in the current fleet to bending stresses equal to or greater than the stresses caused by the inventory-rating vehicle.

In addition, it presents the number and percent of bridges subjected to stresses greater than or equal to 1.05, 1.10, 1.15, 1.20, 1.25, 1.30 and 1.364 times stresses caused by the inventory-rating vehicle. The percent of bridges estimated to experience bending moments greater than the moments caused by the inventory-rating vehicle varies greatly by State, from 92 percent for Colorado to 44 percent for Wyoming. This percentage is a function of the size and weight of the vehicles in the current fleet as well as the strength of the bridges in each State.

Following completion of the *CTS&W Study*, many comments were received indicating that States would not have to replace all structurally-deficient bridges, as was assumed in that study, but rather could strengthen some bridges. As noted above, not all types of bridges can be strengthened, and it would not be cost effective to strengthen others if significant other improvements were required to bring them up to current safety and geometric standards. To reflect the fact some bridges perhaps could be strengthened rather than having to be replaced, a second set of costs is estimated for each set of overstressed bridges. These lower costs are based on the assumption that one half the deficient bridges could be strengthened rather than replaced and that the cost of strengthening would be one-third the replacement cost. These costs and the assumptions upon which they are based are purely illustrative. The number of bridges that could be strengthened rather than having to be replaced cannot be estimated in a study such as this, and the costs to strengthen various types of bridges can vary widely.

Table V-3
Analysis of the Base Case Trucks on the Interstate and National Network Highway Systems

State	Number and Percentage of Actual Bridges Experiencing "Overload" for Given Thresholds[1]															
	0%		5%		10%		15%		20%		25%		30%		36.4 %[2]	
Colorado	1,626	91.7%	1,574	88.7%	1,288	72.6%	919	51.8%	680	38.3%	532	30.0%	426	24.0%	323	18.2%
Idaho	562	75.3%	337	45.1%	173	23.2%	82	10.9%	45	6.0%	29	3.8%	19	2.6%	11	1.5%
Kansas	1,974	66.5%	1,494	50.4%	1,123	37.9%	865	29.2%	663	22.3%	515	17.4%	396	13.3%	287	9.7%
Montana	1,290	76.7%	862	51.3%	345	20.5%	295	17.6%	243	14.4%	142	8.5%	123	7.3%	86	5.1%
N. Dakota	197	61.2%	114	35.5%	59	18.2%	29	9.1%	20	6.2%	14	4.2%	8	2.6%	4	1.3%
Nebraska	1,167	72.0%	1,038	64.0%	619	38.2%	376	23.2%	277	17.1%	201	12.4%	168	10.3%	122	7.5%
Nevada	403	90.7%	275	61.9%	94	21.1%	23	5.1%	6	1.4%	1	0.2%	1	0.2%	0	0.0%
Oklahoma	747	69.9%	341	31.9%	237	22.2%	172	16.1%	144	13.4%	133	12.5%	132	12.4%	122	11.4%
Oregon	1,194	79.8%	736	49.2%	348	23.3%	146	9.8%	80	5.3%	55	3.7%	31	2.1%	19	1.3%
S. Dakota	3,803	89.7%	2,723	64.2%	2,187	51.6%	1,669	39.3%	1,254	29.6%	1,053	24.8%	947	22.3%	858	20.2%
Utah	392	46.0%	81	9.5%	23	2.7%	11	1.3%	7	0.9%	7	0.9%	6	0.7%	6	0.7%
Washington	1,840	66.5%	1,134	41.0%	648	23.4%	410	14.8%	293	10.6%	220	7.9%	155	5.6%	126	4.6%
Wyoming	553	43.5%	331	26.1%	171	13.4%	80	6.3%	44	3.5%	28	2.2%	19	1.5%	11	0.9%
TOTAL	**15,749**	**74.1%**	**11,041**	**52.0%**	**7,315**	**34.4%**	**5,079**	**23.9%**	**3,756**	**17.7%**	**2,931**	**13.8%**	**2,431**	**11.4%**	**1,975**	**9.3%**

1. "Overload" simply means that the vehicles produce a greater moment (and therefore a greater bending stress) than the bridge's inventory rating computed by the State.
1. Effectively, this represents the operating rating.

Cost of Replaced/Strengthened Bridges

Bridge replacement costs are based on the unit costs per square foot for each State as reported by the State to FHWA. The length and width of the bridge as reported in the NBI are multiplied together to get the area, that area is increased by 25 percent, and the result is multiplied by the unit cost per square foot to estimate the replacement cost. The increase of 25 percent is because FHWA data shows that replacement bridges, for reasons of safety and horizontal and vertical alignment, average about 25 percent longer than the bridges they replace.

Table V-4 below presents the costs associated with each level of overstress for total replacement and for the assumed less-than-full-replacement scenario described above. Based on assumptions in this analysis, base case bridge improvement costs in the scenario States could range from nearly $13 billion to slightly more than $0.5 billion. This is a large range, but as noted above it is unlikely that States would replace or improve many bridges subjected to stresses no greater than those of the basic bridge design vehicle, and it is also unlikely that States would allow bridges to be repeatedly subjected to stresses equivalent to the bridge operating rating without making plans to replace or improve those bridges. If one were to assume that on average bridges would be replaced or improved when stresses exceeded design stresses by from 15 to 20 percent (about half way between the inventory and operating rating), the range of base case bridge improvement costs would be between $3,257 million and $1,586 million. All of those improvements would not have to be made immediately. If costs were spread over a 20-year period, the average annual cost would be between $163 million and $79 million.

Table V-4
Base Case Cost Associated with Full Replacement and Less than Full Replacement for Eight Different Overstress Thresholds

Overstress Threshold (Percentage of Inventory Rating)	Number of Actual Deficient Bridges	Full Replacement Costs ($ millions)	Less Than Full Replacement Costs ($ millions)
1.00	15,749	$12,922	$8,614
1.05	11,041	$8,628	$5,746
1.10	7,315	$5,317	$3,544
1.15	5,079	$3,257	$2,171
1.20	3,756	$2,379	$1,586
1.25	2,931	$1,656	$1,104
1.30	2,431	$1,294	$ 863
1.3664	1,975	$839	$ 559

Analysis Results – Western Uniformity Scenario

The analysis of the scenario trucks follows identically the procedure for the base case vehicles. Earlier in this Chapter, Table V-2 describes the scenario vehicles. Because some of the vehicles are assumed to operate only on the Interstate System and others on both Interstate and non-Interstate portions of the National Network, each set of highways/vehicles was analyzed separately and the results combined to prevent double counting of overstressed bridges. Table V-5 shows estimates of the number of bridges that would be overstressed at various assumed thresholds relative to the inventory rating, and Table V-6 contains cost estimates to replace or improve those bridges. Again the third column represents the Less Than Full Replacement scenario based on the same assumptions as were used in the Base Case analysis.

The two alternative cases of the Western Uniformity Scenario – the high-cube allowing a combined trailer length of 101-feet and the low-cube that only allows a combined trailer length of 95-feet - do not make a difference in the analysis of bridge impacts.

Table V-5
Analysis of the Uniformity Scenario Trucks on the Interstate and National Network Highway Systems

State	Number and Percentage of Actual Bridges Experiencing "Overload" for Given Thresholds[1]															
	0%		5%		10%		15%		20%		25%		30%		36.4 % [2]	
Colorado	1,572	88.6%	1,402	79.0%	1,150	64.8%	889	50.1%	687	38.7%	495	27.9%	360	20.3%	230	13.0%
Idaho	463	62.0%	346	46.3%	237	31.7%	167	22.4%	108	14.5%	71	9.6%	52	7.0%	36	4.8%
Kansas	2,314	78.0%	1,986	66.9%	1,623	54.7%	1,308	44.1%	1,055	35.6%	841	28.3%	689	23.2%	522	17.6%
Montana	1,173	69.7%	610	36.3%	397	23.6%	336	20.0%	268	15.9%	138	8.2%	124	7.4%	99	5.9%
N. Dakota	228	71.0%	188	58.6%	158	49.2%	106	32.9%	74	23.1%	52	16.3%	36	11.1%	26	8.1%
Nebraska	1,421	87.6%	1,132	69.8%	819	50.5%	654	40.3%	484	29.9%	331	20.4%	243	15.0%	182	11.2%
Nevada	371	83.5%	289	65.2%	179	40.4%	106	23.9%	77	17.4%	47	10.7%	43	9.7%	41	9.3%
Oklahoma	625	58.4%	478	44.7%	418	39.1%	368	34.5%	290	27.2%	172	16.1%	140	13.1%	132	12.4%
Oregon	1,181	79.0%	997	66.6%	761	50.9%	526	35.2%	435	29.0%	339	22.7%	307	20.5%	246	16.5%
S. Dakota	3,333	78.6%	3,030	71.4%	2,794	65.9%	2,331	55.0%	1,992	47.0%	1,701	40.1%	1,518	35.8%	1,367	32.2%
Utah	680	79.8%	571	67.0%	281	33.0%	167	19.6%	100	11.7%	54	6.3%	46	5.4%	31	3.6%
Washington	1,815	65.6%	1,463	52.9%	1,162	42.0%	893	32.3%	690	25.0%	487	17.6%	374	13.5%	302	10.9%
Wyoming	1,007	79.3%	793	62.5%	627	49.4%	408	32.1%	269	21.2%	169	13.3%	93	7.3%	38	3.0%
TOTAL	**16,183**	**76.2%**	**13,287**	**62.5%**	**10,604**	**49.9%**	**8,260**	**38.9%**	**6,530**	**30.7%**	**4,899**	**23.1%**	**4,023**	**18.9%**	**3,254**	**15.3%**

1. "Overload" simply means that the vehicles produce a greater moment (and therefore a greater bending stress) than the bridge's inventory rating computed by the State.
2. Effectively, this represents the operating rating.

Table V-6
Western Uniformity Scenario Cost Associated with Full Replacement and Less than Full Replacement for Eight Different Overstress Thresholds

Threshold as Percent Greater than Inventory Rating	Number of Actual Deficient Bridges	Full Replacement Costs ($ millions)	Less than Full Replacement Costs ($ millions)
0	16,183	$13,507	$9,004
5	13,287	$11,561	$7,707
10	10,604	$9,472	$6,314
15	8,260	$7,382	$4,921
20	6,530	$5,872	$3,914
25	4,899	$3,881	$2,587
30	4,023	$3,113	$2,075
36.64	3,254	$2,543	$1,695

Differential Costs Attributable to the Western Uniformity Scenario Trucks

Subtracting the numbers of bridges and the replacement costs of the Western Uniformity Scenario results from the results of the base case analysis yields the costs attributable to the scenario vehicles. The number of bridges is presented in Table V-7, and the costs in Table V-8.

Table V-7
Analysis of Additional Overstressed Bridges on Interstate and National Nework Systems

State	Number and Percentage of Additional Actual Bridges Experiencing "Overload" for Given Thresholds[1]															
	0%		5%		10%		15%		20%		25%		30%		36.4 %[2]	
Colorado	-54	-3.0%	-172	-9.7%	-138	-7.8%	-31	-1.7%	7	0.4%	-37	-2.1%	-66	-3.7%	-92	-5.2%
Idaho	-99	-13.3%	9	1.2%	63	8.5%	86	11.5%	63	8.5%	43	5.7%	33	4.4%	24	3.3%
Kansas	340	11.5%	491	16.6%	499	16.8%	443	14.9%	393	13.2%	326	11.0%	293	9.9%	235	7.9%
Montana	-117	-7.0%	-252	-15.0%	51	3.1%	41	2.4%	25	1.5%	-4	-0.2%	1	0.1%	13	0.8%
N. Dakota	31	9.8%	74	23.1%	99	30.9%	76	23.8%	54	16.9%	39	12.1%	27	8.5%	22	6.8%
Nebraska	253	15.6%	94	5.8%	199	12.3%	278	17.1%	207	12.8%	130	8.0%	76	4.7%	60	3.7%
Nevada	-32	-7.2%	14	3.2%	86	19.3%	83	18.8%	71	16.0%	46	10.4%	42	9.5%	41	9.3%
Oklahoma	-122	-11.4%	137	12.9%	181	16.9%	196	18.3%	147	13.7%	39	3.6%	7	0.7%	10	1.0%
Oregon	-13	-0.9%	261	17.4%	413	27.6%	380	25.4%	355	23.7%	284	19.0%	276	18.4%	227	15.2%
S. Dakota	-470	-11.1%	306	7.2%	607	14.3%	662	15.6%	737	17.4%	647	15.3%	571	13.5%	509	12.0%
Utah	288	33.8%	490	57.5%	258	30.3%	155	18.2%	92	10.8%	47	5.5%	39	4.6%	25	2.9%
Washington	-26	-0.9%	329	11.9%	514	18.6%	483	17.5%	397	14.4%	268	9.7%	219	7.9%	176	6.4%
Wyoming	454	35.8%	462	36.4%	456	35.9%	328	25.8%	225	17.7%	140	11.1%	74	5.8%	27	2.1%
TOTAL	**435**	**2.0%**	**2,245**	**10.6%**	**3,289**	**15.5%**	**3,182**	**15.0%**	**2,773**	**13.0%**	**1,968**	**9.3%**	**1,592**	**7.5%**	**1,278**	**6.0%**

1. "Overload" simply means that the vehicles produce a greater moment (and therefore a greater bending stress) than the bridge's inventory rating computed by the State.
2. Effectively, this represents the operating rating.

An examination of these tables reveals some very interesting results. From Table V-7 one sees several negative numbers in the "greater than zero percent" and "greater than 5 percent" overload column. This means that the Western Uniformity Scenario vehicles produce greater moments than the inventory vehicle (or inventory vehicle plus 5 percent) on fewer bridges than the base case vehicles. This is not surprising since it became clear early on in the study that a few States allow some very large and heavy trucks on their systems through monthly or annual permits. Consequently, if those States fully allowed the scenario vehicles to operate *in lieu of, not in addition to,* the currently operating vehicles, fewer bridges would be overstressed. However, as the overstress threshold increases to the Inventory rating plus 10 percent or more, then the scenario vehicles overstress more bridges than the current vehicles.

This occurs for several reasons including the behavior of continuous bridges and the varying effects of long versus short trucks.

Table V-8
Incremental Cost Differences between Base Case and Western Uniformity Scenario with Full Replacement and Less than Full Replacement for Eight Different Overstress Thresholds

Threshold As Percent Greater than Inventory Rating	Number of Actual Deficient Bridges	Full Replacement Costs ($ millions)	Less Than Full Replacement Costs ($ millions)
0	435	$585	$ 390
5	2,245	$2,933	$1,955
10	3,289	$4,155	$2,770
15	3,182	$4,125	$2,750
20	2,773	$3,494	$2,329
25	1,968	$2,224	$1,483
30	1,592	$3,113	$2,075
36.64	1,278	$2,543	$1,695

Conclusion

Many western States already allow operations of vehicles that produce stresses exceeding the inventory rating of many bridges on the National Network in those States. States recognize there is a substantial safety factor built into bridge design when deciding which bridges might need to be replaced or strengthened because of truck loadings, and typically would not consider a bridge stressed only to its inventory rating to require replacement or strengthening. If there were questions about the strength of particular bridges, inspection schedules on those bridges might be accelerated.

Analysis done for this study indicates that fewer than 2,000 bridges currently are subjected to stresses that exceed their operating rating, which typically represents the greatest loads that States allow, even for single trip permits. This analysis assumes that vehicles that are allowed to operate under multi-trip permits may utilize every route on the NN. This assumption may overstate the number of bridges that are subjected to stresses exceeding their operating rating because some permits may contain route restrictions to prevent operations on roads with inadequate bridges. It is unlikely that States would allow widespread operations of trucks that stressed bridges to their operating rating without putting those bridges into their bridge improvement programs for either replacement or strengthening.

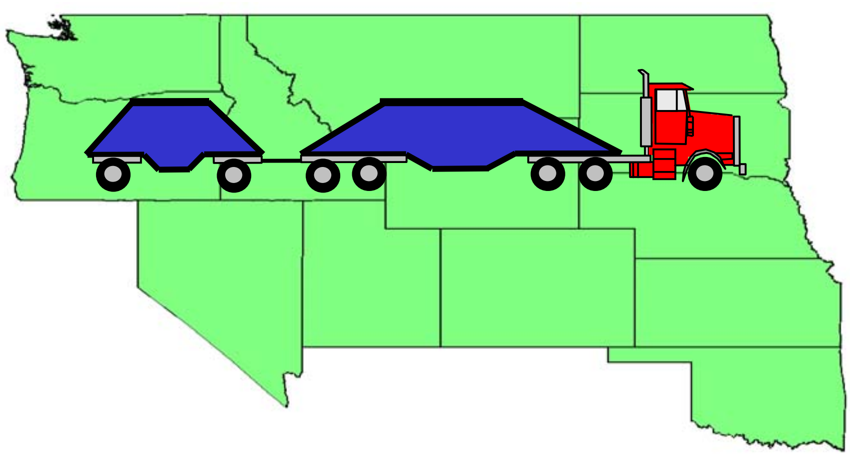
In the long term, States likely would replace or strengthen bridges subjected to stresses falling between the inventory and operating rating. Decisions on improvement needs for specific bridges would depend on a variety of factors including the volume and characteristics of truck traffic using those bridges, the availability of alternative routes, and the degree to which the bridge is being overstressed. For purposes of estimating bridge investment needs associated with the Western Uniformity Scenario, it is assumed that bridges overstressed by 15 to 20 percent compared to the inventory rating would require eventual replacement or strengthening because of those stresses.

Without a detailed structural analysis of each bridge, it is impossible to determine, on a national basis, which bridges States might strengthen rather than replace. Furthermore, the cost to strengthen various bridges could vary widely. The *CTS&W Study* did not consider the potential to strengthen some bridges, but comments from some States indicated that strengthening would be an option for some bridges. For purposes of this analysis it is assumed that 50 percent of the bridges might be able to be strengthened and that the cost to strengthen the bridges would be one-third the cost to replace the bridge.

Based on these assumptions the incremental bridge costs attributable to the Western Uniformity Scenario would be between $2.329 billion and $4.125 billion. In some cases the States could open some bridges to the larger and heavier vehicles assumed in this scenario without having to make the improvements first. States could be expected to determine the priority and timing of needed bridge improvements based on the volumes of traffic and the degree to which the bridge was being overstressed. In some cases States might not allow larger, heavier trucks to use all segments of the network immediately but rather would open segments only when the infrastructure was adequate to accommodate the new vehicles.

CHAPTER VI

Roadway Geometry



Introduction

This chapter focuses on the interaction of the Western Uniformity Scenario's truck configurations with roadway ramps, interchanges and intersections. The Scenario's longer combination vehicles (LCVs) are potentially less maneuverable than vehicles currently in use.

The addition of longer LCVs on more roadways in the Scenario would require intersection and interchange improvements to allow for the safe operation of these vehicles. Also in the Western Uniformity Scenario TPD and triples would be restricted to a limited network of highways. These trucks would need to be assembled and disassembled at staging areas adjacent to the highway. This chapter includes a discussion of current staging area practices in the Western States and provisions for staging areas under the Scenario.

Roadway Geometry and Truck Operating Characteristics

This section provides an overview of the relationship between vehicle turning characteristics ("offtracking") and roadway geometry. A more detailed discussion is provided in the *CTS&W Study* Volume II, Chapter VI and Volume III, Chapter VII.

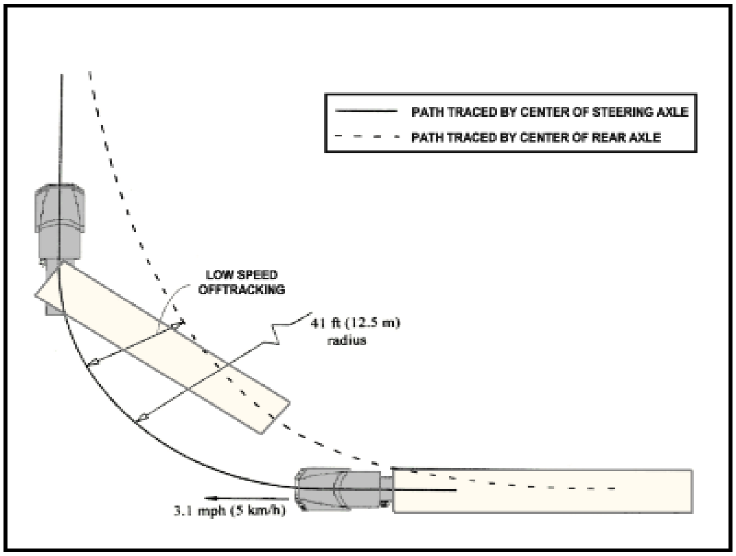
Offtracking

Offtracking is said to occur when a vehicle makes a turn and it rear wheels do not follow the same path as its front wheels. The magnitude of this generally increases with the spacing between the axles of the vehicle and decreases for larger radius turns. Offtracking is considered in determining the extent to which roadway geometrics would need upgrading to accommodate less maneuverable LCVs. There are two types of offtracking: low-speed and high-speed.

Low-Speed Offtracking occurs when a combination vehicle makes a low-speed turn – for example a 90-degree turn at an intersection – and the wheels of the rearmost trailer axle follow a path several feet inside the path of the tractor steering axle. Figure VI-1 illustrates low-speed offtracking in a 90-degree turn for a tractor-semitrailer. Excessive low-speed offtracking makes it necessary for the driver to swing wide into adjacent lanes when making a turn to avoid climbing inside curbs, striking curbside fixed objects or other vehicles. On an exit ramp excessive offtracking can result in the truck tracking inward onto the shoulder or up over inside curbs. For single trailer combinations, this performance attribute is affected primarily by the distance of the tractor kingpin[18] to the center of the trailer rear axle or axle group. For multitrailer combinations the effective wheelbase(s) of all the trailers in the combination, along with the tracking characteristics of the converter dollies, dictate low-speed offtracking. In general longer wheelbases worsen low-speed offtracking.

