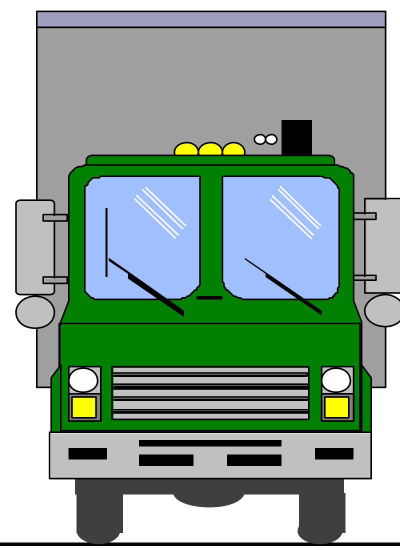
U.S. Department of
Transportation

The U.S. Department of Transportation's

Comprehensive Truck Size and Weight Study



Volume III
Scenario Analysis

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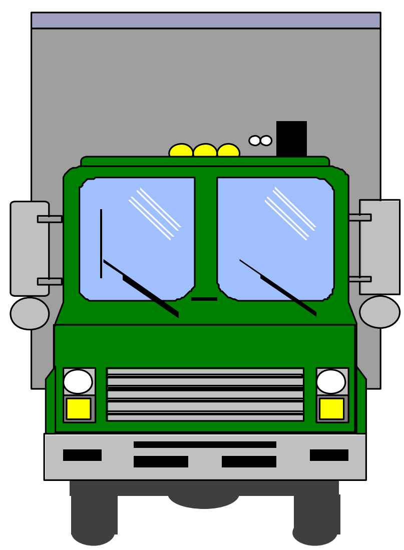
List of Acronyms

ANPRM	Advanced Notice of Proposed Rulemaking
AAR	Association of American Railroads
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
AAA	American Automobile Association
ATA	American Trucking Association
AVC	Automatic Vehicle Classification
AVI	Automated Vehicle Identification
CALTRANS	California Department of Transportation
CRASH	Citizens for Reliable and Safe Highways
CVISN	Commercial Vehicle Information Systems and Networks
CFS	Commodity Flow Survey
CTS&W	Comprehensive Truck Size and Weight
COFC	Container-On-Flat-Car
DOT	Department of Transportation
DST	Double Stack Train
DIVINE	Dynamic Interaction Vehicle Infrastructure Experiment
DLC	Dynamic Loading Coefficient
EDI	Electronic Data Interchange
ESAL	Equivalent Single Axle Loads
EWS	Extended Weight System
FAP	Federal-Aid Primary
FBF	Federal Bridge Formula
FHWA	Federal Highway Administration
GAO	General Accounting Office
GIS	Geographic Information System
GVW	Gross Vehicle Weight
HCA	Highway Cost Allocation
ITS-CVO	Intelligent Transportation Systems-Commercial Vehicle Operations
ICC	Interstate Commerce Commission
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
JIT	Just-In-Time
LTL	Less-Than-Truckload
LTSA	Land Transport Safety Authority
LRFD	Load and Resistance Factor Design
LCV	Longer Combination Vehicle
MRI	Midwest Research Institute
MCA	Motor Carrier Act of 1980
MCSAP	Motor Carrier Safety Assistance Program
NHTSA	National Highway Traffic Safety Administration

NHS	National Highway System
NN	National Network
NPTC	National Private Truck Council
NAFTA	North American Free Trade Agreement
OIG	Office of Inspector General
OECD	Organization for Economic Cooperation and Development
PSI	Per Square Inch
POG	Policy Oversight Group
PPI	Producer Price Index
QR	Quick Response
RF	Rating Factor
RPL	Reduction of Pavement Life
RCCC	Regular Common Carrier Conference
RTAC	Road Transport Association of Canada
RMD	Rocky Mountain Double
SHV	Specialized Hauling Vehicle
SEP	State Enforcement Plan
STAA	Surface Transportation Assistance Act
TTI	Texas Transportation Institute
TOFC	Trailer-On-Flat-Car
TRB	Transportation Research Board
TS&W	Truck Size and Weight
TIRRA	Trucking Industry Regulatory Reform Act of 1994
TL	Truckload
TPD	Turnpike Double
UPS	United Parcel Service
VMT	Vehicle Miles of Travel
VS&C	Vehicle Stability and Control
WIM	Weigh-In-Motion

CHAPTER I

Introduction



Introduction

The Federal government first became involved in truck size and weight (TS&W) regulation during the 1950s when truck axle and vehicle gross weight and width limits were established for the Interstate System.