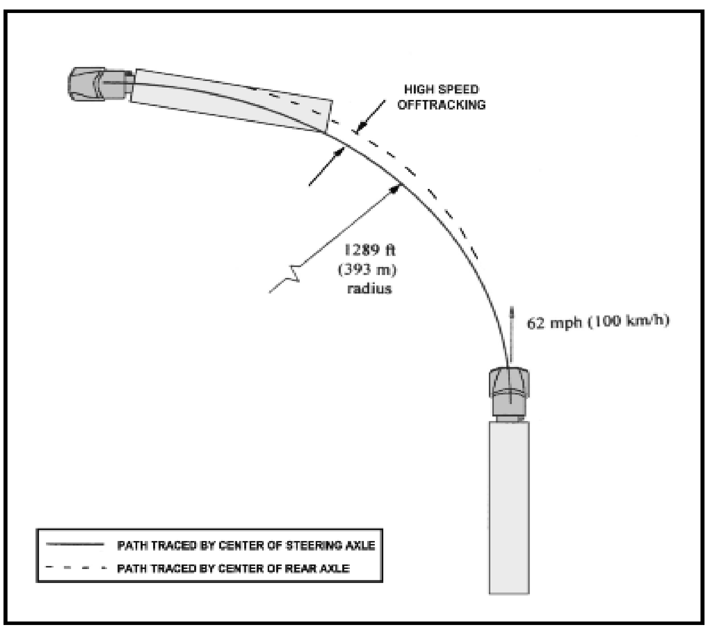
[18] Kingpin setting refers to the truck-tractor fifth wheel connection point for the kingpin which is located to the front of the semitrailer

Figure VI-1 Low-Speed Offtracking



High-Speed Offtracking results from the tendency of the rear of the truck to move outward due to the lateral acceleration of the vehicle as it makes a turn at higher speeds. Figure VI-2 illustrates high-speed offtracking for a standard tractor-semitrailer. The speed-dependent component of offtracking is primarily a function of the spacing between truck axles, the speed of the truck, and the radius of the turn; it is also dependent on the loads carried by the truck axles and the truck suspension characteristics.

Figure VI-2 High-Speed Offtracking



Analytical Approach

This study examines the impact that scenario truck configurations would have on freeway interchanges, at-grade intersections, mainline curves and lane widths of the current roadway system, determines what improvements would be needed to accommodate the new trucks, and estimates the costs of these improvements. The focus of this research is to compare the new truck configurations with the current tractor-semitrailers and LCVs operating in the Scenario States.

Unlike the analysis for the *CTS&W Study* Volume III, the base case vehicle in this analysis varies by State depending on that State's grandfather laws under the 1991 ISTEA freeze. The chosen base case vehicle represents the worst vehicle from an offtracking perspective currently allowed on the analyzed roadway segment. For example if the worst off-tracking vehicle currently allowed on the roadway is a TPD then the TPD is used as the base case for that road segment, if the RMD is the worst offtracking vehicle then it is used as the base case vehicle, and if the 53-foot tractor semitrailer has the worst offtracking then it is the base case vehicle. Table VI-1 shows the base case RMD and TPD for each State. This precise framing of the base case is an improvement to the *CTS&W Study's* analysis that used the 48-foot tractor semitrailer at 80,0000 pounds as the base case vehicle for all roads.

Table VI-1
Dimensions of Base Case Vehicles
(feet)

State	Rocky Mountain Double	Turnpike Double
Colorado	43.5 + 31	48 + 48
Idaho	35 + 20	35 + 20
Kansas	48 + 28.5	45 + 45
Montana	38 + 28	45 + 45
Nebraska	38 + 20	38 + 20
Nevada	48 + 28.5	48 + 48
North Dakota	48 + 28.5	48 + 48
Oklahoma	48 + 28.5	48 + 48
Oregon	35 + 20	N/A
South Dakota	48 + 28.5	48 + 48
Utah	48 + 28.5	48 + 48
Washington	35 + 20	N/A
Wyoming	38 + 27	N/A

Table VI-2 shows the low-speed offtracking and swept path for the analyzed configurations. The measure is shown for a standard 90-degree right-hand turn with a 42-foot radius[19] negotiated at a speed of 5 kilometers per hour. Low Speed Offtracking is the one measure where the STAA Double outperforms all the other configurations. The long TPD with twin 48-foot trailers performs the worst of the vehicles.

Table VI-2
Offtracking Characteristics

Vehicle Description*	Configuration**	Performance Data	
		Low Speed Offtracking (feet)	Swept Path
Single (53')	3-S2	16.12	24.12
STAA Double (2@28)	2-S1-2	13.52	21.52
RMD (38', 27')	3-S2-3	18.57	26.57
RMD (38', 27')	3-S2-4	22.08	30.08
RMD (38', 27')	3-S2-2	21.54	29.54
RMD (35', 20')	3-S2-2	15.78	23.78
RMD (38', 28')	3-S2-4	20.06	28.06
RMD (38', 20')	3-S3-2	18.42	26.42
RMD (38', 27')	3-S2-4	21.02	29.02
RMD (43.5', 31')	3-S2-4	20.78	28.78
RMD (38', 27')	3-S3-4	19.13	27.13
RMD (48', 28.5')	3-S2-3	21.87	29.87
Short TPD (2@45')	3-S2-4	27.98	35.98
Long TPD (2@48')	3-S2-4	30.63	38.63
Triple A-Train (3@28')	2-S1-2-2	20.38	28.38
Triple C-Train (3@28')	2-S1-2-2	20.38	28.38

* Vehicle description shows the vehicle type where RMD is a Rocky Mountain Double and TPD is a Turnpike Double. The numbers in parenthesis give the length of each trailer.
** The first number in the series indicates the number of axles on the power unit; the next set refers to the number of axles supporting the trailing unit ("s" indicates it is a semitrailer) and the subsequent numbers indicate the number of axles associated with the remaining trailing unit(s).

Impact Analysis

Geometric

The four roadway geometric elements impacted by truck offtracking are mainline horizontal curves, horizontal curves on ramps, curb return radii for at-grade ramp terminals and curb return radii for at-grade intersections. Data on these elements were collected for nine States in the CTS&W Study. Two of those States, Kansas and Washington, are in the current Scenario. Data from that two State sample were used by

[19] The *CTS&W Study* analyzed a 38-foot path radius.

researchers to examine the five highway types in the sample States and determined the mainline curve radii based on Highway Performance Monitoring System (HPMS) data. Where HPMS data were not available the sample States provided existing aerial photographs and as-built plans on ramp curve and curb return radii at ramp terminals and intersections.

Roughly 25 rural interchanges, 25 urban interchanges and 25 rural at-grade intersections in each of the sample States were examined. The locations were selected because they carried substantial truck traffic.

The feasibility of widening each curve radius was rated as: minor difficulty (just add a little more pavement), moderately difficult, or extremely difficult (requiring major construction or demolition of existing structures). Sample data were expanded to the National Network for Large Trucks (NN). Estimates were made for the number of locations or mileage that needed improvements and the amount and cost of widening for each truck that offtracks more than the currently operating longest vehicle on that roadway segment.

The amount of widening was based on the offtracking of the scenario trucks. For horizontal curves and ramps, it was decided that no encroachment of shoulders or adjacent lanes would be allowed. For intersections and ramp terminals, trucks were not allowed to encroach upon shoulders, curbs, opposing lanes, or more than one lane in the same direction.

For some facilities, the cost of widening existing highway features is required even for the current vehicle fleet if there are turns and highway curves that cannot accommodate existing trucks. Those costs are reported in the Base Case Scenario. Similar to the bridge cost analysis, the Base Case Scenario results are subtracted from the Western Uniformity Scenario results to estimate the incremental cost of the proposed scenario vehicles.

Staging Areas

As shown in Table VI-3, the scenario States vary in their current treatment of staging areas. Most States like Montana and Wyoming specify limited access but do not require staging areas. On the other hand, Idaho publishes a list of staging or “breakdown” areas close to the road network. These staging areas are privately owned and operated at truck stops or warehouse facilities.

Table VI-3
Current Access Provisions

State	Provision
Colorado	Limited to 10 miles
Idaho	Specified Staging Areas (privately operated)
Kansas	State Issued Access Permit
Montana	Triples Limited to 2 miles off Interstate; Doubles - Reasonable Access
Nebraska	Within 6 miles of Interstate and approved by State
Nevada	Reasonable Access
North Dakota	Reasonable Access
Oklahoma	Limited to 5 miles from Interstate or 4 lane divided highway
Oregon	Staging at Private Facilities for Triples
South Dakota	Reasonable Access
Utah	Off-Interstate Routes as authorized by State
Washington	Reasonable Access
Wyoming	Reasonable Access

To minimize the infrastructure repairs it is assumed the Turnpike Double is not allowed off the Interstate Network, except where already permitted by a State. Also, the triple trailer combination is restricted to the Interstate but that restriction is driven less by offtracking concerns but more by automobile driver concerns. Staging areas are assumed to exist at key rural interchanges and the fringes of major urban areas.

The *CTS&W Study* explicitly estimated the number and cost of staging areas, see Volume III, page VII-9. The present analysis employs the experience of Idaho DOT as a model for how the other 12 States would enact the necessary staging areas. Idaho DOT publishes maps showing the routes for extra-length configurations that provide the locations of breakdown or staging areas. The areas are built and maintained by private companies and users must make arrangements with the owners for use of the staging areas.

Therefore, it is assumed in this study that staging areas would be privately provided and States would make lists and maps publicly available to the truck operators.[20]

[20] To match State practices staging areas are not estimated for this Scenario, but it is recognized that adequate truck parking is a broader but separate problem (see NCHRP 314: Strategies for Managing Increasing Truck Traffic, 2003).

Scenario Impacts

Geometric Improvements

The model used in the *CTS&W Study* was used to estimate geometric improvement costs for the Base Case and Western Uniformity Scenarios based on the offtracking performance of the specified truck configurations, and the mileage and location of the roads upon which the vehicles are expected to operate. The 1994 costs were updated to 2000 using the Annual Price Trends for Federal-Aid Highway Construction Composite Index for the Scenario States.[21]

The costs to upgrade the roadway geometry are shown in Table VI-4. This upgrading improves the mainline curves, intersection and interchange features such that the scenario vehicle with the worst offtracking characteristics would not offtrack excessively, that is, offtrack outside the width of its lane.

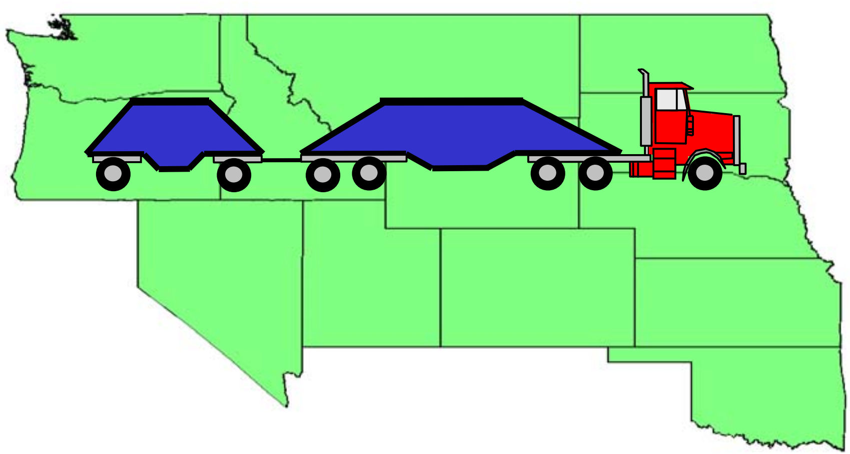
Table VI-4
Scenario Roadway Geometric Impacts

Analytical Case	Worst Offtracking Vehicle On Roadway	Improvement Costs ($ million)				
		Mainline Curves	Intersections	Interchanges	Total	Incremental to Base Case
Base Case	RMD	$47	$99	$5	$152	
	TPD	$112	$214	$387	$713	
	Total Cost	**$159**	**$313**	**$393**	**$864**	**NA**
Western Uniformity Low Cube	RMD	$165	$394	$12	$571	
	TPD-45	$109	$159	$445	$714	
	Total Cost	**$274**	**$553**	**$457**	**$1,284**	**$420**
Western Uniformity High Cube	RMD	$165	$394	$12	$571	
	TPD-48	$150	$221	$698	$1,069	
	Total Cost	**$314**	**$615**	**$710**	**$1,639**	**$775**

[21] Price Trends for Federal-Aid Highway Construction, FHWA-IF-02-038.

CHAPTER VII

Safety



Introduction

Considerable debate has focused on the safety of commercial heavy trucks, and particularly questioning if changing truck sizes and weights would alter roadway safety. As noted in the *Comprehensive Truck Size and Weight* (*CTS&W*) *Study*, the safety of freight moving on the roadway is a combination of many factors: vehicle miles traveled (VMT) or exposure; vehicle performance characteristics; driver performance and ability; enforcement; roadway design; road conditions; motor carrier management; and vehicle condition and maintenance. Among these factors isolating the impact of TS&W is difficult. Because larger and heavier trucks are a relatively small subgroup of all trucks, differentiating their crash involvement patterns from those of other truck types is problematic. This study will discuss the safety performance and exposure factors for the Western Uniformity Scenario vehicles.

Discussing these safety aspects is not intended to diminish other facets of the safety picture. Difficult to quantify aspects, such as alternative enforcement mechanisms, vehicle maintenance and driver qualifications are discussed in the *CTS&W Study*.

The analysis presented in this chapter confirms three important factors highlighted in the *CTS&W Study*. First, travel on undivided, higher speed-limit roads with many at-grade intersections and entrances significantly increases crash risks compared to travel on Interstate and other roadways with design characteristics similar to Interstate highways. Second, higher traffic density increases the crash risk. Third, TS&W policies can influence vehicle stability and control because they directly impact key vehicle design attributes such as number of axles, track width, wheelbase, number of units in a combination, loaded weight and overall length.

This chapter contains two major sections. The first highlights the vehicle safety performance analysis undertaken for Western Uniformity Scenario. The analysis uses the same methodology as the *CTS&W Study* to examine current western LCVs and the Scenario's LCVs. The second section reviews recent crash data analysis and presents an updated crash data analysis.

Vehicle Safety Performance Analysis

Three performance measures are often used as indicators of a truck's crash risk: Static Rollover Threshold, Rearward Amplification, and the Load Transfer Ratio. All three metrics describe aspects of a vehicle's inherent propensity to rollover. Crashes where the first event was a truck rollover accounted for 20 percent of the fatal single-vehicle crashes for large trucks in 2000.[22]

Both the current population of LCVs operating in the Western States and the Western Uniformity vehicles were analyzed. All the Scenario's vehicles currently operate in some part of the study region. This allowed the researcher to obtain "real-world" physical

[22] 2000 Large Truck Crash Facts, Publication No. FMCSA-RI-02-002, "Table 25: Crashes Involving Large Trucks by First Harmful Event and Crash Severity."

measurements for the stability input variables (for example, king pin setting, axle spacings, typical loads etc.).

In addition, current LCVs were analyzed because the large differences in State LCV regulations produce significant variations in vehicle design. These differences also translate into variations in vehicle dynamic performance. A sizable effort was made to fully understand the priorities and constraints unique to the Western States that would influence vehicle design particularly with respect to safety performance optimizations. The simulation and safety analysis reflects basic vehicle design, commodity types and loading variations occurring in the Western States.

Analyzed Vehicles

Table VII-1 shows the configuration, body type, trailer length(s), articulation type and GVW for the analyzed vehicles. These parameters were used to determine the vehicle stability and control performance.

The analysis includes van-type configurations including: the 5-axle tractor semitrailer, STAA Doubles, Rocky Mountains Doubles (RMD), Turnpike Doubles (TPD) and Triples. The analysis shows results for both the A-train and C-train Triples configurations. The tank vehicles are truck trailers, RMD A-train and its equivalent B-train configuration. This Chapter provides the results for the 96-inch axle width.[23]

The articulation type (see Figure VII-3) strongly influences the vehicle's stability and control. Both the C-dolly and B-train connections effectively eliminate an articulation point and increase stability and dynamic control of the vehicle. On the other hand, the reduced articulation decreases the maneuverability of the vehicle through curves and turns, impacting roadway geometry and traffic operations. The same trade-off exists for the vehicles with wider axle widths (see Woodrooffe, 2003).

The vehicles are evaluated at their respective maximum allowable weight conditions since the Western LCVs used for bulk transport are typically loaded to their maximum allowable gross weight. This represents the most severe operational case for vehicle stability since the center of gravity is the highest.

[23] Results in are shown in the present Chapter for the 96-inch axle width since that is the predominate vehicle width in the U.S. fleet (VIUS, 1997). The report *Western Longer Combination Vehicle Scenario: Vehicle Operations and Safety Analysis* by John Woodrooffe for this study includes analysis for some tank trailers with 102-inch width axles and also extended chassis. The wider trailer and extended chassis are analyzed to show the improvements to stability and control.

Table VII-1
List of Analyzed Vehicles

Configuration	Body Type	Trailer Length (Feet)	Articulation Type	GVW (Pounds)
STAA Double	Van	28 X 28	A-Train	80,000
Tractor Semitrailer	Van	53	-	80,000
Turnpike Double	Van	45 X 45	A-Train	129,000
Turnpike Double	Van	48 X 48	A-Train	129,000
Rocky Mountain Double	Van	48 X 28	A-Train	117,000
Rocky Mountain Double	Van	48 X 28	A-Train	113,000
Rocky Mountain Double	Hopper	35 X20	A-Train	105,500
Rocky Mountain Double	Hopper	38 X 28	A-Train	123,000
Rocky Mountain Double	Hopper	38 x 20	A-Train	109,250
Rocky Mountain Double	Hopper	38 x 27	A-Train	127,500
Rocky Mountain Double (long)	Hopper	44 x 31	A-Train	123,000
Rocky Mountain Double	Hopper	38 x 27	A-Train	128,000
Rock Mountain Double	Tank	41 X 22	A-Train	117,000
Rock Mountain Double	Tank	41 X 22	B-Train	117,000
Triple	Van	28 X 28 X 28	A-Train	118,500
Triple	Van	28 X 28 X 28	C-Train	118,500
Truck Trailer	Tank	38	-	114,300

The load for all van type trailers is 'general freight' occupying the full height of the load space. This assumes general freight has 30 percent of the payload in the top half of the container and 70 percent in the bottom half. Thus, the load has a relatively high center of gravity but not as high as a homogeneous load of the same dimensions. The analysis for the *CTS&W Study* used a homogeneous load to maximize the instability. Such a loading is atypical. Fancher et al[24] found general freight to have the 30 – 70 distribution and that is the distribution used in the present analysis.

Results

This section discusses the stability results for Static Rollover Threshold, Rearward Amplification and Load Transfer Ratio. These factors measure the impact of a sudden lane change, swerve and/or curve if negotiated at too great a speed potentially resulting in a rollover accident.

Static Rollover Threshold

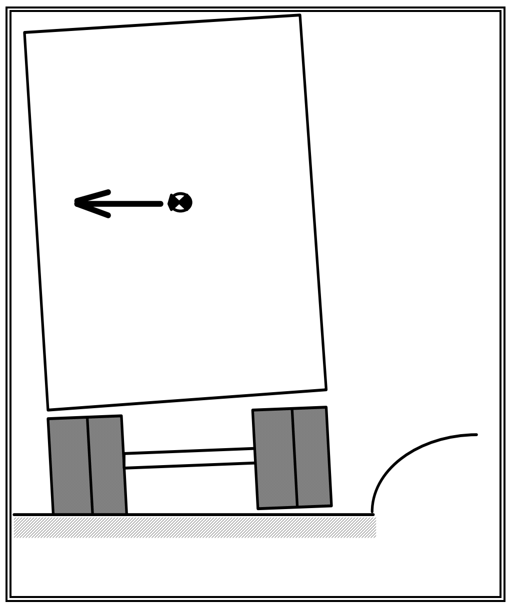
Static Rollover Threshold is a significant vehicle performance measure because it reflects overall vehicle stability for both emergency lane changes and typical negotiation of a well-designed roadway curve. The likelihood for a vehicle having to perform an evasive maneuver during a given trip is very low. By comparison, all vehicles must routinely

[24] Fancher, P.S., Ervin, R.D., Winkler, C.B., Gillespie, T.D. 1986. *A Factbook of the Mechanical Properties of the Components for Single-Unit and Articulated Heavy Trucks. Phase 1. Final Report.* Michigan University, Ann Arbour, Transportation Research Institute. 190 p. Sponsor: National Highway Traffic Safety Administration, Washington, D.C. Report No. UMTRI-86-12/DOT/HS 807 125. UMTRI-74246

negotiate curves and turns. In either case, vehicles with a low Static Rollover Threshold will be challenged.

The Static Rollover Threshold is the minimum amount of lateral acceleration needed to result in wheel lift-off from the ground – the point at which the vehicle then rolls over (Figure VII-1). Higher scores indicate better performance. Larger, heavier vehicles do not necessarily have poorer Static Rollover Threshold performance than smaller, lighter ones. The important variables are how the payload is distributed along the length of the vehicle and the height of the center of gravity. In general the lower the center of gravity and the more uniformly distributed the payload then the more stable the vehicle.

Figure VII-1
Illustration of Rollover Initiation

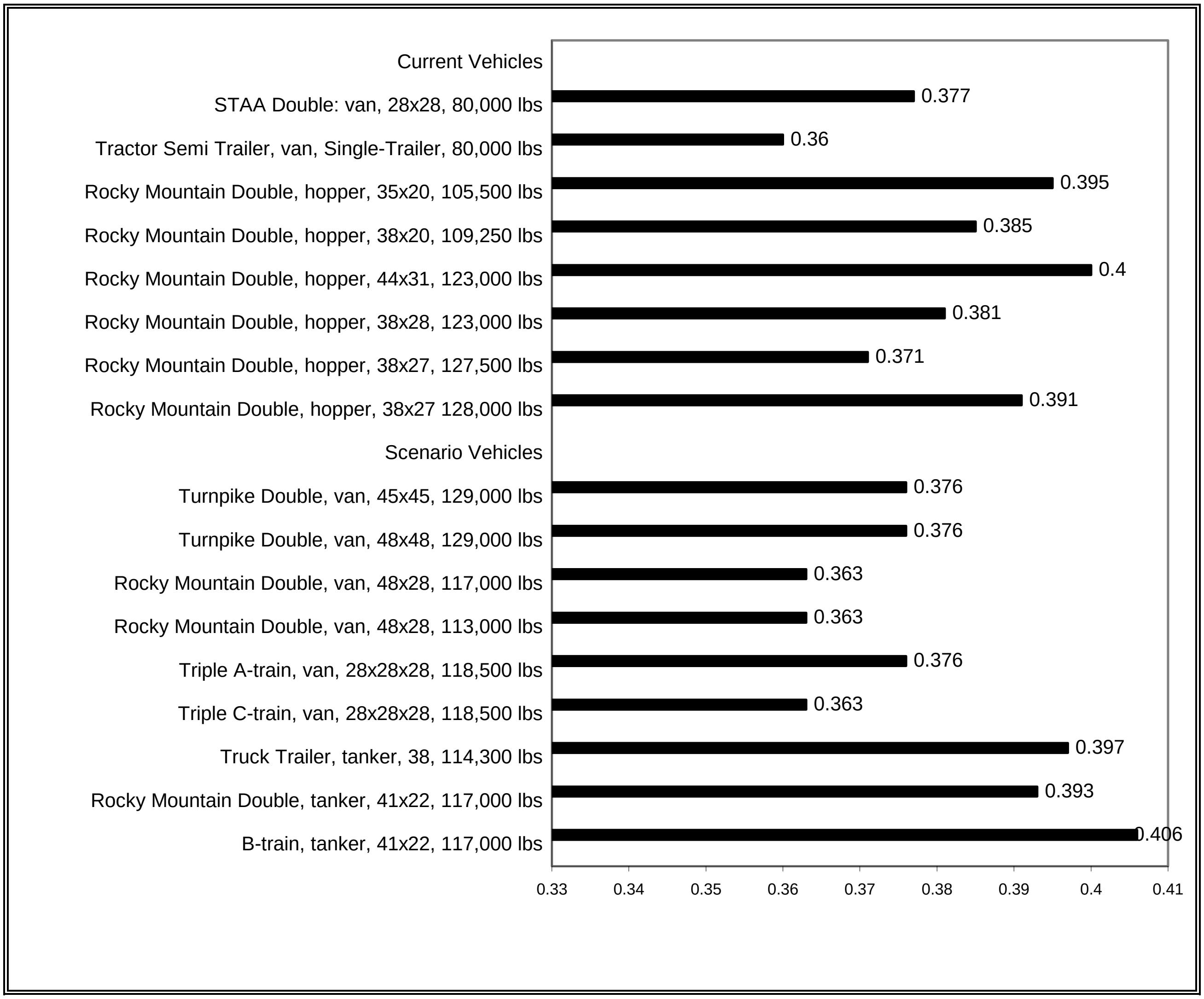


Static Roll Threshold can vary with the density of the commodity by up to 25 percent. On the other hand, since each van trailer is "loaded" with 70 percent of the load in the bottom half and 30 percent in the top half, all van trailers will have a rollover threshold of approximately 0.36g. These values represent a van with 96-inch width. Most new van trailers have a 102-inch width, producing a 5 percent improvement in roll stability. Static Rollover Threshold of the tanker fleet is approximately 0.40g, that is approximately 22 percent better than van trailers. This is due to the lower center of mass of the tank trailers relative to the van trailers.

Figure VII-2 shows the Static Rollover Threshold for 17 analyzed vehicles. The first 8 were chosen from the fleet of current vehicles operating in the West and the latter 9 are the Scenario vehicles – some of which already operate in the West. Static Rollover Threshold less than 0.30 is considered very poor, between 0.30 and 0.35 is poor, between 0.35 and 0.40 is good and greater than 0.40 is excellent. All the configurations analyzed have a good to excellent rating for Static Rollover Threshold.

As shown in Figure VII-2, most of the van trailer Scenario vehicles perform worse than the STAA double. This is critical since currently over 50 percent of the LCVs in the Western States are van-trailers,[25] a pattern that would continue under the Scenario. Past studies have shown that the Static Rollover Threshold can be improved through different vehicle designs – such as wider vehicles, lower floor heights; new equipment such as enhanced electronic braking, tire and suspension systems; and B-train and C-dolly trailer connections (see Figure VII-3). The B-train improvement can be seen comparing the final two vehicles in Figure VII-2, a RMD tanker versus the B-train, with all other variables held constant, there is a 3 percent improvement.

Figure VII-2
Static Rollover Threshold
Current Vehicles and Scenario Vehicles



[25] Vehicle Inventory and Use Survey, 1997.

Rearward Amplification

When articulated vehicles undergo rapid steering, the effect at the trailer is magnified. This can result in excessive movement of trailers, which can be very dangerous if, for instance, they move into other lanes and interfere with other vehicles. In the extreme, LCVs' rearward amplification can cause rear trailers to rollover.

Rearward amplification is influenced by the center-of-gravity, axle group weights, wheelbase dimensions, coupling types and locations, drawbar dimensions, suspension and tire characteristics. Mathematically, rearward amplification is the ratio of the lateral acceleration experienced at the rearmost trailer in a combination to that of the tractor, when a lane-change evasive maneuver is executed. In this case, values of 2.0 or less indicate acceptable performance.[26]

Figure VII-4 shows that certain configurations of LCVs are more prone than typical tractor-semitrailers to rearward amplification. For example, rearward amplification is 1.73 times greater for trucks with twin 28-foot trailers than for typical tractor semi-trailers, but can be 2.18 times worse for triple-trailers (with their five points of articulation) than it is for typical tractor semi-trailers. The type of mechanism connecting the trailers can affect the rearward amplification. A mechanism with a single connection point to the lead trailer, the most common type in the United States, is referred to as an "A-train" or "A" converter dolly. This type allows more rearward amplification than does the "B-train" or "C-train". Figure VII-3 illustrates and discusses these different connecting mechanisms.

Figure VII-4 shows that typical tractor-semitrailer combinations have a rearward amplification of 1.24. Currently -- designed STAA doubles (two 28-foot trailers) have rearward amplifications of 2.15. Also the RMD at 105,500 pounds with medium and light density commodities would be considered to have poor dynamic performance. The Triple-trailer A-train, at a value of 2.72, has the highest Rearward Amplification of all vehicles examined. When the Triple-trailer combination is fitted with C-dollies, dynamic activity is reduced by 39 percent and is in line with the remaining vehicles. The most stable vehicle examined is the B-train tanker at 117,000 pounds and a trailer width of 102" – it performs even better than the single-trailer combination.

[26] *Performance Based Standards for Heavy Vehicles in Australia*, 1999

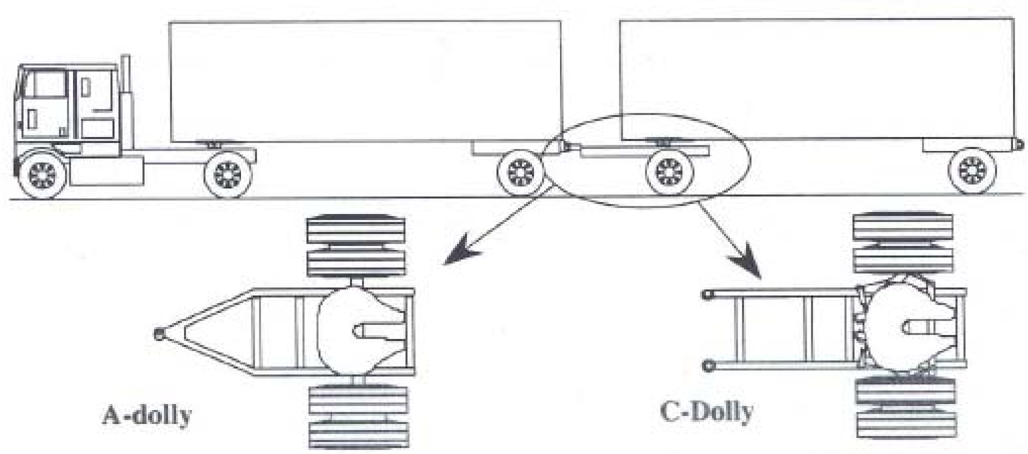
Figure VII-3 Major Types of Converter Dollies

In the case of multi-trailer combinations, roll coupling is a vehicle design feature that counters dynamic roll instability. It uses a coupling feature designed to take advantage of the fact that two adjacent units in a multi-trailer combination roll in different directions during a dynamic lane change maneuver. By making the coupling or hitch more rigid along the roll axis, each unit in the combination "helps" the other counteract excessive roll forces.

Roll coupling is a special attribute of "B-train" and "C-dolly" connections. A "B-train" connection between two trailers in a twin configuration essentially creates a semitrailer/semitrailer combination with two articulation points instead of three. A standard “fifth-wheel” connection is used to couple the two trailers together, thereby providing significant counter-roll forces between the two trailers.

A "C-dolly" connection also provides roll and coupling stiffness through the use of two drawbars between trailers. "A-dollies", which are used today, have one drawbar. Both B-train and C-dolly connections between two trailers effectively eliminate an articulation point and provide a large counter-roll force for each of the two trailers when dynamic forces act in opposing directions during an evasive lane change maneuver.

Some researchers believe the same effect can be accomplished through the use of such advanced technology as electronically controlled braking systems (currently the subject of a field operational test), which employ load and speed sensitive differential braking to maintain the direction of the individual units in combination vehicles making evasive maneuvers. This could reduce the crack-the-whip phenomenon and dynamic roll instability especially inherent in multi-trailer vehicles.



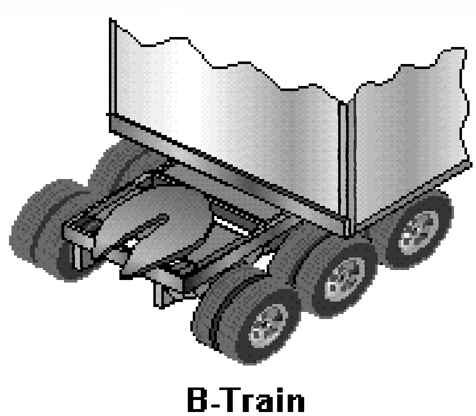
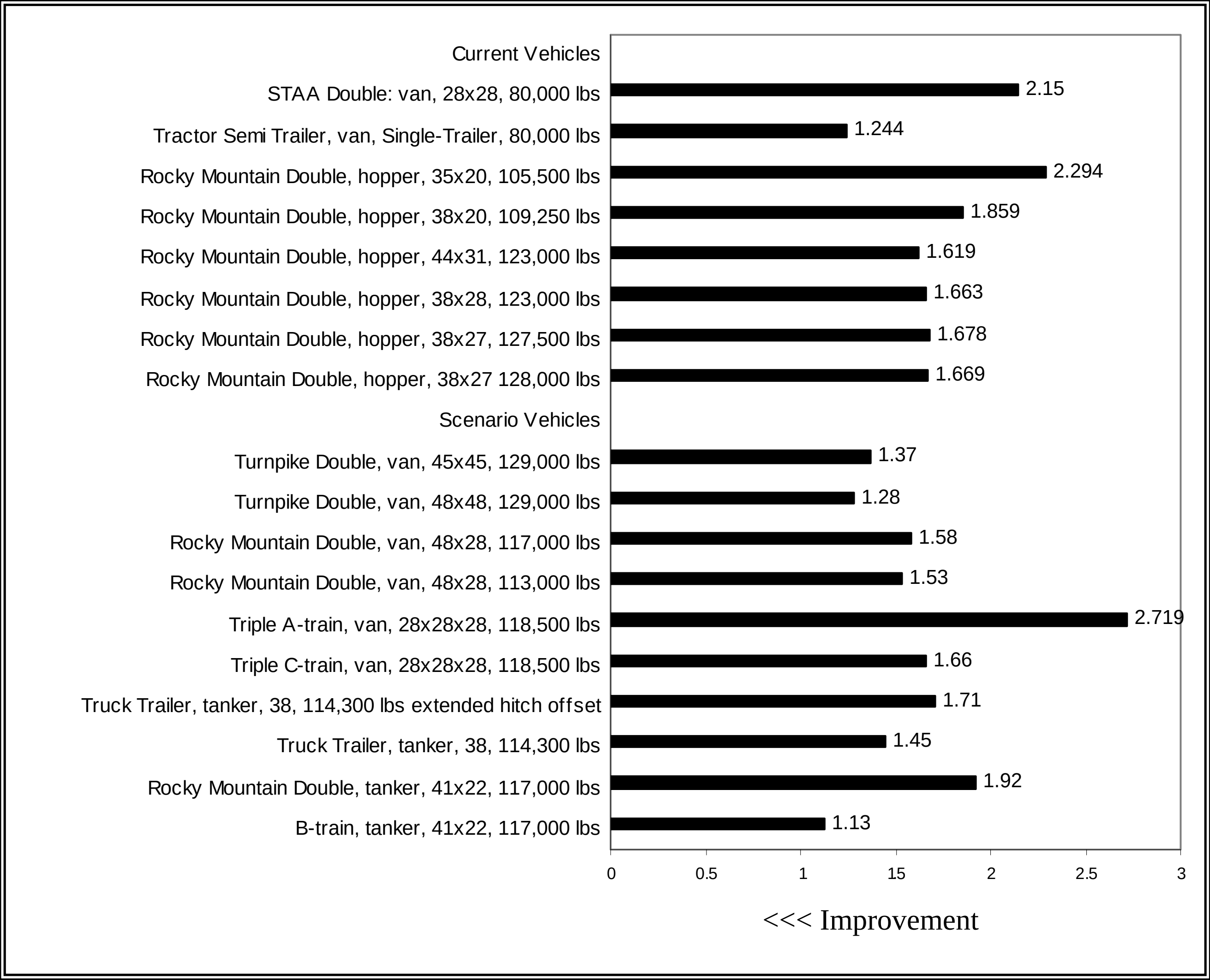


Figure VII-4
Rearward Amplification: Current and Scenario Vehicles



Load Transfer Ratio

Load transfer ratio is the proportion of load transferred to one side of a vehicle in a transient evasive steering maneuver. When the load transfer ratio reaches 1, the entire vertical component of the load is being transferred through the wheels on one side of the vehicle and rollover is about to occur. The load transfer ratio directly expresses the proximity to rollover in rapid maneuvers and emergency avoidance situations. In important respects, the load transfer ratio combines the influence of steady-state rollover and rearward amplification in one performance index. The load transfer ratio is computed for a standard maneuver based on a standard steering input. Load transfer ratio is influenced by the center-of-gravity, axle group weights, vehicle width, lateral load shift, wheelbase dimensions, coupling types and locations, drawbar dimensions, suspension characteristics and tire characteristics.

The Canadian performance standards recommend when a loaded vehicle "negotiates an obstacle avoidance, or lane change maneuver at highway speeds, the load transfer ratio should not exceed 0.60."[27] This is the generally accepted standard for other jurisdictions that employ performance measures. Of the current double configurations, only the STAA double and 105,500 pound LCV were found to have sub-standard performance.

Among the Scenario vehicles, Figure VII-6 shows that the B-train fuel tanker has the most stable characteristics followed closely by the Triple C-train. The improved performance by the B- and C-train configuration is attributed to the elimination of one articulation point per trailer and the addition of roll coupling between trailers. The Load Transfer Ratio of the RMD fuel tanker with a GVW 117,000 pounds was 2.4 times greater than the B-train tanker at the same GVW. However, the RMD compared favorably with the other vehicle classes including the tractor semi-trailer. This underscores the superior characteristics of the B- and C-train configurations.

The Load Transfer Ratio performance of the Triple A-train and the STAA Doubles is very poor. In the simulation, the Triple A-train achieved the theoretical maximum of unity, which means that the vehicle would have rolled over given the standardized test maneuver.

The TPD at GVW 129,000 pounds with 48-foot trailers out-performed the tractor semi-trailer at a GVW 80,000 pounds. When the trailers of the TPD were shortened from 48 feet to 45 feet, the Load Transfer Ratio increased by approximately 7 percent. This finding indicates that the stability performance of the TPD improves with trailer length.

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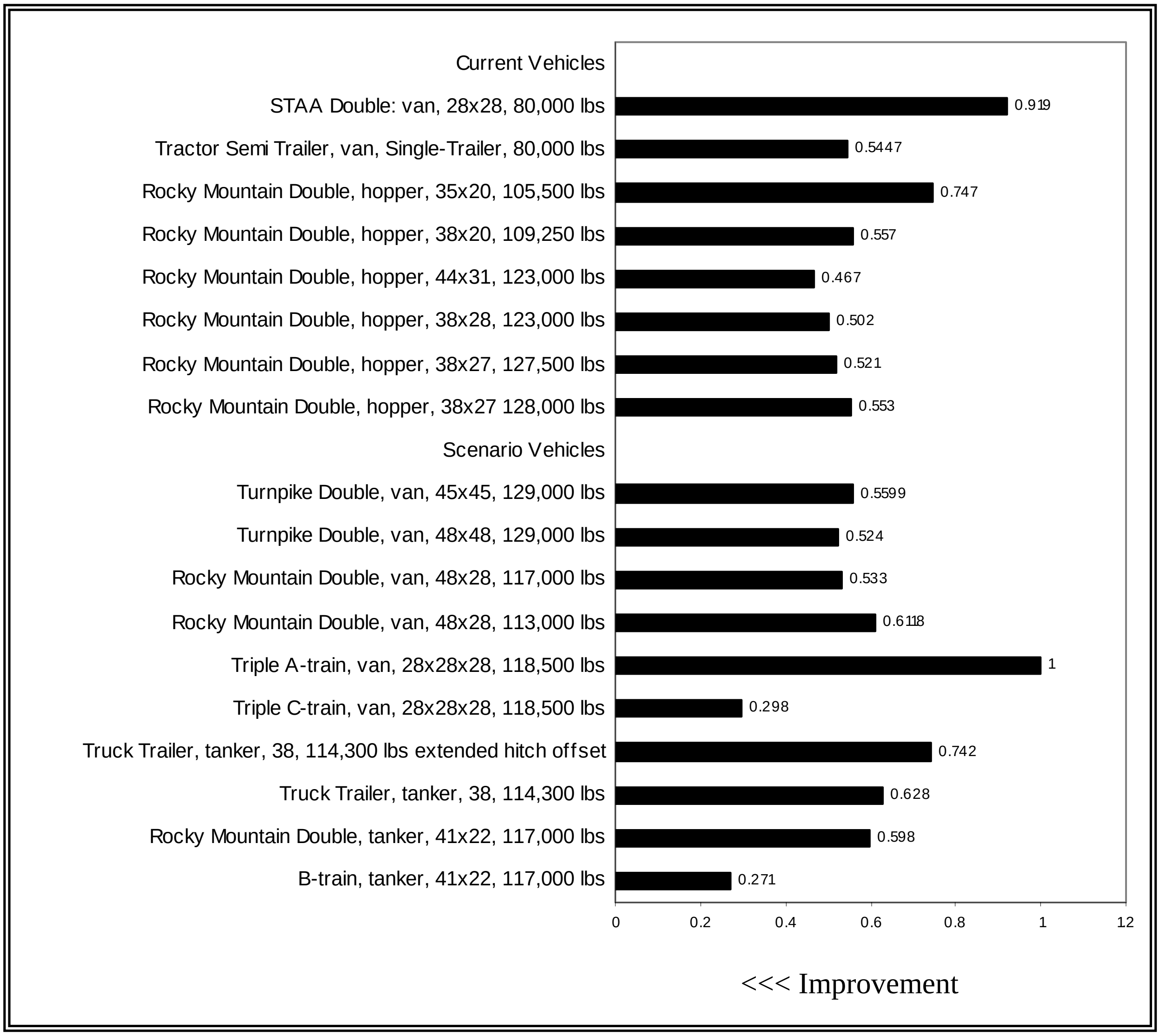
[27] *Recommended Regulatory Principles for Interprovincial Heavy Vehicle Weights and Dimensions*, Vehicle Weights and Dimensions Study Implementation Planning Subcommittee, final release September, 1987.

Figure VII-5
Load Transfer Ratio Current and Scenario Vehicles



Crash Database Analysis

Many studies have attempted to identify how crash propensity varies with TS&W, with particular focus on doubles and/or LCVs. Some studies have reported that multiple-trailer trucks have lower crash rates than single-trailer trucks and other studies have reported the opposite. The disparity in findings is explained, in large part, by the difficulty in analyzing a relatively small population of vehicles and obtaining reliable accurate VMT and crash data for each vehicle type. To try to overcome these difficulties researchers have used various methodologies and data sets in different studies, resulting in different conclusions.

Prior studies are examined in an attempt to obtain indications of potential crash impacts associated with estimated changes under the Western Uniformity Scenario. Past studies do differentiate between single-trailer combination trucks and multi-trailer combination trucks, but the multi-trailer group includes STAA doubles (tractor and two 28-foot trailers) along with RMDs, TPDs, and Triples. STAA doubles dominate the multi-trailer crash history since they are the most common multi-trailer combinations. Nevertheless, the multi-trailer/single-trailer distinction is still important since LCVs are configured similar to STAA doubles and have similar dynamic handling/stability performance characteristics. But as discussed in the previous section on stability and control, most longer LCVs are more stable than STAA doubles although they off-track to a much greater degree. The greater length of LCVs may also make passing maneuvers on two-lane highways, and merging and weaving maneuvers on freeways more difficult than for shorter STAA doubles.