Federal law now regulates TS&W limits by specifying basic standards and excepting certain situations from those standards by grandfather rights and/or provision of special permits. Federal laws governing truck weights apply to the Interstate System while Federal laws governing vehicle size apply to a designated National Network (NN) for STAA vehicles which includes the Interstate System. Interstate weight limits are intended to prevent premature deterioration of the infrastructure, while minimum length limits are intended to enhance uniformity and productivity. (See Figure I-1 for current Federal limits).

Underlying Federal regulation of TS&Ws is a myriad of State and local regulations. The size and weights of vehicles have been controlled by State and local law since the early part of this century. Today, while some States closely follow Federal limits on non-Interstate or non-NN highways, many differ from at least one of the Federal limits. Over the years, State limits have been changed many times in response to need and circumstances. Change continues—often without Federal involvement or influence.

Volume II has a complete discussion of the Nation's TS&W laws, past and present. In addition, Chapter 3 of this Volume summarizes Federal and State TS&W regulations.

TS&W limits directly affect motor carrier productivity because vehicle capacity determines the number and cost of trips required to transport a given amount of freight. Changes in this fundamental relationship may impact the size of the Nation's freight bill as well as international competitiveness.

Vehicle capacity is only one factor affecting freight transportation efficiency, however. Highway system reliability is an important determinant of the efficiency of the freight transportation system. Advanced production and logistics processes, such as just-in-time delivery, depend on carriers meeting their schedules. The lowest cost transportation often is not as important as the most reliable when entire production processes depend on receiving goods on time.

Current Federal Truck Size and Weight Limits

Current Federal law includes the following limits:

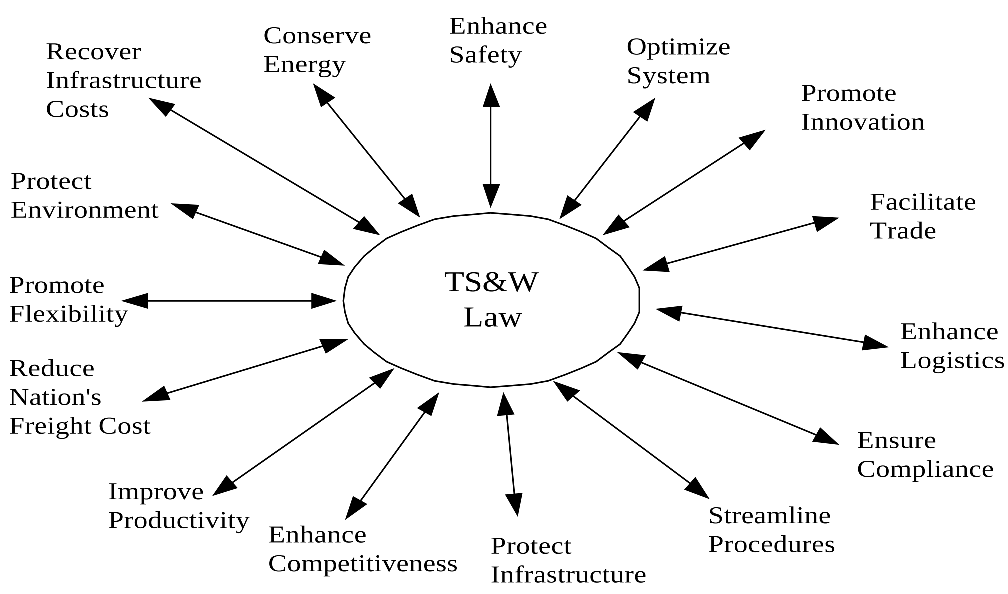
- 20,000 pounds for single axles on the Interstate System;
- 34,000 pounds for tandem axles on the Interstate;
- Application of the Federal Bridge Formula for other axle groups up to the maximum of 80,000 pounds gross vehicle weight on the Interstate;
- 102 inches for vehicle width on the National Network (NN) for large trucks;
- 48-foot (minimum) or longer, if grandfathered, for semitrailers in a semitrailer combination on the NN; and
- 28-foot (minimum) for trailers in a twin-trailer combination on the NN.

All levels of government are interested in providing a transportation system that is responsive to the changing requirements of shippers and carriers. However, the optimal way to improve motor carrier productivity and system reliability is not immediately apparent and, in fact, may vary depending on the types of commodities and the origins and destinations being served.