There have been attempts to isolate LCVs' crash experience from STAA doubles through surveys, making assumptions about past and future operating environments, or analyzing the data from countries that allow wider use of LCVs. All these efforts have fallen under criticism. Studies using surveys have difficulty matching the survey respondents to the VMT estimates, or the sample set is not large enough, or the sampled population contains a self-selection bias. Several studies assume that relaxed LCV regulations would translate into LCVs operating on roadways similar to current single trailer combination trucks, even though most States that allow LCVs limit their use to certain highways. Although these State-permitted highways include some two-lane highways, all States that allow LCVs restrict them to a subset of the highway network that is available to single-trailer combination trucks. The assumption that LCVs could operate throughout a State's highway network increases estimated multi-trailer fatal crash rates, since fatal crash rates are higher on rural non-Interstate highways. Finally, there have been attempts to utilize Canadian or Australian data to predict the safety impacts associated with more widespread LCV use in the U.S., but those countries have very different enforcement mechanisms, road networks, and traffic densities, making it difficult to draw implications from their crash experience for the U.S.

The following section discusses the methodology, data, and results for seven recent statistical examinations of multi-trailer combination vehicle safety. Table VII-7 summarizes results from those studies applicable to the current Scenario. Although several of the studies present data on single-unit trucks, this summary does not include that information since the Scenario would not impact those vehicles.

Previous Research

(1) *Truck Safety: The Safety of Longer Combination Vehicles is Unknown*, GAO/RCED-92-66, March 1992, General Accounting Office

The General Accounting Office (GAO) reviewed nine LCV safety studies from 1978 through 1991 and found that they have disparate conclusions, including findings that multi-trailer vehicles are both more and less likely to be involved in crashes than other commercial vehicles. They found the reasons for the opposing conclusions rest with the different approaches used by the researchers, and the difficulty of collecting and interpreting the data used in the studies.

The GAO highlighted the problem of determining the safety of LCVs using crash data predominately based on the experience of twin 28-foot trailers. The GAO recommended an improvement of "truck accident and travel data, especially as they relate to the reporting of nonfatal accidents, the estimates of truck travel, and the identification of truck configurations."

(2) *Larger Dimensioned Vehicle Study – Final Report*, September 1993, FHWA

The purpose of this study was to compare the crash experience of single-trailer combination trucks and the twin 28-foot STAA double following the 1982 Surface Transportation Assistance Act (STAA) in which States were required to allow twin 28-foot trailers on the National Network for Large Trucks (NN). Despite the study's title, it only analyzes the STAA double and not any other larger dimensioned vehicles. Thirteen States provided detailed truck data but only 4 States (Iowa, Kansas, Missouri, and Utah) provided data over the entire collection period from 1983 – 1991.

The study found that twin-trailer trucks had a lower fatal involvement rate than single trailer trucks given their current distribution of travel by functional class, but predicted a rate similar to single trailer trucks would result if they had the same distribution of travel.

(3) *Analysis of Accident Rates of Heavy-Duty Vehicles*, April, 1988, The University of Michigan Transportation Research Institute, Kenneth Campbell, Daniel Blower, R. Guy Gattis, and Arthur C. Wolfe.

This study focuses on the fatal crash involvement for single- and double-trailer combinations. Data on fatal truck crashes (1980 – 1984) and truck travel (1985) were used to estimate the effects of truck configurations, road class and operating environment on crash rates. Researchers reviewed the crash and travel data, conducting follow-up interviews to fill in gaps. The travel data was obtained from telephone surveys of about 5,000 trucks, sampled from the 1983 R.L. Polk vehicle registration file. The fatal crash data was from Trucks Involved In Fatal Accidents (TIFA). Table VII-2 shows the crash and travel data for two vehicle classes.

Table VII-2
Overall Fatal Crash Rates of Single- and Double- Trailers from *Analysis of Accident Rates of Heavy-Duty Vehicles*

Configuration	1985 VMT (millions)	1980 – 1984 Fatal Involvements	1985 Fatal Involvement Rate (involvement/100 million VMT)[1]
Single-Trailer	33,452	16,260	10.2
Double-Trailer	2,008	829	8.6

1. According to the National Highway Traffic Safety Administration's Fatal Accident Reporting System, the average number of fatal involvements by all heavy trucks was 4,294 per year during 1980 – 1984 period and 4,492 in 1985. To obtain 1985 fatal involvement rates for each of the three types of truck configurations, 4492/4294 multiplied average 1980 – 1984 fatal involvements.

Table VII-3 shows estimates of the fatal crash rates by vehicle group for the different road environments derived from data in the 1988 UMTRI study. This analysis highlights the importance of a truck's operating environment. Regardless of the number of trailers, limited access roads have much lower fatal involvements relative to the travel on those roads than do uncontrolled access highways. An examination of the single-trailer fatal crash record shows that 39 percent of the single-trailer VMT is on rural limited access but only 14 percent of the single-trailer fatalities occur on these roads. In this UMTRI study twin-trailer combinations were found to have somewhat lower crash rates than single-trailer combinations on all highways types except other rural highways on which their crash rates were substantially higher. Because twin trailers travel relatively less on other rural highways than single trailer combinations, their overall crash rates were found to be lower than those of single-trailer combinations. When researchers adjusted crash rates by assuming that travel characteristics by highway type would be the same for multi- and single-trailer combinations, the overall crash rate for multi-trailer combinations increased from 8.6 to 11.2 involvements per million VMT, a rate higher than the 10.2 involvements per million VMT for single-trailer combinations. These results highlight the issue that changes in fatal crashes will depend on the truck's operating environment.

Table VII-3
Fatal Accident Rates of Tractor-Semitrailers and Doubles by Operating Environment from *Analysis of Accident Rates of Heavy-Duty Vehicles*

Configuration	1985 VMT (million)	1980 – 1984 Fatal Involvements	1985 Fatal Involvement Rate (per 100 million VMT)
Single-Trailer			
Limited Access Rural	12,891	2,775	4.50
Limited Access Urban	6,602	1,829	5.80
Other Rural	9,881	8,865	18.77
Other Urban	4,078	2,791	14.32
subtotal	**33,452**	**16,260**	**10.17**
Double-Trailer			
Limited Access Rural	886	172	4.06
Limited Access Urban	569	117	4.30
Other Rural	366	415	23.72
Other Urban	187	125	13.98
subtotal	**2,008**	**829**	**8.64**

Computed using Campbell et al Appendix Table 15 *Normalized Fatal Accident Involvement Rates by 8 Travel Categories for 5 Truck Types or Configurations NTTIS and 1980 – 1984 TIFA Files.*
According to the National Highway Traffic Safety Administration's Fatal Accident Reporting System, the average number of fatal involvements by all heavy trucks was 4,294 per year during the 1980 – 1984 period and 4,492 in 1985. To obtain 1985 fatal involvement rates for each of the truck configurations, average 1980 – 1984 fatal involvements were multiplied by 4,492/4,294.
Limited Access includes Interstate and Other Freeways and Expressways.

(4) *Truck Weight Limits Issues and Options*, Special Report 225, 1990, Transportation Research Board.

The Transportation Research Board (TRB) utilized the fatal crash rates from Campbell et. al. (1988) adjusted assuming the same distribution of mileage by highway type for each type of vehicle. This assumed that double-trailer distribution of travel would become the same as the current usage of single-trailer tractor-semitrailers. TRB expanded the fatal crash rates using estimates of injury and property-damage-only crashes (Tables VII-4 and VII-5). In the TRB report there was no definitive statement regarding the relative safety of alternative LCV configurations. They did discuss the impact of increasing weights on a given vehicle, but many conclusions are difficult to interpret for this study because findings for combinations and straight trucks are grouped. For all combination vehicles TRB presented data showing that crash rates on limited access highways increase slightly up to a gross vehicle weight of about 60,000 pounds after which they generally level off. On other types of highways crash rates for combinations continue to increase up to about 75,000 pounds, but drop somewhat at higher weights.

Table VII-4
Truck Crashes by Severity Class from *TRB 225*

Crash	Severity Class (percent)
Fatal	1.2
Injury	28.8
Property damage only	70
Total	100

Table VII-5
Base Crash Rates from *TRB 225*

Vehicle	Type of Crash (per 100 million VMT)		
	Fatal	Injury	Property Damage Only
Single Unit Trucks	7.7	185	499
Tractor Semitrailers	10.2	245	595
Doubles	11.2	269	653

(5) *Accident Rates of Multi-Unit Combination Vehicles Derived from Large-Scale Databases*, September 1990, Roger Mingo, Joy Esterlitz and Bret Mingo.

This study focused on estimating fatal crash rates for a single year using large federal databases containing crash, fatalities, and travel data. The crash data are from Fatal Accident Reporting System (FARS) and Trucks Involved in Fatal Accidents Program (TIFA). The researchers derived the vehicle travel estimates using FHWA's State reported travel data and the Truck Inventory and Use Survey (TIUS, predecessor to the current Vehicle Inventory and Use Survey (VIUS)).

The study produced a multitude of crash rates for different years using different data sources. Using FARS and adjusted FHWA travel data the authors estimated the 1988 fatal crash rates for tractor semi-trailers was 4.8 per 100 million VMT and for double-trailer combinations was 5.9 per 100 million VMT. Using TIFA and adjusted FHWA travel data the authors estimated the 1986 fatal crash rates were 4.33 per 100 million VMT for single-trailer combinations and 6.35 per 100 million VMT for multi-trailer combinations. Using TIFA and TIUS they estimated the 1986 fatal crash rates were 6.0 per 100 million VMT for single-trailers and 9.9 per 100 million VMT for multi-trailers. The authors stated that the TIFA and TIUS estimate is the best since TIUS is a sample.

(6) *Long Combination Vehicle Safety Performance in Alberta 1995 to 1998*, March 2001, John Woodrooffe.

This study reviewed the operations and crash rates for LCVs in Alberta, Canada for 1995 through 1998. The Canadian LCVs are similar to LCVs operating in the northwestern United States such as Montana and North Dakota. In Alberta a RMD consists of a 40 to 53 feet semi-trailer and a shorter 24 to 28 feet semi-trailer; a TPD consists of two trailers where both are between 40 and 53 feet; and a Triple trailer combination consists of three trailers all between 24 and 28 feet. Alberta requires selective routing, restrictions on vehicle speed, restricted time of day operation, enhanced driver qualification requirements and operating restrictions for adverse road and weather conditions. In general the operating network is restricted to multi-lane highways with four or more driving lanes except RMDs that may travel on a few two-lane highways.

During the study period there were 53 LCV crashes of which two were fatalities. The crash rates focus on the 37 rural crashes, but not on the 16 urban collisions due to difficulties computing the vehicle kilometers traveled in urban areas. This introduces a bias since the study only analyzes the best performing roads (4 lane rural). Table VII-6 shows the collision rates per 100 million kilometers and 100 million miles.

Table VII-6
Collision Rates on the LCV Sub-Network* by Vehicle Type 1995-1998
from *LCV Performance in Alberta*

Vehicle Type	**Crash**	**Total Distance Traveled** (100 million Km)	**Total Distance Traveled** (100 million miles)	**Crash Rate** (per 100 million Km)	**Crash Rate** (per 100 million Miles)
Tractor Semi	918	11.54	7.17	79.55	128.10
Multi Trailer	418	4.03	2.50	103.72	167.02
Rocky Mountain Doubles	11	1.07	0.66	10.28	16.55
Turnpike Double	20	1.19	0.74	16.81	27.06
LCV Doubles – all	31	2.26	1.40	13.72	22.09
Triples	6	0.09	0.06	66.67	107.35

*Crashes for the LCV sub network only - no urban miles included
To convert to miles, kilometers was multiplied by 0.621.
Multi-Trailer includes RMDs, TPDs and Triples

The study period contains only two fatalities attributed to TPDs implying a doubles crash fatal crash rate of 0.88 per 100 million kilometers or 1.42 per 100 million miles.

(7) *Accident Rates for Longer Combination Vehicles,* October 1996, Publication No. FHWA-MC-97-003, Scientex Corporation, Joel Ticatch, Mustafa Kraishan, Gery Virostek, and Linda Montella.

Seventy-five commercial motor carriers participated in the study comparing crash rates of LCVs to Non-LCVs. All participants operated both LCV's and Non-LCVs. Crash and exposure data covered 1989 - 1994. This study focused on crashes that required the filing of a police crash report, an insurance crash report or recording of information in the motor carrier's crash register.

Among study participants, the mean crash rate was 887.25 crashes per million VMT for LCV's versus 1786.45 crashes per 100 million VMT for Non-LCVs. The difference in the mean crash rates was found to be statistically significant. The fatal crash rate for single-trailers was 24 per 100 million VMT while the LCV rate was 21 per 100 million VMT for the carriers in their study. Even though the crash rate was lower for LCVs, the researchers found that LCV crashes are more severe than non-LCVs: "the average number of fatalities per LCV crash was 90 percent higher than for each non-LCV crash."

The researchers discussed the possible foundations for the crash rate differential noting that LCV operators in their study predominately operated in rural areas on higher quality roads, possessed far better safety fitness records than the carrier population at-large, and tended to assign exceptionally experienced drivers to their vehicles, both LCV's and non-LCV's.

The findings of this study pertain only to the carrier population from which the sample was drawn. In this study, one cannot disregard the potential for self-reporting and selection biases.

Summary of Prior Studies

The previous studies noted above have estimated a wide range of crash rates due to different databases, time frames, methodologies, and biases. Table VII-7 summarizes all the non-fatal and fatal crash rates from these various studies.

Table VII-7
Summary of Truck Crash Rates
(per million VMT)

Source	Time Period Analyzed	*Type of Crash* Non-Fatal Injury	Fatal
Longer Dimensioned Vehicle Study - FHWA	1983 - 1991		
Single Trailers		31.46	2.44
Rural Interstate		19.48	1.16
Rural Other		34.86	4.77
Urban Interstate		41.85	1.6
Urban Other		114.55	7.37
Multi Trailers		25.15	2.08
Rural Interstate		17.68	1.09
Rural Other		32.29	4.5
Urban Interstate		29.9	1.31
Urban Other		137.3	12.87
Analysis of Accident Rates of Heavy-Duty Vehicles - Campbell et al	1980 - 1984		
Tractor plus single trailer			
Rural - Limited			4.50
Rural - Other			18.77
Urban - Limited			5.80
Urban - Other			14.32
Tractor plus double trailers (includes STAA Doubles)			
Rural - Limited			4.06
Rural - Other			23.72
Urban - Limited			4.30
Urban - Other			13.98
Truck Weight Limits Issues and Options - TRB	1980-1984, presented for 1985		
Tractor plus single trailer		245	10.20
Tractor plus double or Triple trailers (includes STAA Doubles)		269	11.20
Accident Rates of Multi-Unit Combination Vehicles Derived from Large-Scale Databases - Mingo et al	1986		
Tractor plus single trailer			6.02
Tractor plus double or Triple trailers (includes STAA Doubles)			9.96
Long Combination Vehicle Safety Performance in Alberta – Woodrooffe	1995 - 1998	Collisions	
Tractor plus single trailer		128.10	
Rocky Mountain Doubles		16.55	
Turnpike Doubles		27.06	
Tractor plus double trailers		22.09	1.42
Tractor plus three trailers		107.35	

*The reader should exercise care when comparing across studies since different data sources and definitions of variables were used in each study.

Crash Database Analysis – Update

With the exception of the Woodrooffe study in Canada, the cited studies all rely on data that is many years old. The present study updates and focuses on the fatal involvement rates in the Scenario States by examining 1995 - 1999 fatal involvement and travel data. The data for number-of-crashes and number-of-trucks-involved came from the 1995 - 1999 Fatal Analysis Reporting System (FARS) final report. FARS provides data on the number of trailers for the combination vehicles involved in the crash and highway classification for all fatal crashes[28]. Where a crash involved an unknown truck configuration or highway functional class, the crash was proportioned among the population of known crashes. The fatal crash numbers exclude single unit trucks and trucks not hauling a trailer (i.e. bobtails).

The 13 State VMT estimate is from the *Highway Statistics* VM-2 Table that lists the VMT by State and highway functional class. The splits between combination trucks and also between single-trailer and multi-trailer units utilize the detailed 1999 estimates of VMT by highway functional class prepared for this study and shown in Table II-4.

Although this represents more recent data than the previous studies, the analysis has many of the same limitations found in previous statistical safety analyses that attempt to estimate the respective safety of LCVs compared to other truck configurations. These include: (1) examination of past safety data may be an inaccurate predictor of future roadway safety; and (2) the analysis is unable to isolate LCVs from STAA doubles. Despite these shortcomings, the analysis demonstrates the importance of operating environment and potential trends.

Table VII-8 summarizes the fatal crash and travel data for 1995 – 1999 for the 13 States in the Western Uniformity Scenario. The data include 5 years of data to remove any bias that would be present in only examining a single year of data.

Table VII-8
Travel and Fatal Crashes for Scenario States 1995-1999

Functional Class	VMT (million)		Fatal Crashes (number of Crashes)[2]		Fatal Crashes (count of Trucks involved)[1]	
	Single Trailer	Multi Trailer	Single Trailer	Multi Trailer	Single Trailer	Multi Trailer
Interstate Rural	28,699.86	2,897.88	387	51	434	53
Other Rural	25,059.63	1,948.69	1,148	121	1,180	123
Interstate Urban	7,017.00	876.10	130	9	140	12
Other Urban	7,548.32	990.15	212	21	215	21
Total	68,324.81	6,712.81	1,878	203	1,970	210

Sources: Fatality Analysis Reporting System (FARS), Highway Statistics VM-1 Table and 1999 expanded VMT prepared for this report.

1. Count of Trucks Involved contains all the trucks in a fatal crash. For example if two single-trailer trucks create a fatality then the entry for number of trucks involved is 2.
2. Number of Crashes contains the number of fatal crashes. For example if two single-trailer trucks create a fatality then the entry for the number of crashes is 1.

[28] FARS does not provide details on the trailer length(s) or other details to distinguish between STAA and other double-trailer combinations.

Table VII-9
Fatal Crash Rates for Scenario States 1995-1999
(per 100 million VMT)

Functional Class	Fatal Crash Rate (Number of Crashes)		Fatal Crash Rate (Number of Trucks Involved)	
	Single Trailer	Multi Trailer	Single Trailer	Multi Trailer
Interstate Rural	1.35	1.78	1.50	1.83
Other Rural	4.58	6.22	4.73	6.36
Interstate Urban	1.85	1.03	2.01	1.39
Other Urban	2.81	2.12	2.84	2.13
Total	2.75	3.02	2.88	3.13

*National crash rates were created using the same methodology and differences were found to not be significant at the 95% confidence interval.

Table VII-9 shows the fatal involvement rates given the VMT and fatal involvements in Table VII-8. Among the 13 States, the fatal crash involvement was 2.88 per 100 million VMT for single trailer combinations and 3.13 per 100 million VMT for multi-trailer combinations.[29]

Table VII-10 further develops the crash involvement rates from Table VII-9 by showing upper and lower bounds based on the 95 percent confidence intervals for single- and multi-trailer combinations on the different highway classes. A 95 percent confidence interval means that there is a 95 percent likelihood that the crash rate for a given year between 1995 and 1999 does not deviate from the mean crash rate for all years by more than approximately 2.0 times the standard error. For example, while the mean (or average) crash rate for multi-trailer combinations was 3.13, it could be expected – with 95 percent confidence – that the multi-trailer rate for a given year would fall between 2.42 and 3.84 crashes per million VMT. Similarly, while the mean crash rate for single-trailers was 2.88, it could be expected – again with 95 percent confidence – that the single-trailer crash rate for a given year would fall between 2.81 and 2.95 crashes per million VMT.

[29] In this analysis, "the vehicle involved in the collision" is the primary investigative factor therefore focusing on the "total" number of vehicles involved in a collision. If there are 100 fatal collisions involving 200 single-trailer trucks then the number of vehicles involved in the fatal collisions will be counted as 200.

Table VII-10
Bounded Fatal Involvement Rates for the Scenario States 1995-1999
(per 100 million VMT)

Functional Class	Single Trailer			Multi Trailer		
	Lower Bound*	Fatal Crash Rate	Upper Bound*	Lower Bound*	Fatal Crash Rate	Upper Bound*
Interstate Rural	1.35	1.50	1.64	1.48	1.83	2.17
Other Rural	4.53	4.73	4.95	4.50	6.36	8.25
Interstate Urban	1.81	2.01	2.22	0.71	1.39	2.07
Other Urban	2.53	2.84	3.16	1.28	2.13	3.02
Total	2.81	2.88	2.95	2.42	3.13	3.84

*Lower and Upper Bounds are set by the 95% confidence interval.

It is tempting to look at Table VII-10 and conclude, among other things, that multi-trailer combinations are less safe than single trailer combinations. Tests for statistical significance show that such a conclusion would be incorrect.

Assessment of Scenario Impacts

This section discusses the data limitations that impede the prediction of fatal involvements under the Western Uniformity Scenario. Although quantitative estimates are not available, the Scenario may be judged in terms of the relative shifts that are projected to occur from: one configuration to another; the operating environments in which various types of LCVs would begin to operate; the relative stability and control characteristics of each configuration; the changes in truck travel miles that would result; the availability of qualified drivers; and the regulations that might be put in place to promote safe operations.