Truck size and weight regulations have many potential effects that must be considered when evaluating the desirability of changing those regulations. Figure I-2 illustrates important interrelationships between TS&W regulations and other public policy objectives. For example, increases in vehicle capacity, while potentially reducing the number of trucks, may have negative safety consequences. Also of concern are the fiscal implications of preserving and enhancing the condition of the highway infrastructure. Larger and heavier trucks can impose additional costs due to increased pavement wear, the need to improve intersections and interchanges to accommodate longer vehicles, and the need to strengthen or reconstruct bridges to safely carry heavier vehicles.

Government officials, as well as interest groups and the general public, are interested in the environmental impacts of changes to the Nation's TS&W limits. Further, competing modes concerned about inequitable operating conditions and potential loss of market share are important stakeholders in this issue. Finally, the TS&W issue includes an international dimension. For example, the flow of North American continental trade is constrained by differences in allowable limits imposed by the United States, Mexico and Canada. Also, contain-ers used in international trade often cannot be hauled in the

Public Policy Objectives Affected by Truck Size and Weight Regulations



United States without special overweight permits.

The competing economic and social dimensions of the TS&W issue challenge policy makers to find a reasonable balance. This has proven very difficult in the past as some of the factors are not readily quantifiable. For example, the ability to assess the historical accident and safety experience of certain specific truck configurations is very limited. There are simply too few operations in many cases to establish such a record and to extrapolate that experience to different operating environments. Further complicating the discussions are the different perspectives of those participating in the debate and the different operating conditions in various regions of the country.

In an effort to better understand the effects of TS&W policy changes on the wide range of possible impacts, the Department of Transportation (DOT) has undertaken this *Comprehensive TS&W (CTS&W) Study*.

The last such study conducted by the DOT was completed in 1981. The Transportation Research Board (TRB) and the General Accounting Office conducted studies looking at specific aspects of the TS&W issue in the late 1980s and 1990s. (See Figure I-3)

Study Purpose

The purpose of this study is to provide a policy architecture within which the Nation's current body of TS&W laws may be assessed. The study tools can be used to estimate the impacts of alternative TS&W laws on safety, intermodal competition, infrastructure performance, economic productivity, traffic flow, environmental quality and energy consumption. However, limitations in data and analytical methods preclude precise answers.

The study is not intended to provide specific policy recommendations. Rather, it will provide a fact-based framework within which policy alternatives to the current Federal TS&W regulations may be considered.

Study Approach

This study draws heavily from the several TS&W studies that have been conducted by the Department, the Transportation Research Board, the General Accounting Office, and others. Figure I-3 summarizes key TS&W studies since 1981. An extensive review process was established within the Department to coordinate both this study and the 1997 Federal Highway Cost Allocation Study. Outreach to the many groups with an interest in TS&W issues was also an important element of this study. Finally, the study was designed to establish an ongoing TS&W analysis capability within the Department. The study approach is described in detail below.

Internal Departmental Coordination

Policy oversight and direction were provided by a Department Policy Oversight Group (POG). The POG comprises executives from

Major Truck Size and Weight Studies Since 1981

U.S. Department of Transportation

1981 ***An Investigation of Truck Size and Weight Limits***: This study examined--among other issues--the requirement for, and desirability of, uniformity in maximum truck size and weight (TS&W) limits throughout the United States.

1985 ***Feasibility of a Nationwide Network for Longer Combination Vehicles:*** This study addressed the potential benefits and costs that could be anticipated from the establishment of a nationwide network for Longer Combination Vehicles (LCVs).

1986 ***Longer Combination Vehicle Operations in Western States***: In 1985, the Senate Appropriations Committee called for a study of LCV operations in the western States.

Transportation Research Board

1986 ***Twin Trailer Trucks (Special Report 211)***: This study addressed the safety and infrastructure impacts of vehicles with twin short trailers.

1989 ***Providing Access for Large Trucks (Special Report 223)***: This report defined reasonable access for the longer semitrailer and double-trailer combinations which were allowed by the Surface Transportation Assistance Act of 1982.

1990 ***Truck Weight Limits: Issues and Options (Special Report 225***): This study focused primarily on the grandfather rights issue.

1990 ***New Trucks for Greater Productivity and Less Road Wear: An Evaluation of the Turner Proposal (Special Report 227*)**: This study evaluated a TS&W proposal which provided increased truck weights when additional axles were added.

General Accounting Office

1992 ***Truck Safety: The Safety of Longer Combination Vehicles is Unknown***

1993 ***Longer Combination Trucks: Driver Controls and Equipment Inspections Should be Improved***

1994 ***Longer Combination Trucks: Potential Infrastructure Impacts, Productivity Benefits, and Safety Concerns***

throughout the Department including representatives from the Office of the Secretary of Transportation, FHWA, the Federal Railroad Administration, the National Highway Traffic Safety Administration and the Maritime Administration. The POG is chaired by the Assistant Secretary for Transportation Policy.

In addition to POG oversight, a Multimodal Advisory Group (MAG) was established to ensure that major technical decisions shaping the study would be made on an intermodal basis. The MAG provided ongoing guidance and early review of draft documents associated with the final study.

In 1997, these two groups collaborated to publish a Departmental National Freight Policy Statement. This statement guided development of the study's analytical framework, particularly the selection of relevant impact areas. It establishes the most important principles to guide Federal decisions affecting freight transportation across all modes. The guiding principles are shown in Figure I-4.

Highway Cost Allocation Study

This *CTS&W Study* was coordinated closely with the Federal HCA Study completed in August 1997. The *HCA Study* provides information on highway-

National Freight Transportation Policy Statement

The Department of Transportation established eight principles to guide freight transport policy development:

- Provide funding and a planning framework that establishes priorities for allocation of Federal resources to cost-effective infrastructure investments that support broad National goals;
- Promote economic growth by removing unwise or unnecessary regulation and through the efficient pricing of publicly financed transportation infrastructure;
- Ensure a safe transportation system;
- Protect the environment and conserve energy;
- Use advances in transportation technology to promote transportation efficiency and safety;
- Effectively meet our defense and emergency transportation requirements;
- Facilitate international trade and commerce; and
- Promote effective and equitable joint utilization of transportation infrastructure for freight and passenger service.

rrelated costs attributable to different vehicle classes and relationships between the cost responsibility and user fees paid by different vehicles. The study found large variations in the extent to which user fees paid by different vehicle classes cover highway costs attributable to those vehicles. Infrastructure costs attributable to many of the heaviest vehicles are greater than the user fees they pay which means that other vehicle classes are subsidizing operations of those heavy vehicles. These two studies when taken together, provide information on how alternative TS&W limits might affect highway infrastructure and related costs and the equitable payment of highway user fees by different vehicle classes.

Table I-1 displays (1) the estimated responsibility for Federal highway-related program costs funded from the Highway Trust Fund in 2000; (2) the Federal highway user fees projected to be paid in 2000 assuming the Federal highway user fee structure remains unchanged; and (3) estimated Federal equity ratios in 2000 which assume the current highway user charge structure and the same highway program composition as during the base period.

Ongoing Truck Size and Weight Research Effort

The current *CTS&W Study* effort establishes an ongoing TS&W research activity within DOT. Data will be updated on a continuing basis and the analytical framework for evaluating various impacts of TS&W changes will be refined as the state-of-the-art improves and as new policy issues arise.

The FHWA arranged for the TRB to organize a peer review panel which will provide input to the DOT's long-term TS&W research agenda. The *CTS&W Study* will be a point of departure for exploring future research activities. The panel will address the following questions:
(1) What information is needed to formulate efficient, effective and equitable TS&W laws; (2) What information is available with respect to TS&W issues; and (3) What data and analytical tools are required to bridge the gap between what is available and what is required?

Public Outreach

An unprecedented level of outreach was undertaken in conducting the study. Outreach activities included: (1) a Federal Register Notice requesting initial public comment, (2) public meetings with representatives of large and small carriers, trucking industry associations, safety advocates, and representatives from State and local governments;
(3) regional focus sessions focused on securing input from major constituencies and experts; (4) special teleconference sessions addressing issues of importance with our State partners; and (5) external review of draft documents by Congress, State representatives and other interested parties, prior to finalization.

Study Presentation

Overview

The *1998 CTS&W Study* is provided in four volumes. Volume I, "Summary Report," synthesizes the findings presented in