As noted above, the fatal crash and travel data do not allow a detailed examination of LCVs separately from multi-trailers. The multi-trailer classification largely contains data on twin 28-foot STAA doubles. According to an analysis of 1991-1996 data, LCVs comprise about 22 percent of the multi-trailer combination vehicles involved in fatal crashes,[30] but there is no method to accurately estimate a separate fatal involvement rate. The measurement problem is three fold; fatalities are rare occurrences, there are few LCVs currently operating and there is only limited travel data collected on LCVs. There is no federal requirement to collect data for specific types of multi-trailer combination vehicles. Only 2 of the 13 Scenario States actively collect separate VMT for different types of multi-trailers.[31]

Without the ability to breakout the different multi-trailer types, the fatal involvement rates in Table VII-10 are too broad for predicting the Scenario's multi-trailer fatal involvement rates.

[30] *Longer Combination Vehicles Involved in Fatal Crashes, 1991-1996*, Office of Motor Carrier and Highway Safety, FHWA-MCRT-99-018.

[31] The States are Idaho and Oregon.

No attempt was made in the *CTS&W Study* to estimate changes in the number or cost of crashes that might result from any of the Scenarios analyzed in that study. Among the reasons why such estimates could not be made were (1) the weights and dimensions of many of the vehicles analyzed in that study were substantially greater than vehicles currently operating even in the West, (2) the LCVs were assumed to operate nationwide, including on highways with poorer roadway geometry and higher traffic volumes than on highways they currently use, and (3) uncertainties about the number of experienced drivers that might be available to operate LCVs considering the large increase in the number of LCVs.

In this Scenario, many of those analytical uncertainties are reduced. The Scenario vehicles are typical of vehicles already being operated in the Western States and the highway environment is the same or comparable to the environment in which LCVs currently are being operated. Despite that improvement one is unable to apply the multi-trailer fatal involvement rate to the estimated Scenario VMT since there is limited data on those LCVs currently operating. In addition there could be some uncertainty about the availability of drivers who are experienced in operating multi-trailer combinations,[32] but not to the extent noted in the *CTS&W Study*.

Triples

Triples analysis is conspicuously absent from most prior studies and databases. Obtaining data on Triples travel is difficult since data is collected on tractors and the same tractor can pull either one, two or three trailers depending upon the shipper's needs. Only two of the reviewed studies included a separate analysis of Triples, the Alberta Study and Scientex's *Accident Rates for Longer Combination Vehicles*. The Alberta Study found Triples were involved in 107 non-fatal crashes per 100 million miles traveled. This is roughly 4.8 times the involvement of doubles. The Scientex Study calculated 829 Triple-trailer non-fatal crashes per 100 million VMT. These estimates are different by nearly an order of magnitude because their data was drawn from a low number of observations.

Triples currently operate in all the 13 analyzed States except Washington and Wyoming where Triples are not permitted. Technically, Nebraska does permit Triples, but in practice there are no Triples operating since they can only operate empty. In the Scenario States there were 11 Triples involved in fatal crashes for 1995 – 1999 but since triples are so infrequently involved in fatal crashes the number varies greatly from year-to-year.[33] In 1995 there was only 1 triple-trailer combination involved in a fatal crash but in 1998 there were four.

The biggest challenge in triples fatal involvement analysis, similar to other multi-trailers, is estimating their travel. Since triples' VMT is so small relative to other truck configurations the exact numbers are difficult to derive from National or even State totals. As noted before,

[32] The WASHTO Guide requires LCV drivers to have a minimum of two years' "line-haul" driving experience driving double-trailer combinations before certification for a LCV license.

[33] TIFA narrows the incidents down to only 9 triples involved in fatal crashes in the Scenario States for 1995–1999.

the Highway Performance Monitoring System (HPMS) that provides the best national data on truck travel does not include a classification for triples. Also, triples tend to be operated by less-than-truckload shippers who regularly drop and pick-up trailers from their terminals so on a given 1,000 mile operation one-half could be as a triple and one-half as a double. (This is different than the typical resource hauling LCV that remains as one multi-trailer unit for most operations.) Elsewhere in this study the VMT for triple-trailer combinations is estimated and utilized for impact analysis but due to the problems sited above one is unable to have confidence in an estimate of triple-trailer fatal involvement rate.

One is able to conclude, based on the stability and control properties discussed earlier in this chapter, that triple-trailer combinations have relatively poor dynamic stability in the present configuration. Woodrooffe (2001) suggests that Triple's performance could be improved "if coupled in the B-train or C-train configuration."

Conclusion

Safety is the primary factor when assessing potential changes in TS&W policy. Safety is the U. S. Department of Transportation's preeminent goal, State transportation agencies share this priority, and motorists who must share the road with large and heavy trucks would care strongly about the safety of those vehicles.

TS&W policy changes can affect safety in several ways. First, they can affect the total number of trucks on the road and thus the exposure of the overall truck fleet to crashes. Analyses of potential 2010 VMT changes for Scenario States indicate that the Scenario would reduce total heavy truck travel by between 9 and 25 percent. These figures include not only reductions in truck travel associated with shifts of freight from smaller to larger trucks that would be allowed in some States under this Scenario, but also increases in truck traffic caused by shifts of freight from railroads to trucks. Reductions in truck crashes would not be expected to be as large as reductions in travel for several reasons. First the greatest reductions in truck travel occur on the safest roads – rural Interstate highways. Since travel is not estimated to fall as much on other rural arterials that have much higher crash rates than rural Interstate Highways, the reduction in overall crashes would not be as great as the reduction in overall travel.

Most previous studies of potential safety impacts of changes in TS&W policy have relied primarily on studies that have compared crash rates of single- and multi-trailer combinations. As noted above the problem with this approach is that most multi-trailer combinations are short STAA doubles that are comparable in length and weight to single-trailer combinations. While these STAA doubles are less stable than standard single-trailer tractor-semitrailers when one looks at their rearward amplification and load transfer ratio, they perform better than tractor-semitrailers in terms of their static rollover threshold and offtracking. The various LCVs analyzed typically fall between the tractor-semitrailer and the STAA double in terms of stability and control properties. However, they are much longer and heavier than either of those standard vehicles and they have greater offtracking. These characteristics influence how easily a truck driver can maintain control should operating conditions become challenging or can regain control should it be lost in response to a precipitous event. These factors all make it difficult to extrapolate overall multi-trailer combination crash rates to the fleet of LCVs.

It is also difficult to extrapolate the results from studies conducted outside the U.S. because the operating environment may not be representative of the U.S. environment. Not only may highway and traffic characteristics be different than those in the U.S., but regulatory policies may also differ. Such regulatory differences could be expected to have a significant impact on the safety of LCV operations.

Even without the ability to estimate the potential changes in the crash rates that might be associated with operations under the Western Uniformity Scenario, it is useful to update the crash analysis for the 1995-1999 period, the latest years for which crash data were available. This update was needed since during the 1980's when most of the past studies were conducted the use of double-trailers was still growing and had not reached a steady-state equilibrium. Also vehicle safety in general has drastically improved since the 1980's with the advent of seat-belt requirements, air bags and anti-lock brakes[34] – among many other things. From 1990 to 2000, the number of large trucks in fatal crashes per 100 million VMT declined from 3.3 to 2.4 – down 27 percent.[35]

The statistical analysis indicates the importance of operating environment. Among single trailer configurations the fatal involvements can range from 1.50 to 4.73 per 100 million VMT. Among multi-trailer configurations the fatal involvements can range from 1.39 to 6.36 per 100 million VMT. These numbers indicate that when estimating fatal involvements it is not just the magnitude of VMT change but on what road classes the VMT changes. In the Western Uniformity Scenario multi-trailer trucks operate 61 percent of their mileage on Interstate roads; if a larger portion of their mileage were to shift to non-interstate roads, one would expect the number of fatal crashes involving these vehicles to increase.

This chapter does not explore auto driver perceptions and reactions to LCVs.[36] In surveys and focus groups conducted for the *CTS&W Study*, most drivers expressed concern about the safety of sharing the road with larger and heavier trucks. Any attempt to increase the size of trucks would require a major public education campaign on how to operate around large trucks and the relative safety enhancements that would be required of any new larger truck.

[34] Three-point belts were required in trucks of 10,000 pounds gross-vehicle-weight manufactured beginning September 1, 1990. Antilock brake systems (ABS) have been required since March 1, 1997 for truck-tractors and since March 1, 1998 for trailers.
[35] 2000 Large Truck Crash Overview, Federal Motor Carrier Safety Administration, Publication number FMCSA-RI-02-002.

[36] The recent study "Identifying Unsafe Driver Actions that Lead to Fatal Car-Truck Crashes" discusses auto driver actions and reactions that might differ when interacting with a truck.

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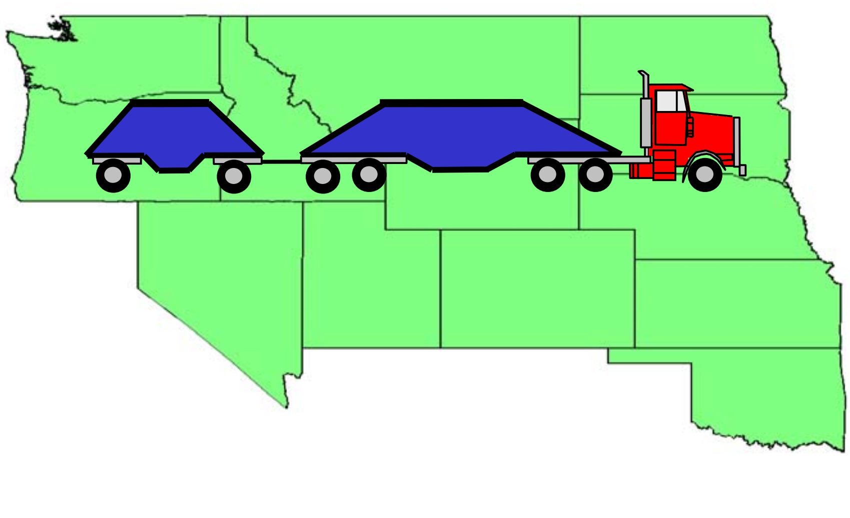
CHAPTER VIII

Traffic Operations



Introduction

Larger and heavier trucks affect traffic basically in two ways. Because of their size, weight and operating characteristics such trucks will reduce the "quality" of traffic flow and, in most cases, increase the number and severity of crashes. To describe the "quality" of highway traffic flow, transportation engineers developed the concept of *Level of Service* (LOS), with ratings from LOS A to LOS F, where LOS A reflects uninterrupted flow, that is, where the movements of any one vehicle does not effectively influence the travel of other vehicles. LOS E reflects that the highway is operating at capacity, while LOS F reflects unstable flow where there is "stop and go" operation. Because of their size, acceleration and braking characteristics larger trucks negatively affect the roadway's LOS.

Secondly, these truck effects on the traffic stream not only impinge on flow quality, but they also affect safety in several ways. In addition to the obvious impact on crash severity due to truck weight, research has shown that speed differential among the vehicles in the traffic stream increases the probability of crashes. Because of trucks' poorer acceleration capability (as compared to passenger cars and other smaller vehicles with lower weight-to-horsepower ratios) the effects of any posted differential speed limits are magnified. Generally, traffic operations degrade as the proportion of trucks in the traffic stream increases, and as the acceleration and stopping distance differentials between trucks and other vehicles increase.

This chapter presents qualitative assessments of the traffic operations impacts of the Western Uniformity Scenario trucks in the 13 analyzed States. Although traffic originating or terminating outside the region that shifts from a single-trailer combination vehicle to a "scenario LCV" may change its travel route outside the region to access the Western Uniformity Scenario network, these volume shifts will be negligible. This is because the Scenario network is comprehensive and connectivity to the outside-the-region network is pervasive. In addition to these minor route changes, traffic that originates or terminates outside the region and diverts from a 53-foot single-trailer vehicle in the Basecase Scenario to an LCV in the Western Uniformity Scenario may generate an increase in the number of truck trips outside the region. Under the Western Uniformity Scenario, no LCV configuration allows a 53-foot trailer and the analysis assumes that trailers conforming to the Uniformity length regulations are paired up at the region's border and not reloaded from non-conforming trailers. Such changes in truck travel outside the region affect only a very small amount of the overall truck travel.

Vehicle Characteristics and Their Affect on Traffic Flow and Safety

Acceleration and Speed Maintenance

Acceleration performance determines a truck's basic ability to blend well with other vehicles in traffic. Poor acceleration or speed maintenance is a concern as it results in large speed differentials between vehicles in traffic, and crash risks increase significantly with increasing speed differentials. The *Comprehensive Trucks Size and Weight Study* (*CTS&W*) Volume III showed that crash involvement might be 15 – 16 times more likely at a speed differential of

20 miles-per-hour than when there is no difference in speeds. Also poor acceleration performance increases vehicle interaction and subsequent delay, thereby degrading the LOS.

Engine manufacturers have responded to the needs of heavier trucks by building engines with up to 600 horsepower. These engines are sufficient to maintain a minimum speed of 20 mph for a 130,000 pound truck on a 6 percent grade. This provides sufficient power to allow these vehicles to operate in conformity with Federal policy standards for the Interstate System. For example, Federal policy states that highways with design speeds of 70 mph may not have grades exceeding 3 percent. However, gradients may be up to 2 percent steeper when in rugged terrain. Table VIII-1 shows the engine horsepower necessary to yield selected weight-to-horsepower ratios. This table provides a point of reference as to the horsepower required for vehicles operating at increased weights that maintains the weight-to-horsepower ratio of the lower weight vehicle. For examqle, to maintain the ratio of 250 an 80,000-pound 5-axle tractor-semitrailer combination needs a 320 horsepower engine, but an LCV loaded to the Western Uniformity Scenario maximum weight of 129,000 pounds would require a 516 horsepower engine. Although the 600 HP engine permits LCVs to operate in a similar fashion to most single trailer trucks, it is not sufficient for a fully loaded 18-wheeler with a 450+ HP engine, which is not uncommon among such trucks.

Table VIII-1
Horsepower Requirements
Select Weight-to-Horsepower Ratios and Gross Vehicle Weights

Weight/ Horsepower Ratio (pounds)	**Horsepower Required for Weight-to-Horsepower Ratio in Right Column**					
	Typical 3S2* Tare Weight 30,000 lbs	**Typical 3S2* Partial Load 60,000 lbs**	**Maximum 3S2* Load 80,000 lbs**	**Triples Uniformity Weight 110,000 lbs**	**Typical Uniformity 8-axle LCV 120,000 lbs**	**Maximum Uniformity LCV 129,000 lbs**
150	200	400	533	733	800	860
200	150	300	400	550	600	645
250	120	240	320	440	480	516

*3S2 is a 5-axle tractor semitrailer with 3-axles on the tractor and 2-axles on the semitrailer.

Size and Acceleration Impacts on Congestion

Trucks are larger and, more importantly, accelerate more slowly than passenger cars, and thus have greater impacts on traffic flow than passenger cars. In the *CTS&W Study* Volume III, the impact on traffic congestion was assessed in terms of changes in passenger car equivalents (PCE). A PCE represents the number of passenger cars that would use the same amount of highway capacity as the vehicle being considered under the prevailing roadway and traffic conditions.

A significant variable for acceleration and speed maintenance is the grade or steepness of the road. The mountainous western States in this study contain a preponderance of steeply graded rural Interstate. *CTS&W Study* Volume III reports that on level terrain and in uncongested conditions conventional trucks may be equivalent to about two passenger cars, but on hilly or mountainous terrain and in congested traffic, their effect on traffic flow is much greater and may be equivalent to 15 or more passenger cars. Table VIII-2 shows PCE values for trucks operating in rural and urban areas under different conditions. The Rural portion of Table VIII-2 indicates the marked effect that percent and length of grade have on truck climbing ability if the truck has a high weight-to-horsepower ratio. Likewise, the urban portion of the table indicates that congested traffic conditions increase PCEs relative to uncongested conditions.

Table VIII-2
Truck Passenger Car Equivalents

Roadway Type	Operating Environment		Weight/ Horsepower Ratio (pounds)	Truck Length (feet)		
				40	**80**	**120**
Rural						
	Grade					
	Percent	**Miles**				
Interstate	0	0.50	150	2.2	2.6	3.0
			200	2.5	3.3	3.6
			250	3.1	3.4	4.0
	3	0.75	150	9.0	9.6	10.5
			200	11.3	11.8	12.4
			250	13.2	14.1	14.7
Other Principal Arterial	0	0.50	150	1.5	1.7	Not Simulated
			200	1.7	1.8	Not Simulated
			250	2.4	2.7	Not Simulated
	4	0.75	150	5.0	5.4	Not Simulated
			200	8.2	8.9	Not Simulated
			250	13.8	15.1	Not Simulated
Urban						
	Traffic Flow					
Interstate & Other Freeways, Expressways	Uncongested		150	2.2	2.6	3.0
			200	2.5	3.3	3.6
			250	3.1	3.4	4.0
	Congested		150	9.0	9.6	10.5
			200	11.3	11.8	12.4
			250	13.2	14.1	14.7
Other Principal Arterial	Average Conditions		150	1.9	2.2	2.4
			200	2.0	2.2	2.6
			250	2.4	2.7	3.2

Intersections

If a tractor with an engine of insufficient capacity is used to provide motive power for a longer and heavier truck operating under size and weight limits of the Western Uniformity Scenario, the vehicle could take more time to accelerate into the traffic stream from a complete stop at a stop sign or a signalized intersection than the alternative Status Quo vehicle. The Western Uniformity Scenario increases off-Interstate weight limits for RMDs in nine of the thirteen States studied. In addition, Scenario RMD length limits increase in two of the nine States with increased RMD weights. [37]

Off-Interstate intersections pose potential challenges for increased RMD weight and length. Heavier and longer trucks turning onto an intersecting roadway, or crossing an intersection from a stopped position, will take longer to get up to traffic-flow speed or to clear the intersection than a lighter, shorter vehicle unless the vehicle horsepower is increased proportionately to maintain acceleration rates. Any additional time spent accelerating to flow speed after a turn or crossing an intersection would increase the risk of collision for through vehicles approaching intersections where sight distances are limited by physical features such as curves, hills, signage and foliage. LCVs crossing intersections from a stopped position could increase the distance required for the driver of a vehicle in cross traffic to see the truck and bring the vehicle to a stop to avoid a collision by up to ten percent.

The Western Uniformity Scenario mitigates or completely eliminates traffic impacts, relative to vehicles in the current fleet, related to the braking capability of trucks. Scenario weight limits for individual axles and axle groups are restricted to Federal limits, the same as Status Quo limits. For freight shifts from one configuration to another – for example from a 5-axle tractor-semitrailer at 80,000 pounds to a 9-axle TPD at 129,000 pounds – the gross vehicle weight per braking axle will generally decrease, thereby reducing braking demand on individual axle groups.

Passing on Two-Lane Roads

Cars passing RMDs on two-lane roads need up to 8 percent longer passing sight distances compared to passing tractor-semitrailer combinations. The Western Uniformity Scenario significantly expands the off-Interstate RMD's network in only four of the thirteen states – Oklahoma, Kansas, Nebraska and Colorado.[38] No-passing zones for the expanded off-Interstate portions of the RMD network in these four States would need to be reengineered to maintain the current level of safety of passing single-trailer combinations for passing RMDs.

For their part, longer and heavier trucks would also require longer passing sight distances to safely pass cars on two-lane roads. Of the remaining nine states not adding significant RMD network mileage, five would increase RMD weight limits. These five states would also need to reengineer no-passing zones to accommodate any degradation in truck acceleration during passing to maintain the current level of safety.

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[37] See Chapter II, Figures II-5 and II-6 for current weight and length limits in the study States.
[38] See Chapter II, Figures II-9 and II-14 for Rocky Mountain Double base case and scenario networks.

Aerodynamic Effects

Truck-generated splash and spray is sensitive to vehicle aerodynamics. Another aerodynamic effect is the buffeting of adjacent vehicles from air turbulence. Air turbulence around trucks is not increased with truck length or weight, but rather the front of the truck and gaps between the tractor and the semitrailer(s) it tows can be the source of a transient disturbance to adjacent vehicles, especially if they are operating in substantial crosswinds. Double-trailer combinations have two of these gaps, while triple-trailer combinations have three.

As previously discussed, the thrust of the Western Uniformity Scenario is to harmonize weight limits in the western States where LCVs are already allowed. The impacts of aerodynamic effects would not be as much from LCVs being allowed on additional roadways, as it would be from the increased VMT of LCVs and the increased exposure of other vehicles to LCVs. States might consider weather related restrictions on LCV operations, or examine existing ones for revision, if the Western States were to proceed with harmonization.

Offtracking

As with aerodynamic effects, most impacts related to offtracking will be due to increased LCV VMT and not to the introduction of new vehicles. Offtracking measures how well a vehicle "fits" the dimensions of the existing highway system. There are three different types of offtracking that measure the configuration/roadway fit. They are: (1) low-speed offtracking; (2) high-speed offtracking; and (3) dynamic high-speed offtracking. Low-speed offtracking occurs when a combination vehicle makes a low-speed turn – for example at a 90-degree intersection – the wheels of the rearmost trailer axle follow a path several feet inboard of the path of the steering axle. If excessive, this phenomenon may force the truck to swing wide into adjacent lanes to avoid climbing inside curbs or striking curbside objects. Excessive offtracking can disrupt traffic operations or result in shoulder or inside curb damage at intersections and interchange ramp terminals.

High-speed offtracking is the swing out of the rear combination vehicle going through a gentle curve at high speed. Dynamic high-speed offtracking is a swinging back and forth due to rapid steering inputs.

Although these measures relate to a vehicle's operations with traffic, a full discussion of offtracking is presented in Chapter VI, Roadway Geometry, since the roadway curves and intersections dictate how well a vehicle performs.

Assessment of Scenario Impacts

It is not possible to definitively estimate the impacts of the policy scenario on traffic, Level of Service, highway user delay, congestion costs and safety; however these issues can be qualitatively discussed. The *CTS&W Study* Volume III presented quantitative estimates for the congestion impact for each scenario, but unfortunately, the congestion model is not applicable to the Western Uniformity Scenario because the model does not allow for analysis at less than a national level. The model uses the aggregate national delay derived using PCE values, traffic counts and roadway capacity. The model then applies changes in VMT for the alternative configurations' PCE values to estimate the change in delay.