Table I-1. 2000 Federal Cost Responsibility and User Fees by Vehicle Class

Vehicle Class/ Registered Weight	Cost Responsibility cents-per-mile	User Fee Payments cents-per-mile	Ratio of User Charges to Occasioned Costs
Autos Pickups/Vans Buses All Passenger vehicles	0.65 0.65 2.57 0.66	0.64 0.89 0.27 0.70	1.0 1.4 0.1 1.1
Single Unit Trucks			
≤ 25,000 pounds 25,001 - 50,000 pounds > 50,000 pounds All Single Units	1.75 4.38 14.60 3.51	2.66 3.18 6.57 3.13	1.5 0.7 0.5 0.9
Combination Trucks			
≤ 50,000 pounds 50,001-70,000 pounds 70,001-75,000 pounds 75,001-80,000 pounds 80,001-100,000 pounds > 100,000 pounds All Combinations All Trucks	2.78 4.25 6.25 7.08 12.50 16.60 6.90 5.48	4.53 4.72 6.24 6.41 7.18 8.30 6.30 4.92	1.6 1.1 1.0 0.9 0.6 0.5 0.9 1.0

Source: 1997 Federal Highway Cost Allocation Study Summary Report

Volume II and Volume III. Volume II, "Background and Issues," summarizes the information developed during the course of the study in the following areas: (1) TS&W regulations; (2) motor carrier operations and industry structure; (3) truck-rail competition; (4) shipper concerns; (5) highway safety and traffic operations; (6) highway infrastructure; and (7) enforcement.

Volume III, "Scenario Analysis," is described in the following section. Volume IV, "Guide to Documentation," presents a listing of the technical reports where methodological details related to analytical aspects of the study may be found.

Organization of Volume III

Volume III presents a broad assessment of the impacts that could be expected as a result of changes in TS&W limits. Part I (Chapter 1 - Chapter 3) provides back-ground information required to understand the analytical findings. The first chapter includes the motivation for the study, the study's purpose and the Department's

approach. Chapter 2 provides an overview of the analytical framework. Chapter 3 offers descriptions of the illustrative TS&W policy scenarios evaluated for the study.
Part II (Chapter 4) presents a key component of the TS&W analysis: the freight distribution model. The methodology for estimating diversion from rail boxcar to truck, from rail intermodal to truck and from one truck configuration to another is provided. The chapter concludes with a presentation of the travel (vehicle miles and car miles) expected for each of the illustrative scenarios.

Part III - Part V (Chapter 5 - Chapter 11) is organized by impact area. Each impact area discussion includes a brief description of the issue and analytical approach, the sources of data and any relevant caveats. Within the context of the impact area discussions, analytical findings for each scenario are provided.

Part III (Chapter 5 - Chapter 7) deals with the relationship between commercial vehicle sizes and weights and highway agency costs associated with pavements, bridges and roadway geometry.

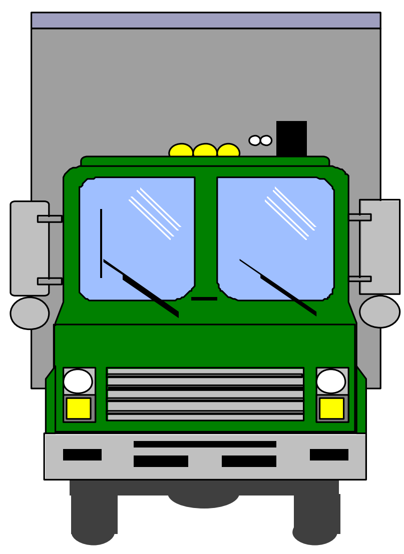
Part IV (Chapter 8 - Chapter 10) provides a discussion of the projected external costs (or benefits) associated with a new mix of commercial vehicles in terms of configurations, sizes and weights. Externalities included are safety, traffic flow, energy consumption and environmental quality.

Part V (Chapter 11 - Chapter 12) offers information on the change in shipper transportation costs that could result from each of the illustrative scenarios. Specifically, post scenario costs to truck and rail customers are provided.

The Volume concludes with a summary chapter in Part VI (Chapter 13) where the illustrative scenarios are discussed and guiding principles, based on the analysis, are provided.

CHAPTER II

Analytical Framework



Introduction

The truck size and weight (TS&W) analytical framework provides a structure for assessing the impacts of alternative truck configurations and policy options. Data and analytical tools have been developed to evaluate critical impact areas such as safety, pavement wear, bridge stress, and rail competitiveness. The framework is a flexible tool useful in examining a wide range of TS&W options, from more restrictive to more liberal.

As indicated in Chapter I, the data and methodologies underlying the framework will be periodically updated, allowing the Department of Transportation (DOT) to respond to TS&W proposals without embarking on a new study for each request.

Figure II-2 provides an overview of the analytical framework. The structure reflects input from the extensive outreach process underlying the study and from the DOT's internal coordination process. The participatory and oversight features of the study are described in Chapter I.

Supporting the analytical process is an objective technical foundation. The analytical framework includes state-of-the-art models and/or procedures designed to evaluate alternative TS&W policy scenarios.

Five illustrative TS&W scenarios are analyzed in this study. Scenarios were selected to illustrate potential impacts of a broad range of TS&W options involving both more liberal and more restrictive limits. The scenarios are discussed with respect to (1) the policy and technical considerations they address, (2) the truck configurations they include, (3) the highway networks on which the configurations are assumed to operate, and (4) other key assumptions.

This chapter provides an overview of the analytical process. Subsequent chapters discuss potential impacts of TS&W policy options, the analytical methods used to assess those impacts, and findings for each scenario.

Technical Foundation

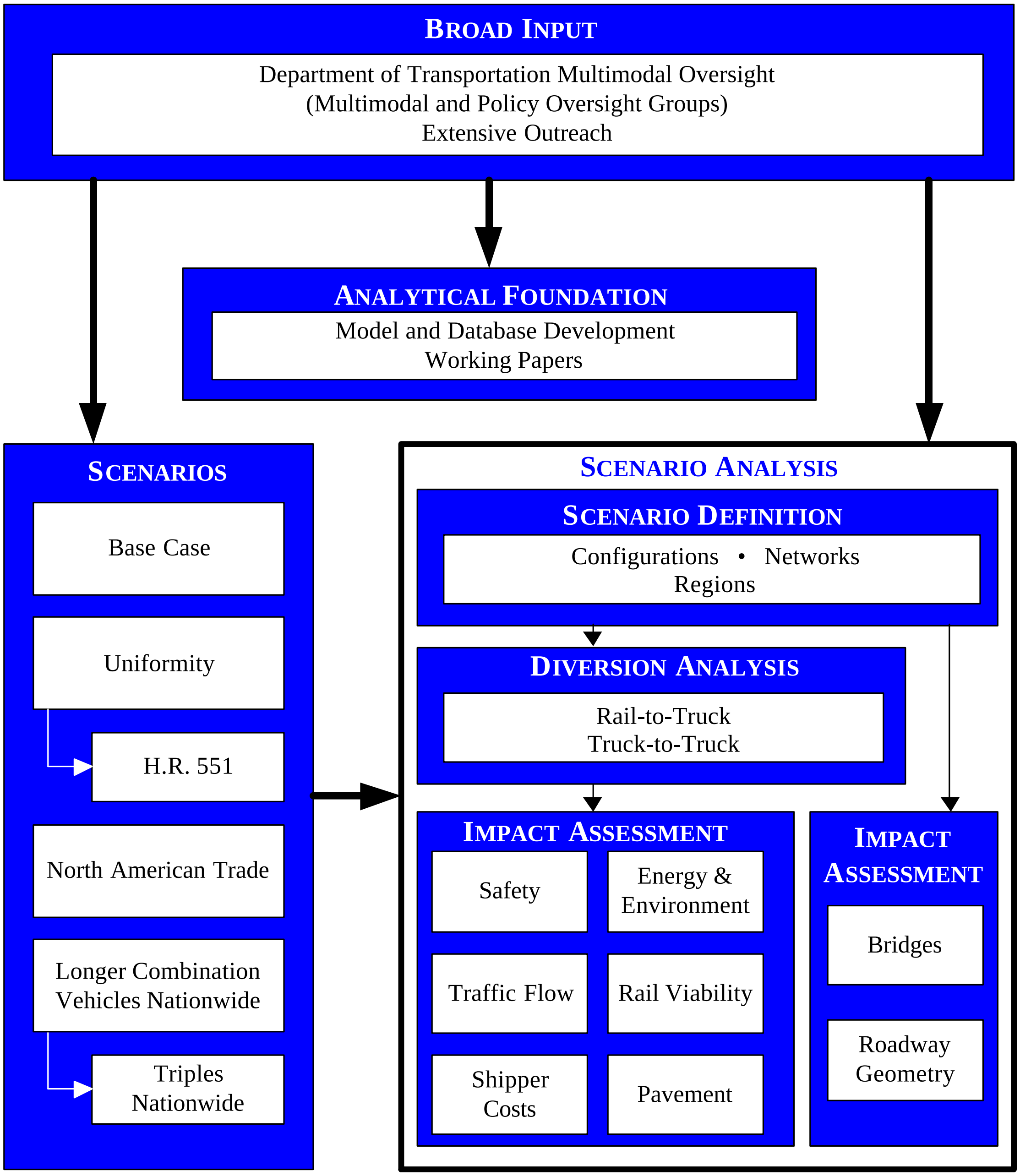
The analytical component of the study was developed along four distinct tracks. The first focused on developing background papers on current issues and trends related to freight markets and motor carriers. Figure II-1 shows issues investigated in thirteen working papers commissioned for the study. The papers describe the state-of-the-knowledge in critical areas as they relate to TS&W discussions.