Also since the *CTS&W Study* Volume III, there have been changes to the FHWA congestion estimation technique. The new, more empirical approach measures the delay in 75 urbanized areas during peak travel periods as developed by the Texas Transportation Institute. To appropriately apply the urban delay data to changes in the scenario's VMT one would need to determine the number of trucks traveling through the urbanized areas during peak travel times. This is difficult since most long-haul trucks try to avoid city centers at peak travel periods and may entirely avoid urban areas enroute from origin to destination.

Table VIII-3 gives some estimates for the congestion among the analyzed States. Both the Seattle-Everett and Portland-Vancouver areas rank among the 10 most congested urban areas in the country.

Table VIII-3
Percent of Congested Travel for 13 Analyzed States, Year 2000

Urban Area	Percent of Travel that is Congested in Peak Period	Percentage of Daily Travel that is Congested
Seattle-Everett, WA	79	39
Portland-Vancouver, OR, WA	76	38
Denver, CO	75	38
Las Vegas, NV	65	32
Tacoma, WA	62	31
Salt Lake City, UT	51	26
Colorado Springs, CO	38	19
Eugene-Springfield, OR	33	16
Kansas City, MO-KS	30	15
Salem, OR	30	15
Tulsa, OK	29	14
Spokane, WA	26	13
Boulder, CO	24	12

Source: 2000 Urban Mobility Study, Texas Transportation Institute.

Figures VIII-1 and VIII-2 show that, without any change to truck size and weight, congestion is projected to grow for the Western Uniformity States. This is especially true in coastal Washington and Oregon, Denver and I-80 through Wyoming and Nebraska. It is noteworthy that in the Denver and Seattle/Tacoma areas long doubles are not presently allowed during peak travel times and the scenario assumes that those restrictions would continue. However, because of the shift of some freight to the more productive scenario trucks, thereby reducing total truck VMT, even with these exceptions, one would expect a slight decrease in delay for the 13 States under the Uniformity Scenario. In fact, it appears that the scenario is predicted to at least not degrade and perhaps even improve traffic operations in a small way across all impacts. However, for some of the impacts, this is based on the assumption that increased engine power is available for those configurations with increased gross vehicle weights. Table VIII-4 summarizes the results.

Table VIII-4 Western Uniformity Scenario Traffic Impacts

Impact	2000 (base case)	2010 (scenario)
Traffic Delay (million vehicle-hours)	National Total 3,599*	Small decrease
Congestion Costs ($ million)	National Total $67 billion***	Small decrease
Low-Speed Off-tracking		Degradation (28 – 30 feet** for turnpike double versus 16 feet for semitrailer)
Passing		Requires operating restrictions.
Acceleration (merging and hill climbing)		Requires sufficient engine power.
Lane Changing		Some degradation due to additional length. (This is counterbalanced by decrease in heavy truck VMT.)
Intersection Requirements		Some degradation due to additional length. (This is counterbalanced by decrease in heavy truck VMT.)

*Computed by Texas Transportation Institute as the aggregate for 68 urban areas (not comparable with Comprehensive Truck Size and Weight Volume III).
**28 feet off-tracking for twin 45-foot TPDs and 30 feet off-tracking for twin 48-foot TPDs.
***Estimated for 75 largest urban areas.

Figure VIII-1 Truck Volumes, Estimated Congested Segments – 1998

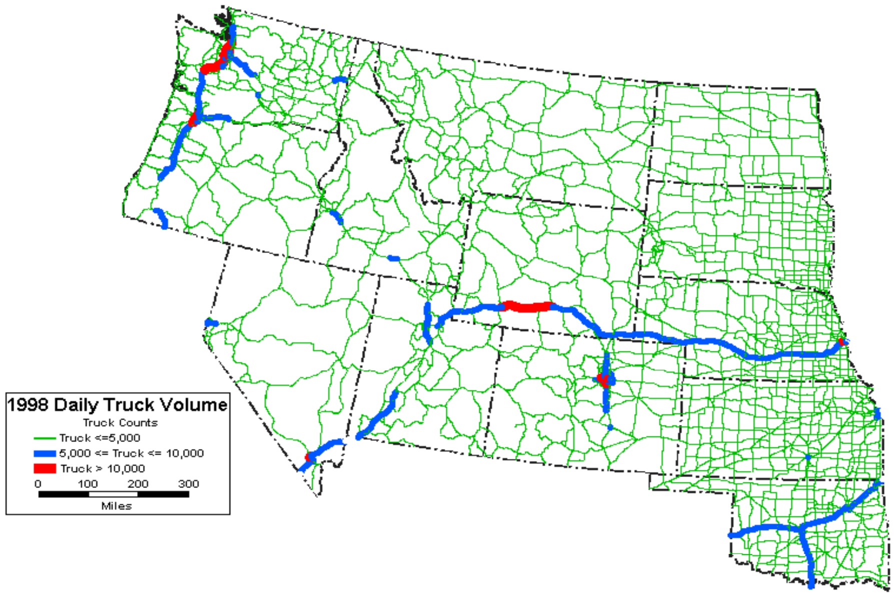
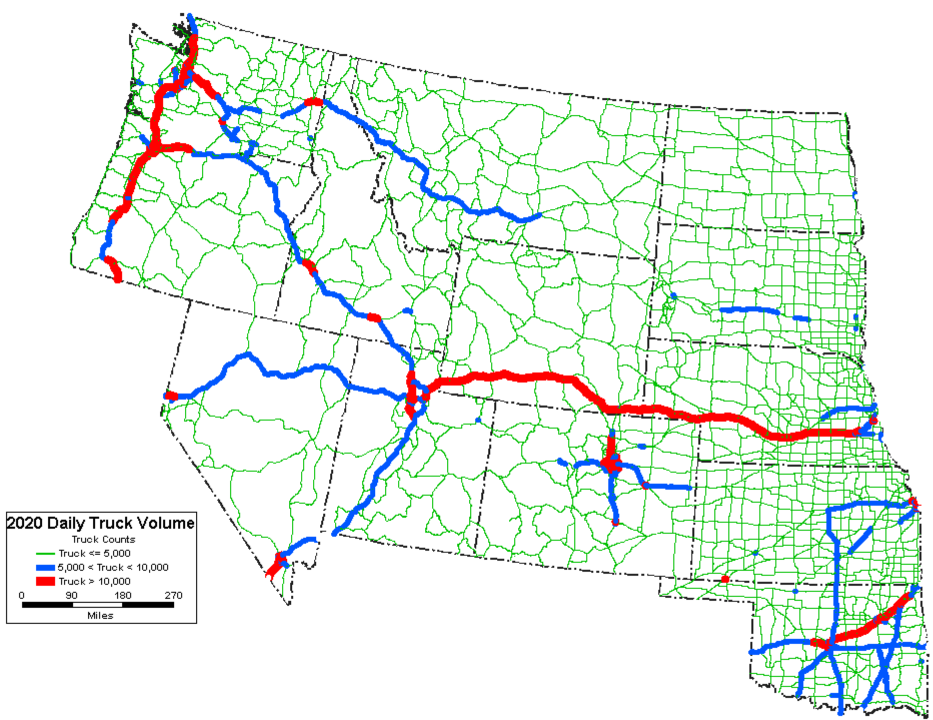
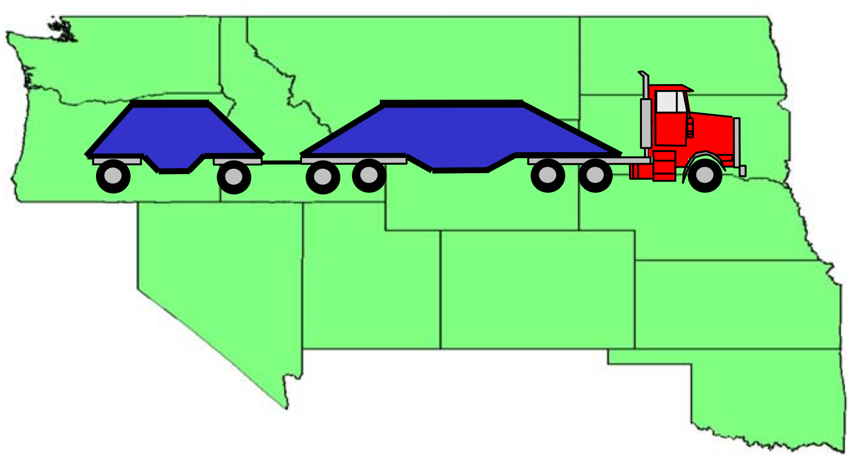


Figure VIII-2 Truck Volumes, Estimated Congested Segments – 2020
No Change in Size and Weight Regulations



CHAPTER IX

Energy & Environment



Western Uniformity Scenario Analysis

Introduction

Changes in truck sizes and weights will impact energy consumption, air quality, global warming, and noise emissions. The magnitude of each of the four areas is influenced by the extent of truck travel, vehicle weight, speed, and other truck operational parameters. This chapter discusses how estimated changes in truck travel resulting from the Western Uniformity Scenario might affect each of these four areas. The overall reduction in VMT is expected to result in an overall reduction in energy consumption and emissions.

Noise emissions are very localized. They can be measured in terms of the impact of the noise on residential property values. To be affected, residences must be immediately adjacent to a high volume roadway; the denser the residential development, the greater the total impact. The cost of noise is estimated based on the estimated residential density adjacent to freeway sections, as reported in the Highway Performance Monitoring System (HPMS) database and on changes in noise levels caused by changes in truck VMT resulting from truck size and weight (TS&W) policy changes.

Air pollution impacts are highly dependent on meteorological conditions and to a lesser extent on geographic features that cause air stagnation. Air pollution tends to be regional with some long distance conveyance in the lower levels of the atmosphere. Air pollutant emissions are related to VMT, but the transformation of those emissions into secondary pollutants involves complex chemical processes that may vary considerably from area to area depending on other sources of pollution in the area, climatic factors, and other variables.

Estimating total nationwide economic costs of air pollution attributable to motor vehicles is complex. The Department collaborated with the Environmental Protection Agency (EPA) to develop a nationwide cost estimate in connection with the *1997 Highway Cost Allocation (HCA) Study*. Resource constraints prohibited development of such estimates for the illustrative scenarios in the *CTS&W Study*. In general, the reduction in truck VMT under the Western Uniformity Scenario would reduce air pollution costs, but changes are not proportional to changes in VMT, particularly at specific locations. However, changes in truck emissions would be largely proportional to changes in VMT.

Analytical Approach

Energy Consumption

Table IX-1 illustrates how fuel consumption varies with truck configuration and weight. It shows that a longer configuration at the same weight does not necessarily have a higher rate of fuel use. Inherent for each truck configuration is the selection of the most efficient engine for that configuration and use. Fuel use information developed for the *1997 HCA Study* provided the basis for the analysis of annual energy consumption associated with the introduction or elimination of particular vehicle configurations and weights. Although the fuel efficiency values used here do not reflect the more stringent 2004 EPA emissions regulations, it is expected that the differences in miles-per-gallon from one configuration to another and from one weight to another for engines meeting those regulations will be similar to the differences shown here.

A configuration's impact on diesel fuel use depends on its miles of operation at its given weight, speed, and roadway grade. For this study, each configuration is assumed to operate at the same speed under the same conditions. It is important to note that fuel use does not increase on a one-to-one relationship with vehicle weight.

Base Case VMT for the Year 2010 by truck type and operating weight was multiplied by gallons-per-vehicle-mile-of-travel estimates to estimate total truck fuel consumption. The same was done for the Scenario's VMT estimates. The difference measures the fuel consumption impact of the Western Uniformity Scenario for the 13 analyzed States.

Table IX-1
Miles per Gallon by Truck Configuration and Weight

Configurations	Gross Vehicle Weight (pounds)				
	60,000	80,000	100,000	120,000	140,000
Five-Axle Semitrailer	5.44	4.81	4.31		
Six-Axle Semitrailer	5.39	4.76	4.27		
Five-Axle STAA Double	5.95	5.29	4.79		
Seven-Axle Rocky Mountain Double		5.08	4.58	4.36	4.16
Eight-Axle (or more) Double		5.08	4.82	4.58	4.36
Triple-Trailer Combination		5.29	5.01	4.76	4.54

Air Quality

As noted above, relating changes in truck travel to changes in nationwide economic costs of air pollution is complex and resource intensive. Furthermore, effects in any specific location could be very different from effects estimated for the Nation as a whole. As indicated earlier, DOT is working with EPA to develop an air quality impact methodology based on the best and most current information available.

Important factors in estimating changes in air quality costs are the dollar values assigned to mortality (death), morbidity (illness), visibility impairment, soiling, materials damage, effects on plants and wildlife, and other impacts caused by air pollutants. These are extremely difficult to quantify in terms of their effects and wide ranges of costs have been estimated in previous studies. Furthermore, our understanding of the health effects of various pollutants continues to evolve, and thus estimates of motor vehicle related air pollution costs must be periodically updated to reflect the latest scientific knowledge. A key issue that will be the subject of future research is the relationship between vehicle weight and emissions. The EPA's models currently do not differentiate among the vehicle classes of interest in TS&W policy options.

Noise Emissions

Truck noise comes from three sources—the engine (as a function of engine revolutions per minute), the exhaust pipe (particularly from the use of engine compression brakes), and tires (tire noise increases significantly with speed and begins to dominate other truck noise sources above 30 miles-per-hour). Truck noise begins to dominate noise from other traffic once trucks account for more than 3 percent of the traffic. For example, to produce a noticeable difference in highway noise, such as a decrease of 2.5 decibels, the percentage of trucks in the traffic stream would have to drop from 20 percent to 5 percent of all traffic. The cost per noise equivalent was estimated for each vehicle class based on a synthesis of research findings from other studies.

The DOT has developed models for evaluating impacts of traffic-related changes in noise levels. These models served as the basis for the noise emission cost calculations for the *HCA Study* and *CT&W Study*.[39] Using passenger cars as the base, noise equivalency factors were determined under differing operating circumstances for each vehicle class and weight group. Noise equivalency factors for trucks relative to passenger cars are shown in Table IX-2. These cost per noise equivalent were estimated for each vehicle class based on a synthesis of research findings from other studies.

Table IX-2
Noise Passenger Car Equivalents for Trucks

Vehicle Type	Speed				
	20	**30**	**40**	**50**	**60**
Passenger	1.00	1.00	1.00	1.00	1.00
Truck	84.85	43.82	27.42	19.06	14.16

Noise-related costs are only estimated for freeway travel. There are several reasons why the analysis was limited to freeway travel including: (1) virtually all studies used as background for the cost estimates were limited to freeway locations, and (2) except in commercial areas where there are many other sources of noise, truck volumes in urban areas are relatively low.

Exhaust Emissions

There has been little past research on relationships between vehicle size and weight and emissions. Changes in overall truck volumes under the scenario are not likely to cause significant changes in speeds or other traffic characteristics that affect emissions rates. The primary factor that would cause emissions to change is the change in total truck volumes and the change in traffic composition with more LCVs and fewer conventional trucks. Since other environmental, technological, and geographical factors that might affect emissions are assumed to be the same for the base case and the scenario, it is assumed for purposes of this study that total emissions vary directly with changes in fuel consumption. This is consistent

[39] See those studies for further information and documentation of the noise emission model.

with methods used by the Environmental Protection Agency to estimate heavy truck emissions in its Mobile 6 model.

Scenario Impacts

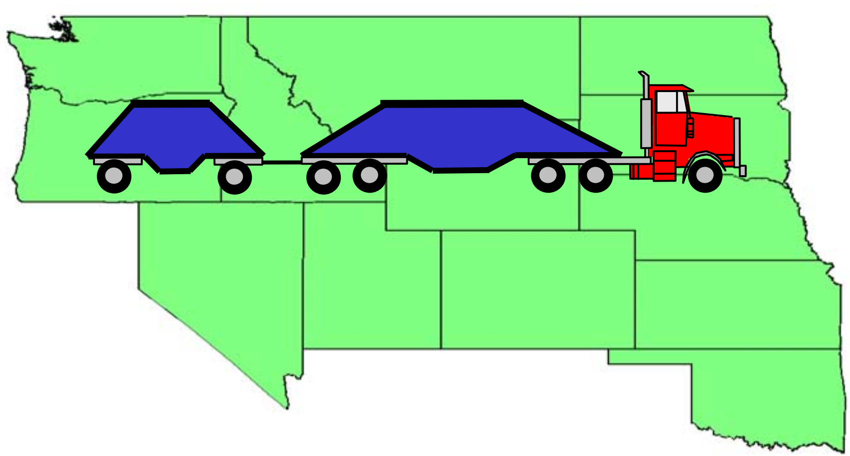
Table IX-3 shows the impact of the scenario, both high- and low-cube cases, for energy consumption, emissions and noise costs. As mentioned previously, air pollution costs for the scenario could not be estimated within the scope of this study, therefore the impact table shows that these costs are not available (NA).

Table IX-3
Energy and Environment Impacts for 13 Analyzed States

Impact	Base Case	Low Cube – Change from Base Case		High Cube – Change from Base Case	
		Absolute	Percentage	Absolute	Percentage
Energy Consumption (million gallons)	5,084	4,921	- 3.20%	4,471	- 12.06%
Emissions			-3.20%		-12.06%
Air Pollution Costs	NA	NA	NA	NA	NA
Noise Cost ($ millions)	$539	$532	- 1.43%	$487	- 9.67%

CHAPTER X

Rail



Introduction

Railroads, motor carriers, barge, and pipeline are the major modes of transportation for moving intercity freight throughout the nation. Rail and motor carriage account for the greatest share of total freight tons and revenues, with motor carriers accounting for 90 percent of the combined rail and truck revenue share.[40] Railroads handle significantly more bulk traffic such as coal and chemicals than trucks, but compete with trucks for certain high value commodities, primarily through intermodal service offerings.

As discussed in the Department's *Comprehensive Truck Size and Weight (CTS&W) Study*, increases in truck sizes and weights change the economics of truck-rail competition by providing new opportunities for truck productivity improvements. Allowing heavier payloads reduces truck transportation and other logistics costs facing the shipper. To the extent that the trucking industry is able to offer shippers lower total logistics costs, shippers will tend to shift freight that currently moves by rail to the larger, heavier trucks. Because rail is a decreasing cost industry (See Figure X-1) with high fixed costs, loss of traffic will necessarily require spreading those costs across a smaller traffic base, increasing the rail unit cost for handling the remaining traffic. Consequently, shippers remaining on the railroad may face higher rail rates, and to the extent that is the case the net national shipper cost saving attributable to productivity improvements of larger trucks will be reduced.

Figure X-1
Decreasing Cost Industry

> Railroads are a decreasing cost industry because they face high fixed and common costs to maintain an extensive network, including the costs of right-of-way acquisition, roadbed preparation, installation of track and signals, etc. This network must be in place before any freight can move.
>
> Once an initial investment has been made to provide a given level of capacity, per-unit-costs decline as production increases up to capacity. As output increases to that point, per unit fixed costs and common costs decrease because they are spread over more and more units. Conversely, as railroad traffic shrinks, fixed and common costs are spread over a smaller traffic base, resulting in higher costs per unit.

The Western Uniformity Scenario studied in this report is analyzed in this chapter by estimating the effects on railroads' financial condition when new LCV configurations, TPDs, RMDs, and triples are more generally permitted in the identified Western States.[41] The analysis measures the financial impact on the nation's Class I rail industry as a whole, and separately on the two western carriers that would be affected the most – the Burlington Northern and Santa Fe Railway Company (BNSF) and the Union Pacific Railroad Company (UP). The analysis considers both the shorter doubles (low-cube case) and the longer doubles (high-cube case) - triples are permitted in both cases.

[40] Transportation in America: A Statistical Analysis of Transportation in the United States, 19th edition, p. 28.
[41] See Chapter II for a complete discussion of both cases and the states in which they are allowed to operate.

Overview of the Class I Railroad Industry[42]

In 2000, the data year for this study, the freight railroad industry produced a record 1.47 trillion ton-miles that generated revenue of $34.1 billion, despite the fact that revenue yield fell to 2.26 cents per ton-mile - a level 15.1 percent lower in nominal dollars, and 30.7 percent lower in real dollars than in 1990.[43] Eight major railroad systems accounted for 91 percent of the industry's total revenue.

The Class I railroad industry is in comparatively better financial condition today than in previous decades, having addressed serious structural problems, upgraded plant and facilities, and taken advantage of technological improvements to better serve customers. Net revenues after operating expenses reached $5.1 billion in 2000, and net income, a measure of profitability, totaled $3.9 billion. The industry operating ratio (expense/revenue) was 85.2, providing an indicator of how efficiently costs were managed. Nevertheless, the industry's return on investment (ROI) was only 6.5 percent, reflecting a continuing decline in ROI since registering a high of 9.4 percent in 1996.

Profile of Study Carriers

As noted above, the principal carriers affected by the Western Uniformity Scenario are the BNSF and the UP - the two Class I railroads that traverse the geographic region of the study. In 2000, these two rail systems accounted for 55 percent of total industry miles of railroad operated, originated over 51 percent of industry carloads, and generated 58 percent of industry revenues. Principal commodities handled by these carriers are coal, chemicals, grain, and intermodal traffic.

The UP is the larger of the two railroads, owning nearly 29,000 miles of road and operating over an additional 4,000 miles of road through trackage rights. The somewhat smaller BNSF owns close to 26,000 miles of road, but operates over a total of about 33,400 miles with trackage rights included. UP originated nearly 7.4 million carloads and BNSF originated 6.9 million carloads in 2000. This traffic generated more than $10.5 billion in operating revenue for UP, and $9.2 billion for BNSF. BNSF's ROI at 8.1 percent, topped UP's 6.6 percent ROI.