The second track involved work to support development and calibration of the analytical tools. Activities included developing databases to describe truck weights, body types, commodities and truck flows; conducting commodity case studies covering the transportation of coal, farm products,

Figure II-1. Working Paper Topics

- Safety
- Pavement
- Bridges
- Roadway Geometry
- Traffic Operations
- Truck Costs
- Logistics
- Truck Travel and Mode Share
- Enforcement
- Environment
- Energy Conservation
- State Regulations

Figure II-2. Analytical Framework Overview



petroleum, and forest products; and carrier studies covering less-than-truckload, truckload and intermodal operations. The study also included corridor studies of Los Angeles to Chicago, Los Angeles to Houston, Minneapolis to New Orleans, Detroit to Tampa, New York to Atlanta, Seattle to Chicago, and Fargo to Laredo.

The third track incorporated findings from the first two tracks to develop analytical tools designed to assess the broad range of potential TS&W impacts. These tools include a vehicle stability and control database and a performance analyzer; long- and short-haul freight diversion models and a companion load-shift model; and pavement, bridge, rail industry, highway geometry and traffic operations impact analysis models.

The fourth track brings together the products resulting from the earlier work to evaluate alternative illustrative TS&W policy scenarios. This analytical approach may be used to evaluate regional TS&W policy options and impacts of TS&W scenarios for shipments of specific commodities.

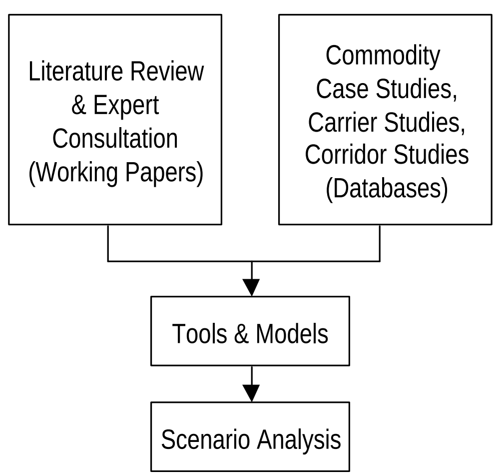
Illustrative Scenario Development

Scenario "building blocks" were identified in a Federal Register Notice published on April 25, 1996. The building blocks consist of configuration, highway network and geographic options that could be used to define alternative policy scenarios. A wide range of truck configurations was evaluated to assess the consequences of maintaining current TS&W limits as well as potentially restricting or expanding those limits.

It should be noted that although an infinite number of scenarios could theoretically be evaluated, time and budget constraints dictated that a limited set of scenarios be analyzed for this report. However, the Department is able to analyze other scenarios using the tools developed for this study.

The gross vehicle weights (GVW) and networks assumed to be available for certain configurations in the illustrative scenarios were chosen for analytical purposes only. They do not reflect weights or networks that the Department believes are necessarily

Figure II-3. Truck Size and Weight Analytical Process



appropriate.
A number of simplifying assumptions limit the ability to extend the theoretical scenario findings to actual "real world" impacts. For example, this study does not evaluate how impacts might vary if States and the Federal Government changed user fees to reflect changes in infrastructure and other costs associated with TS&W policy options. In practice it would be appropriate for States and the Federal Government to consider changing their user fees, but there was no basis for assumptions about the extent to which user fees might change and the types of changes that might be made.

Another set of simplifying assumptions concerned operating restrictions that might be placed on certain vehicle configurations. Most States that currently allow LCVs require those vehicles to operate under revokable permits that restrict when, where, and under what conditions they may operate. No such restrictions were explicitly assumed in the diversion analysis, except that LCVs would be limited to operating on certain defined networks. In practice some States might place restrictions on LCV operations such as allowing operations only during daylight hours or only during dry conditions. To the extent that such restrictions would limit the use of LCVs, the analysis may overestimate somewhat the potential use of LCVs.