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[42] In 2000, the Surface Transportation Board defined a Class I railroad as one having annual operating revenues greater than or equal to $261.9 million. The threshold is adjusted annually for inflation. The eight Class I railroads are BNSF, CSX Transportation, Grand Trunk Western Railroad, Illinois Central Railroad, Kansas City Southern Railway, Norfolk Southern Railroad, Soo Line Railroad, and UP.

[43] The major rail-carried commodities (in terms of ton-miles) included coal (35 percent), intermodal traffic (trailers and containers on flat cars or well cars) (15 percent), chemical products (10 percent), and farm products (predominantly grain and soybeans) (9 percent). The fastest growing segment of rail traffic has been intermodal traffic, with the number of trailers and containers increasing substantially from an average of 3.4 million loadings in the early 1980's, when doublestack container trains were introduced, to 9.2 million in 2000. The highest traffic corridor for intermodal traffic is between California and Illinois reflecting the land portion of container shipments between the U.S. and Asia's Pacific Rim. This traffic is handled by the BNSF and the UP, which are the subject railroads of the current analysis.

Methodology

This section describes the procedure for estimating financial impacts on the rail industry, and the two western carriers, due to diverted rail shipments, and carrier rate reductions to retain shippers' traffic on the railroad. The objective of the analysis is to compute revised industry and study railroads' balance sheets for the year 2010 and reflect the effects of the scenario's low-cube and high-cube cases. Measures of impacts on revenues, freight service expense (FSE), contribution to overhead and profit, and ROI are assessed.

The rail impact analysis employed two models - the DOT's Intermodal Transportation and Inventory Cost (ITIC) Model (discussed in Chapter III) and an Integrated Financial Model. Exercising these models required that data for the analysis be extrapolated from the year 2000 to the Study Year 2010. To accomplish this, rail traffic growth rates developed from the Freight Analysis Framework (FAF)[44] were applied to the following data sources: 1) Class I railroad financial and operating statistics in the *Analysis of Class I Railroads—2000*;[45] and 2) the 2000 Surface Transportation Board's (STB's) Carload Waybill Sample (CWS).

Traffic and revenue diversions used to assess rail impacts were derived from the ITIC Model. Using the forecast 2010 rail freight flows of the CWS as a base case, the ITIC Model estimates shipper transportation and inventory costs for moving the freight by rail and by the competing truck configurations. The ITIC model assumes that railroads respond to increased truck productivity by reducing their own rates - down to variable cost if necessary - to prevent diversion of rail freight traffic to trucks.[46] If motor carriers can offer shippers lower transportation and inventory carrying costs than rail variable cost plus inventory carrying costs, the model predicts that the railroad will lose the traffic and the shipments divert to truck. This assumption produces a conservative estimate of diverted rail traffic.

As truck transportation costs decrease, the rail industry will experience three separate but related post-diversion effects:

1. Fewer rail shipments will reduce rail revenue.
2. As the railroads offer discounted rail rates to shippers to compete with motor carriers, additional revenue will be lost.
3. As rail ton-miles decrease due to losses in traffic, the unit (ton-mile) costs of handling the remaining freight traffic will increase.

It is important to note that for diverted traffic, railroads lose revenue and some costs. When discounting rates to hold traffic, railroads lose revenue but all costs remain. The effects

[44] Growth rate estimates for traffic volumes, both rail and truck, for the Year 2010 were developed from the FAF. For rail, the growth rates from the FAF were applied to the 2000 rail waybills by corridor and commodity. To expand 2000 ton-miles, revenue, and FSE to the Year 2010, a traffic-weighted average of these rail growth rates was applied to the *Analysis of Class I Railroads—2000* base year data.

[45] As compiled by the Association of American Railroads (AAR) from R-1 reports submitted by the railroads to the STB.

[46] The rail rates used in the analysis were the actual, or unmasked, rates resident in the STB's "highly confidential" CWS file. To protect their confidentiality, the STB performed the analysis for DOT.

listed above were measured for both low- and high-cube cases using two key ITIC Model outputs: 1) the remaining rail revenues after accounting for losses in revenues from both diversion and from rate discounting to hold traffic; and 2) the remaining post-diversion rail ton-miles. Percent changes from the 2010 base case revenues and ton-miles were calculated using these outputs for each study scenario, and applied to the comparable financial and operating statistics in the Association of American Railroads' (AAR), *Analysis of Class I Railroad 2000* (grown to the Year 2010). The adjusted AAR data on revenues and ton-miles were subsequently used as inputs to an Integrated Financial Model. The financial model uses measured changes in income statement variables - revenues, expenses, income, and cash generated and expended to produce revised industry, and study railroad balance sheets that reveal the effect of the lost revenues and ton-miles on the railroads' financial condition.[47]

The revised Balance Sheets reflect a new rail cost resulting from traffic diversion (freight service expense (FSE) in the AAR data). To calculate the reduction in FSE, the model applies a cost elasticity coefficient that measures the change in cost associated with a change in ton-miles.[48] For the rail industry the cost elasticity used is 0.6264, reflecting that as railroads lose traffic, costs do not decrease in a one-to-one relationship with ton-miles. Rather, railroads shed costs much more slowly because of the high fixed and common cost components of total cost that characterize the industry. To illustrate, if there were a 10 percent decline in rail ton-miles, the application of the 0.6264 elasticity coefficient indicates that freight cost (FSE) would only decline by about 6.3 percent. As a consequence, the cost to handle the remaining traffic in terms of cost per ton-mile would increase in the post-diversion case. This increased cost for remaining rail traffic can be thought of as a partial offset to calculated shipper cost savings found for rail shippers shifting to trucks as a result of the two cases, yielding the net national change in shipper costs.

The cost elasticities applied in the analysis for the industry and the Study railroads are noted in the Table X-1.

Table X-1
Industry and Railroad Cost Elasticities

Railroad	Elasticity
Industry	0.6264
Burlington Northern Santa Fe	0.6632
Union Pacific	0.7113

[47] The Integrated Financial Model was also used to calculate the post-diversion railroad ROI. For a complete discussion and overview of the model see the *CTS&W Study*, Volume III, Scenario Analysis, Chapter XI.

[48] The cost elasticity coefficient(s) used for the industry, and the separate railroads, were derived by John Bitzan of the Upper Great Plains Transportation Institute under FRA sponsored research, and published in the 2000 report, *Railroad Cost Conditions — Implications for Policy*. The report is available at http://www.fra.dot.gov/downloads/policy/rr_costs.pdf.

Study Caveats

The results of the rail impact analyses are generally plausible but some bias may have been introduced due to data restrictions and, more importantly, because of assumptions made concerning present and future conditions in freight transportation. These assumptions are reflected in the growth rates applied to rail traffic volume.

The railroad industry has experienced large productivity gains since its partial deregulation in 1980. For the purpose of this study, the issue is whether those gains will continue to 2010, and whether the analysis should take account of them. Our review found a consensus among observers of the rail industry that the railroads have virtually exhausted the efficiencies that can be wrung from their existing plant, and significant future productivity gains will require massive infusion of capital investment. Whether, and to what extent that capital investment will be made is highly uncertain, particularly if there is erosion of railroad financial viability. In any case, while stepped up investments will be made to accommodate 2010 traffic (and were included in the Financial Model), efficiency or productivity gain is expected to significantly lag the industry's performance in past decades. Therefore, it can be concluded that the effect on the rail impact results using a static productivity assumption are minor.

As previously noted, the cost elasticity applied to the Class I Railroad industry is 0.6264. It was developed, along with individual railroad elasticities, in an econometric analysis of the industry based on *Railroad R-1 Report* data from 1978 through 1998. The issue is whether the coefficient can be applied credibly to data for the Year 2010, *i.e.*, to what extent will the coefficient change in the intervening years? While the precise change in the elasticity coefficient is unknown, we believe any change in the Study's impact measurements would be insignificant. Table X-2 shows the results of eight studies stretching from 1974 - 2000, where different researchers calculated the elasticity of cost with respect to changes in rail output. In general, the elasticity coefficients have not changed significantly over a period of more than twenty-five years. Therefore, for the purpose of this Study, and calculation of rail financial impacts, use of the 1998 cost elasticity coefficient is unlikely to have a substantially misleading effect on the outcome.

Table X-2 Railroad Cost Studies

Study	Returns to Density**	Cost Elasticity
Keeler (1974)	1.79	0.5586
Harris (1976)	1.72	0.5813
Harmatuck (1979)	1.92	0.5208
Friedlaender & Spady (1981)***	1.16	0.8620
Caves, Christensen, Tretheway, & Windle 1985)	1.76	0.5681
Berndt, Friedlanender, Chiang, & Velturo (1993)	1.57	0.6380
McCullough (1993)	1.64	0.6101
Bitzan (2000)	1.60	0.6264

* Gerard J. McCullough, *A Synthetic Translog Cost Function for Estimating Output Specific Railroad Marginal Costs*, p 4, October, 1993. (We have taken the liberty of expanding McCullough's original table by including the elasticities from his study and the most recent elasticities from Bitzan.

** Returns to density for all of the studies except Berndt et al. are reported in Caves et al. (1985). Elasticity of cost with respect to output is the inverse of returns to density.

*** McCullough notes that early work by Friedlanender & Spady (1981)was subsequently revised downward, which corresponds more closely with the other cost elasticities in the table.

Results

Base Case

Table X-3 illustrates the total freight revenues, FSE, contribution, and ROI for the industry and the two western carriers for the base case. The base case applies the 2000 revenue per ton-mile for CWS shipments to the estimated Year 2010 ton-miles, providing estimates in terms of constant 2000 dollars. For the industry, freight revenues would be $43.2 billion. FSE incurred for moving the traffic would be $37.8 billion. Contribution at less than $5.5 billion is the difference between revenue and freight service expense. It represents the amount available to cover fixed cost, income taxes, shareholder profits, and capital investment to improve and maintain the plant to continue to meet customers' demands. Because contribution is closely linked to ROI, changes in contribution are an important measure of the impact of the scenarios on railroads' financial condition. ROI is the bottom line measure of a railroad's financial health because it affects access to financial markets. An insufficient ROI generally means that a railroad will not be able to marshal sufficient financial resources to replace capital assets over the long run.

Table X-3 Base Case
Revenues, Freight Service Expense, Contribution, and ROI
($, millions)

Railroad	Revenue	Freight Service Expense	Contribution	ROI (Percent)
Industry	$43,233.86	$37,755.30	$5,478.56	6.31%
Burlington Northern Santa Fe	$11,721.65	$9,309.85	$2,411.80	8.89%
Union Pacific	$13,182.53	$11,237.39	$1,945.15	6.67%

Low-Cube Case

Table X-4 illustrates, lost revenues, FSE, and contribution resulting from the analysis of the low-cube case. This case examines the effects on rail when twin 45-foot trailers, Rocky Mountain Doubles, and triple trailers are permitted on a larger continuous network. For the industry, the low-cube case would result in total lost revenues of $38 million, consisting of a $26 million loss from discounting as railroads reduced rail rates to retain traffic (if necessary to a variable cost floor), and $12.1 million lost revenue as traffic diverted to the truck configurations. Rail industry contribution would be depleted by nearly $35 million. Overall, the twin 45-foot trailer LCV accounted for nearly 70 percent of total revenue losses. On the other hand, none of the revenue losses were attributable to broader operation of the triples configuration.

Table X-4 Low-Cube Case
Lost Revenue, Freight Service Expense, and Contribution
($, millions)

Railroad	Revenues Lost from Diversion	Revenues Lost from Rail Discounting	Total Lost Revenues	Lost Freight Service Expense	Lost Rail Contribution
Industry	$12.09	$25.96	$38.05	$3.55	$34.50
Burlington Northern Santa Fe	$5.77	$9.94	$15.71	$0.99	$14.72
Union Pacific	$6.12	$15.51	$21.62	$2.16	$19.46

For the industry, the $12.1 million revenue lost to diversion is associated with only a $3.5 million reduction in FSE, illustrating the fact that railroads do not shed costs proportionately as revenues are lost.

Table X-5 shows the losses in ton-miles, revenues, FSE, contribution, and resulting ROI in percentage terms. Clearly, losses are small in each of the categories. For example, contribution only declined by 0.006 percent, while ROI for the industry only fell from 6.31 percent in the base case to 6.27 percent.

As expected, the western railroads experience the bulk of the losses since the cases examined fall entirely within their operating territories. For the low-cube case, BNSF's and UP's revenue losses makeup 98 percent of the total industry loss. The remaining losses would be spread among the other interline carriers. For BNSF, revenue losses total $15.7 million while UP's are down $21.6 million. Reductions in freight service expense for the two carriers are $988,000 and $2.2 million, respectively. For BNSF, contribution declines by 0.006 percent and ROI falls from 8.89 in the base case to 8.83 in the low-cube case. UP's contribution falls 0.01 percent and ROI declines to 6.61 from 6.67 percent.

Table X-5 Low-Cube Case
Ton-Miles, Freight Service Expense, Revenues from Operation, Contribution, and ROI
(percent change)

Railroad	Ton-miles	FSE	Revenues	Contribution	Post Diversion ROI
Industry	-0.015%	-0.009%	-0.088%	-0.006%	6.27
Burlington Northern Santa Fe	-0.016%	-0.011%	-0.134%	-0.006%	8.83
Union Pacific	-0.027%	-0.019%	-0.164%	-0.010%	6.61

High-Cube Case

Under this case, twin 48-foot LCVs, Rocky Mountain Doubles, and triple trailers are allowed to operate in the study region. Table X-6 shows the effects to the rail industry and the two western carriers resulting from the study vehicles.

Table X-6 High-Cube Case
Lost Revenue, Freight Service Expense, and Contribution
($, millions)

Railroad	Revenues Lost from Diversion	Revenues Lost from Rail Discounting	Total Lost Revenues	Total Lost Freight Service Expense	Total Lost Rail Contribution
Industry	$18.30	$47.85	$66.15	$5.20	$60.94
Burlington Northern Santa Fe	$7.42	$18.60	$26.02	$1.24	$24.79
Union Pacific	$10.48	$28.54	$39.02	$3.44	$32.91

The inclusion of a longer LCV configuration attracts more traffic off of the railroad, forcing them to discount rates more deeply to retain their current traffic moving in and through the region. For the industry, revenue losses totaled $66 million, with the western carriers losses of $65 million comprising over 98 percent of the total. The twin 48-foot configuration accounts for 80 percent of total revenue losses. Freight service expense dropped by $5.2 million for the industry and $1.2 and $3.4 million for BNSF and UP, respectively. Again, none of the losses were attributable to triples operations.

Table X-7 illustrates the percentage changes in ton-miles, revenues, freight service expense, contribution, and ROI. For the industry and BNSF, contribution fell by 0.01 percent with UP's falling by 0.018 percent. ROI for the industry dropped to 6.25 from 6.31 in the base case. For BNSF, ROI fell from 8.89 to 8.80, and UP's to 6.56 from 6.67 in the base case.

Table X-7 High-Cube Case
Ton-Miles, Freight Service Expense, Revenues from Operations,
Contribution, and ROI
(percent change)

Railroad	Ton-miles Percent Change	FSE Percent Change	Revenues Percent Change	Contribution Percent Change	Post Diversion ROI
Industry	-0.022%	-0.014%	-0.153%	-0.011%	6.25%
Burlington Northern Santa Fe	-0.020%	-0.013%	-0.222%	-0.010%	8.80%
Union Pacific	-0.043%	-0.031%	-0.296%	-0.018%	6.56%

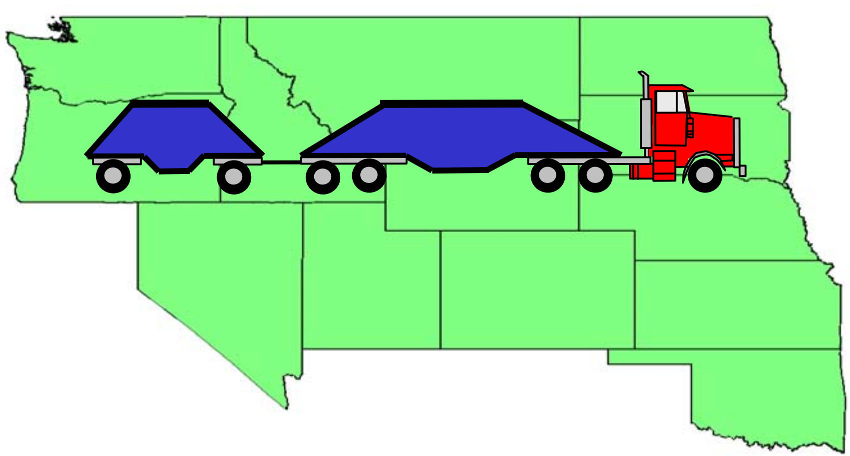
Conclusion

The analysis above estimates the traffic and financial effects that the low-cube and high-cube cases would have on the financial condition of the railroad industry and the two study carriers. As expected, the industry changes in ROI and loss of contribution are small when compared with the effects of the nation-wide LCV scenario analyzed in the *CTS&W Study*—where ROI fell from 9.8 to 5.3 percent and contribution fell by $3.1 billion. Most significant, when compared with the *CTS&W Study*, is the loss in revenues from rail rate discounting to retain traffic, relative to revenue losses from traffic diversion. In the *CTS&W Study*, the loss in revenues from diversion consistently represented a larger share of the revenue losses—generally running 3.5 times greater than that from rate discounting. Here the results are reversed with revenue losses from rate discounting running over 2.5 times the losses from traffic diversion. While an analysis explaining the difference in these results is beyond the scope of this study, it is hypothesized that the geographic boundaries of the scenario studied are largely responsible. Most of the traffic the two western railroads carry originates, terminates, (or both) outside of the scenario States studied. Competing truck traffic, consequently, originates/terminates outside of the scenario States as well—requiring transloading of cargos at State borders to and from conventional configurations and LCVs. The transloading requirement clearly erodes some of the LCV productivity gains—enough that railroads are forced to discount rates, but not so deeply that a large proportion of the affected traffic is diverted to the LCVs.

Although losses to the carriers appear small, as with any business entity, railroads would attempt to make adjustments to return ROI and contribution to levels that were present in the base case. Most likely this would be accomplished through reduced investment and/or increases in the service adjusted rate to rail shippers, particularly those shippers on the BNSF and the UP.

CHAPTER XI

Conclusions



Study Conclusions

Longer combination vehicles have been operating in 13 Western States for many years. Size and weight limits in those States vary as does the extent of the highway network on which LCVs can operate. Some of these differences are due to federal truck size and weight limits, especially grandfather rights under which States can allow vehicles exceeding 80,000 pounds to operate on Interstate Highways. But some of these differences also reflect differences among the States in the vehicle weights and dimensions they believe are appropriate for their highway systems. If States were given the flexibility to increase their truck size and weight limits to levels assumed in this scenario, some States immediately would take full advantage of this flexibility, others might change some but not all size and weight limits, and several might not change truck size and weight limits at all.

Like previous studies that have examined the potential impacts of changing truck size and weight limits, this study has estimated substantial shipper benefits from allowing more widespread use of LCVs. Other benefits from the changes in truck size and weight limits assumed in this scenario are reductions in fuel consumption, emissions, and noise-related costs. The full benefits estimated in this study likely would not be realized, however, because all States would not allow LCV to operate as widely as assumed in this study.

Infrastructure and related costs would not be as great as has been estimated in previous studies because LCVs already operate on at least some highways in each of the 13 States included in the analysis. Thus to a certain extent States have already considered LCV weights and dimensions in pavement, bridge, and geometric design. Nevertheless improvements costing several billion dollars were estimated to be needed to correct deficiencies in bridges, interchange ramps, and other highway elements just to accommodate existing truck operations. These deficiencies may not be severe enough to require immediate improvements, but in the long run would likely have to be corrected, especially if LCV volumes increased. If LCV operations expanded under assumptions in this scenario, added infrastructure costs could be from about $300 million to more than $2 billion. Several factors would affect the magnitude of these additional infrastructure costs including the extent to which States allowed larger LCVs to operate, the length limits imposed on double trailer combinations, and the extent to which bridges can be strengthened rather than replaced. Some States may continue to defer non-essential costs as they have done under current truck size and weight limits, but doing so ultimately may increase costs and could increase safety risks as well.

Few Western States charge fees that cover the infrastructure costs associated with LCV operations. The significant exception is Oregon that routinely conducts highway cost allocation studies to estimate the cost responsibility of various truck classes and adjusts truck-related fees according to results of those studies. When LCVs and other heavy trucks do not pay the full costs of their operations, other motorists must make up the difference. This is inequitable to the highway users who must subsidize LCV operations and contributes to an uneven playing field for railroads and other competitors. States already are experiencing budgetary problems as they look to improve the condition and performance of their transportation systems, and Federal Highway Trust Fund revenues to support the

Federal-aid highway program have been growing more slowly in recent years. Before any action is taken with respect to changes in truck size and weight limits that could increase highway improvement needs, plans for financing those improvements should be developed that include how the longer, heavier trucks responsible for additional costs would contribute to paying those costs. This is consistent with recommendations in the TRBs Special Report 267 in which it concluded, "federal legislation creating the (TRB's recommended) permit program should specify a quantitative test for the revenue adequacy of the permit fees imposed by states that wish to participate….Fees should at least cover estimated administrative and infrastructure costs for the program…"

Safety is always the issue of greatest concern when truck size and weight issues are considered. Data simply are not available upon which to develop reliable estimates of changes in the number of crashes or fatalities that might result from a change in truck size and weight limits such as the Western Uniformity Scenario. While some LCV operators claim the safety experience of LCVs is better than for the conventional vehicles they operate, these claims cannot be borne out for LCV operations as a whole. States in which LCVs operate have not noted particular safety problems with current LCV operations, but they have no formal processes in place to monitor safety. Since there are many uncertainties about the safety of substantially increased use of LCVs as might occur under the Western Uniformity Scenario, it would be prudent to require such processes before any substantial change in federal truck size and weight limits such as the Western Uniformity Scenario was implemented. In addition to monitoring the on-road safety of LCVs, processes might also be considered to ensure that the vehicles to be used meet some minimum thresholds for stability and control, and that companies operating these vehicles have good safety records and vehicle maintenance programs. One of the criticisms of TRB's recommended permit program was that it would involve conducting experiments with vehicles that were not known to be safe. To the maximum extent possible, assurances should be given that the vehicles to be used are at least as safe as vehicles on the road today and that the companies to be operating those vehicles have excellent safety records.

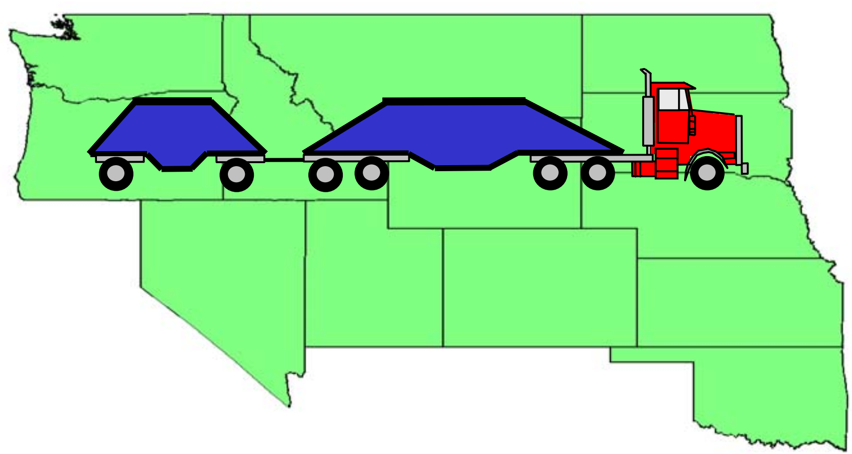
Nationwide, the Department believes that an appropriate balance has been struck on truck size and weight. Western States included in this scenario all can allow LCVs to operate at weights substantially above the 80,000-pound federal limit on Interstate Highways, and a number of other States can allow axle loads exceeding federal limits under grandfather rights. While the widely varying State laws appear to be inefficient, they are the result of political processes that have attempted to balance economic development concerns with concerns for safety and infrastructure protection. This balance has resulted in somewhat different size and weight limits from State to State, but these differences largely reflect factors unique to each State. The pattern of truck size and weight limits that has evolved over the years may not be optimal by any objective measure, but it does allow for some appropriate regional variation without compromising safety, which is the Department's highest priority.

Many proponents of change in truck size and weight limits point to TRB's recommendations in *Special Report 267* as a blueprint for a systematic process to more nearly optimize truck size and weight policy. However, aside from certain segments of the trucking industry and several States interested in truck size and weight increases, strong support for TRB's recommendations has not been evident. The Department has not taken a formal position on the TRB study, in part because it does not favor change in federal truck size and weight policy, but if changes were to be made, the Department believes that the kind of strong monitoring and evaluation that TRB recommends would be essential. Without support for the kind of comprehensive approach to truck size and weight policy and permitting practices recommended by TRB, there would be no mechanism to quickly identify safety or other problems that might arise.

In recent years a number of ad hoc, State-specific exemptions from federal truck size and weight laws have been enacted. For instance, TEA-21 contained special exemptions from federal size and weight limits in four States, Colorado, Louisiana, Maine, and New Hampshire. The Department does not support this kind of piecemeal approach to truck size and weight policy. It makes enforcement and compliance with truck size and weight laws more difficult, it often contributes little to overall productivity, it may have unintended consequences for safety and highway infrastructure, and it reduces the willingness to work for more comprehensive solutions that would have much greater benefits. A regional approach such as the Western Uniformity Scenario could have greater benefits than a series of individual exemptions, but it also could have much more serious adverse consequences unless closely monitored. Unless there were very strong support from State elected officials for a carefully controlled and monitored evaluation of changes in truck size and weight limits such as those in the Western Uniformity Scenario, the risks of adverse impacts from the unmonitored use of LCVs, the divisiveness that might ensue as the current balance in truck size and weight policy is upset, and the further polarization of this very contentious issue would outweigh the benefits that might be realized. Strong support from elected officials of States within the region for a change in truck size and weight limits has not been evident to date, and there is no compelling Federal interest in promoting changes that are not strongly supported by the affected States.

Appendix A

Federal Bridge Formula



This appendix describes in detail why, for example, a simple maximum gross vehicle weight (GVW) limit would not sufficiently protect bridges. It also shows for which types of bridges the Federal Bridge Formula B (BFB) works and for which types it does not.

Consider the following table. This table presents the analysis of two trucks of equal weight; one is a 72,000 pound four axle dump truck with an 18-foot wheelbase and the second is a 72,000 pound 5-axle tractor semitrailer with a 64-foot wheelbase. The sample bridges are simple span steel girder bridges with spans of 40, 60, 80, 100 and 120 feet. The values shown are the ratios of the moments of the selected truck to the HS20 vehicle.

Table A-1
Ratios of Moments of Selected Trucks Relative to the HS20 Vehicle

Span Length (feet)	4 Axle Dump Truck 72,000 lbs. Wheel base = 18 feet	5-axle Tractor Semitrailer 72,000 lbs. Wheel base = 64 feet
20	1.210	0.790
40	1.123	0.778
60	1.086	0.791
80	1.066	0.843
100	1.053	0.891
120	1.044	0.922

This analysis shows that using a straightforward GVW standard will not adequately protect bridges. For short spans the dumb truck produces a moment, and therefore a stress, 21 percent **greater** than the HS20 design vehicle and 53 percent (1.21 ÷ 0.79) **greater** than that of the "eighteen wheeler," even though the GVWs are identical. As expected, as the span length becomes greater, the difference between the two trucks decreases. However, more than 50 percent of the bridges nationwide have span lengths less than 60 feet.

Consequently, a better and fairer standard was needed. Federal Bridge Formula B (BFB) is a formula with which one can calculate the maximum allowable weight on any group of axles. It is function of the number of axles and axle spacing:

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

where:	W =	the maximum weight in pounds that can be carried by a group of two or more axles to the nearest 500 pounds
	L =	the distance between the outer axles of the group
	N =	the number of axles in the considered group

The concept of a bridge formula evolved a half a century ago, and it went through several revisions. Even before the Federal formula was implemented, a number States adopted this or a similar formula in the 1960s and early 1970s. As significant numbers of trucks began to get heavier, Congress established the national implementation of Formula B for Interstate highways in 1974.[49] At the same time Congress raised the maximum allowable Gross Vehicle Weight (GVW) on the Interstate system to 80,000 pounds the maximum single axle load to 20,000 pounds, and maximum tandem axle load to 34,000 pounds. In 1982 Congress prohibited any State from establishing a maximum GVW less than the Federal 80,000 pound "cap". By the mid-1980s effectively all the States established the Federal BFB, but some States allowed trucks to exceed the 80,000 pound cap on the non-Interstate systems as long as the trucks met BFB. Furthermore, a few States were allowed "grandfather" rights to allow trucks greater than 80,000 pounds on the Interstate system, usually for a relatively nominal annual permit fee. Nonetheless, most all States require even the "grandfathered" combination trucks to comply with BFB.

The guideline followed by the developers of BFB was that a typical HS20 rated bridge would not be overstressed by more than 5 percent by the typical combination truck with one trailer. At the time it was implemented, Formula B worked quite well in protecting the bridges on the Interstate system. It also worked quite well in keeping single unit trucks and single trailer combination trucks from damaging bridges in those States that applied the formula to the non-Interstate systems.

Although the analyses conducted in developing Bridge Formula B considered only simply supported superstructures,[50] the resulting formula was generally applicable since the lengths and weights of most trucks in the then current fleet did not differ significantly from the HS20 design vehicle, and because the structural capacity of continuous bridges to accommodate

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[49] FHWA only controls truck size and weight on the Interstate highway system and on Federal lands (national forests, national parks, etc.).

[50] A simply supported structure is one in which each beam between any two supports, in a structure with three or more supports, is independent, that is, not connected to successive beams. A continuous structure is one in which any one-beam spans, i.e. is *continuous*, over at least three supports.

typical single combination trucks is similar to that of simply supported structures subjected to these same loads. However, the moments caused by longer and heavier trucks on continuously supported bridges are much greater than the moments on simply supported bridges of equal rating and of equal span lengths.

To demonstrate this, consider the total (live load plus dead load) moments of seven different vehicles, assuming steel girder bridges, the single most common highway bridge type. The vehicles include the HS20 Short and HS20 Long design vehicles, a 73,280-pound 5-axle tractor semitrailer, an 80,000-pound 5-axle tractor semitailer, an 80,000-pound 5-axle tractor semitailer with a 53-foot trailer, a typical Rocky Mountain Double and a Turnpike Double, see Figure A-1. These vehicles were chosen because they represent typical single trailer trucks from both before and after the 1982 increase in the cap from 73,280 pounds to 80,000 pounds and before and after the increase in trailer length to 53-feet. Also included are two typical double trailer trucks, the Rocky Mountain Double and the Turnpike Double. All of these vehicles comply with Formula B.

Table A-2, presents the ratio of the moments of these selected vehicles to that of the HS20 (short) design vehicle for simply supported bridges and for 2-span and 3-span continuous bridges with spans lengths varying from 20 to 180 feet in 20 foot increments. The ratio in the fourth column is, of course, 1.0 because it is the ratio of the moments of the HS20 (short) design vehicle to itself (i.e., the inventory rating). Single trailer combination trucks do not overstress (i.e., the ratio is < 1.0) simply supported bridges for any span lengths. For continuously supported multi-span bridges, except as noted below, these conventional single trailer combinations weighing up to 80,000 pounds also cause no greater stresses than the HS20 design vehicle (i.e., the inventory rating). However, on continuous bridges with main spans in the 50-70 foot range, these combinations operating at 80,000 pounds have moments (and therefore produce stresses) up to 10 percent greater than the HS20 design vehicles. Since the Inventory Rating of the bridge is HS20, then the 10 percent is probably acceptable, because of the large factor of safety associated with the Inventory Rating.

Longer combination trucks overstress both simply supported and continuously supported bridges. Turnpike doubles are worse than Rocky Mountain doubles at the weights assumed in this analysis. On simply supported bridges Turnpike Doubles overstress the bridge up to 13 percent more than the HS20 design vehicle while Rocky Mountain Doubles overstress up to 8 percent greater. Even this level of overstress is usually acceptable. However, overstresses caused by LCVs are even greater on continuously supported bridges. Turnpike Doubles cause stresses up to 22 percent greater than the HS20 design vehicle and Rocky Mountain Doubles up to 15 percent greater.

Bridge Formula B thus does not provide the same protection against damaging overloads by LCVs as it does for single-trailer combinations, especially on continuously supported bridges. For most span lengths the overstress exceeds the inventory rating significantly and that, for the worst cases, e.g., Turnpike Doubles on 2 span continuous bridges with span lengths equal to 80-feet, this overstress reaches 25 percent. Although this level of overstress is less than the operating rating, the overall factor of safety designed into bridges would be substantially reduced with the continuous use of such LCVs.

Table A-2
Ratio of Total Load Moments of the Study Vehicles to the HS20 (Short) Design Vehicle

Bridge Type	Length of Main Span (ft)	Total Length (ft)	HS20 (Short)	HS20 (Long)	3S2 w/40' trailer 73,280 lbs	3S2 w/45' trailer 80,000 lbs	3S2 w/53' trailer 80,000 lbs	3S2-2 Rocky Mtn Dbl 104,000 lbs	3S2-4 Turnpike Dbl 128,000 lbs.
Simple	20	20	1.00	1.00	0.85	0.89	0.89	0.89	0.83
Simple	30	30	1.00	0.95	0.88	0.89	0.89	0.95	0.95
Simple	40	40	1.00	0.84	0.80	0.82	0.82	0.86	0.90
Simple	50	50	1.00	0.80	0.78	0.80	0.80	0.83	0.88
Simple	60	60	1.00	0.82	0.77	0.80	0.80	0.82	0.87
Simple	70	70	1.00	0.86	0.82	0.80	0.80	0.85	0.87
Simple	80	80	1.00	0.88	0.85	0.84	0.81	0.87	0.88
Simple	90	90	1.00	0.91	0.88	0.88	0.82	0.89	0.90
Simple	100	100	1.00	0.92	0.90	0.90	0.86	0.93	0.93
Simple	110	110	1.00	0.93	0.92	0.92	0.88	0.96	0.97
Simple	120	120	1.00	0.94	0.93	0.94	0.91	0.99	1.00
Simple	130	130	1.00	0.95	0.94	0.95	0.92	1.01	1.03
Simple	140	140	1.00	0.96	0.95	0.96	0.94	1.03	1.06
Simple	150	150	1.00	0.96	0.96	0.97	0.95	1.04	1.07
Simple	160	160	1.00	0.96	0.96	0.98	0.96	1.05	1.09
Simple	170	170	1.00	0.97	0.96	0.98	0.96	1.06	1.10
Simple	180	180	1.00	0.97	0.97	0.99	0.97	1.06	1.11
2-span Cont	20	40	-1.00	-1.05	-0.93	0.92	0.92	-0.92	0.91
2-span Cont	30	60	1.00	-1.02	-0.96	-0.93	0.86	-0.92	0.91
2-span Cont	40	80	1.00	-0.99	-1.00	-1.01	-0.94	-1.03	-1.03
2-span Cont	50	100	1.00	-0.98	-1.01	-1.08	-1.07	-1.16	-1.19
2-span Cont	60	120	-1.00	-0.95	-0.99	-1.07	-1.10	-1.25	-1.23
2-span Cont	70	140	-1.00	-0.92	-0.94	-1.03	-1.07	-1.24	-1.22
2-span Cont	80	160	-1.00	-0.94	-0.92	-0.99	-1.03	-1.21	-1.25
2-span Cont	90	180	-1.00	-0.95	-0.94	-0.95	-1.00	-1.18	-1.25
2-span Cont	100	200	-1.00	-0.96	-0.95	-0.96	-0.97	-1.15	-1.24
2-span Cont	110	220	-1.00	-0.97	-0.96	-0.98	-0.95	-1.12	-1.23
2-span Cont	120	240	-1.00	-0.98	-0.97	-0.99	-0.97	-1.09	-1.21
2-span Cont	130	260	-1.00	-0.98	-0.98	-1.00	-0.98	-1.09	-1.19
2-span Cont	140	280	-1.00	-0.98	-0.98	-1.01	-0.99	-1.11	-1.17
2-span Cont	150	300	-1.00	-0.98	-0.99	-1.01	-1.00	-1.12	-1.15
2-span Cont	160	320	-1.00	-0.99	-0.99	-1.02	-1.00	-1.13	-1.17
2-span Cont	170	340	-1.00	-0.99	-0.99	-1.02	-1.01	-1.14	-1.18
2-span Cont	180	360	-1.00	-0.99	-0.99	-1.02	-1.01	-1.14	-1.20
3-span Cont	20	60	1.00	-1.02	-0.96	-0.92	0.86	-0.95	0.92
3-span Cont	30	90	1.00	-1.00	-0.99	-1.00	-0.92	-1.01	-1.03
3-span Cont	40	120	-1.00	-0.98	-1.00	-1.06	-1.04	-1.12	-1.16
3-span Cont	50	150	-1.00	-0.92	-0.96	-1.03	-1.04	-1.16	-1.16
3-span Cont	60	180	-1.00	-0.91	-0.92	-0.99	-1.02	-1.16	-1.14
3-span Cont	70	210	-1.00	-0.94	-0.91	-0.96	-0.99	-1.15	-1.18
3-span Cont	80	240	-1.00	-0.95	-0.94	-0.94	-0.97	-1.13	-1.19
3-span Cont	90	270	-1.00	-0.96	-0.95	-0.96	-0.95	-1.11	-1.19
3-span Cont	100	300	-1.00	-0.97	-0.96	-0.98	-0.94	-1.08	-1.18
3-span Cont	110	330	-1.00	-0.98	-0.97	-0.99	-0.96	-1.06	-1.17
3-span Cont	120	360	-1.00	-0.98	-0.98	-1.00	-0.98	-1.09	-1.16
3-span Cont	130	390	-1.00	-0.98	-0.98	-1.01	-0.99	-1.11	-1.15
3-span Cont	140	420	-1.00	-0.98	-0.98	-1.01	-1.00	-1.12	-1.15
3-span Cont	150	450	-1.00	-0.99	-0.99	-1.02	-1.00	-1.13	-1.16
3-span Cont	160	480	-1.00	-0.99	-0.99	-1.02	-1.01	-1.14	-1.18
3-span Cont	170	510	-1.00	-0.99	-0.99	-1.02	-1.01	-1.14	-1.19
3-span Cont	180	540	-1.00	-0.99	-0.99	-1.02	-1.01	-1.14	-1.20

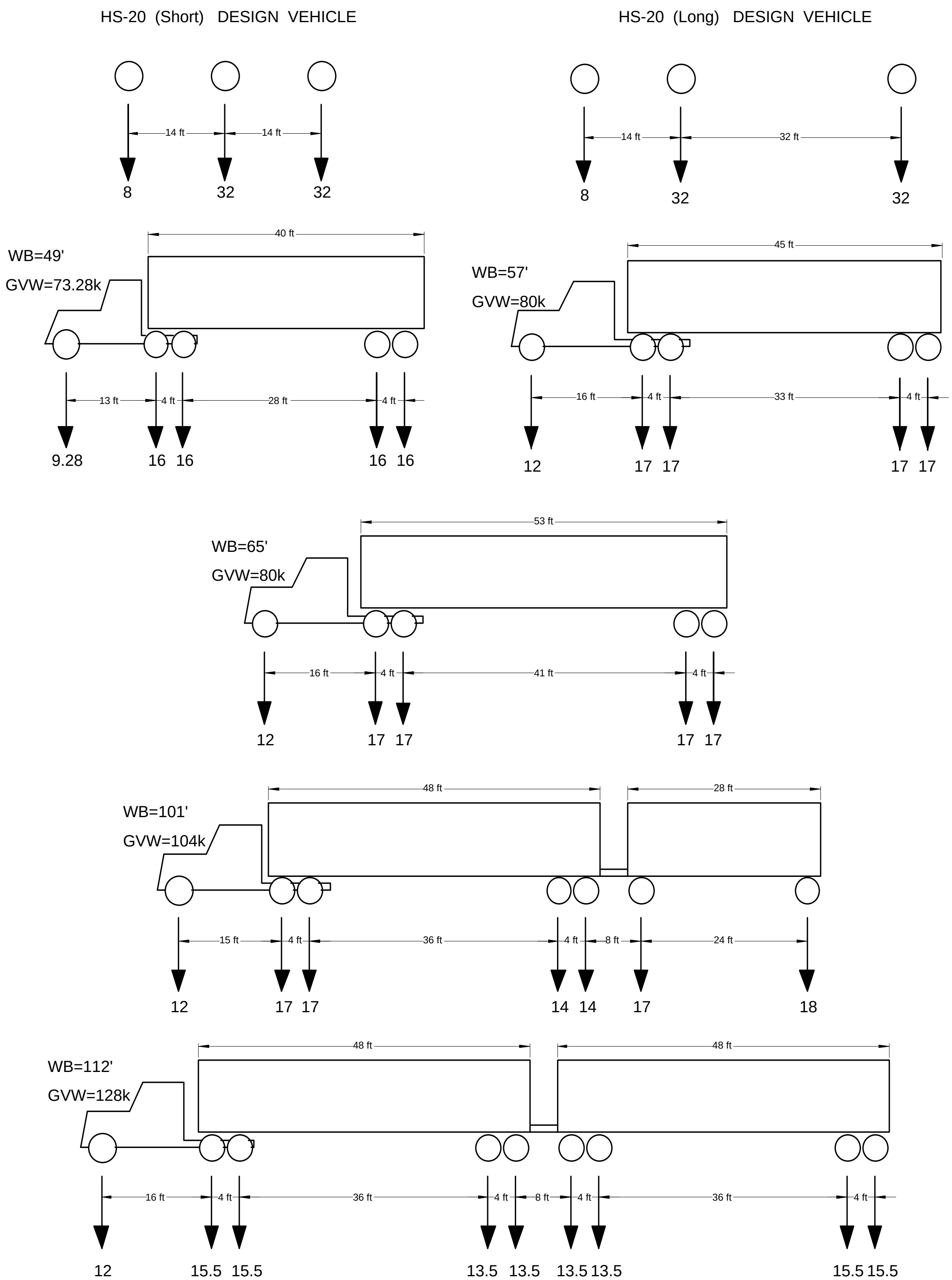
HS-20 (Short) DESIGN VEHICLE
14 ft
14 ft
8
32
32
HS-20 (Long) DESIGN VEHICLE
14 ft
32 ft
8
32
32
WB=49'
GVW=73.28k
40 ft
13 ft
4 ft
28 ft
4 ft
9.28
16 16
16 16
WB=57'
GVW=80k
45 ft
16 ft
4 ft
33 ft
4 ft
12
17 17
17 17
WB=65'
GVW=80k
53 ft
16 ft
4 ft
41 ft
4 ft
12
17 17
17 17
WB=101'
GVW=104k
48 ft
28 ft
15 ft
4 ft
36 ft
4 ft
8 ft
24 ft
12
17 17
14 14
17
18
WB=112'
GVW=128k
48 ft
48 ft
16 ft
4 ft
36 ft
4 ft
8 ft
4 ft
36 ft
4 ft
12
15.5 15.5
13.5 13.5
13.5 13.5
15.5 15.5

Figure 1