Configurations

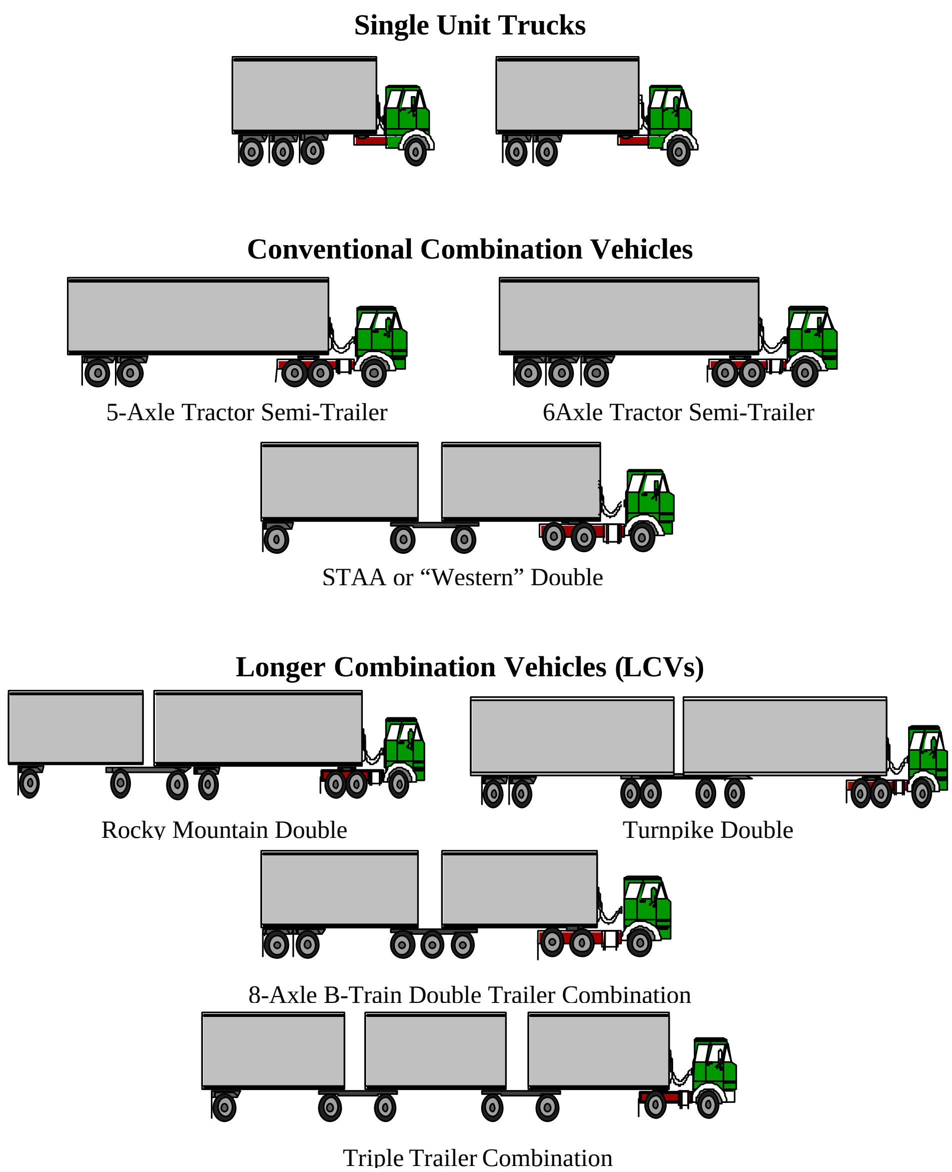
Only commercial trucks are considered in this study. These vehicles are either single-unit trucks (SUTs) whose cargo-carrying units are mounted on the same chassis as the engine, or are combination vehicles that have separate cargo-carrying trailers pulled by a truck or a truck-tractor.

The study scenarios include a broad range of commercial truck configurations: three- and four-axle SUTs; five- and six-axle semitrailers; double trailer combinations; and triple-trailers. These are illustrated in Figure II-4. The configurations are analyzed at operating weights based on assumptions about axle weight and bridge overstress criteria.

It should be noted that a large set of truck configurations, some of which are not specifically addressed in the study scenarios were considered in developing the vehicle stability and control, vehicle offtracking, and roadway geometry impact databases. These databases have the flexibility to accommodate a broad range of policy options and will be useful in evaluating policy scenarios well beyond the five selected for initial analysis.

The nomenclature describing the vehicles in Figure II-4 provides a useful shorthand for referring to the study configurations. The first number in the series indicates the number of axles on the power unit; the next set (alphanumeric), refers to the number of axles supporting the trailing unit

Figure II-4. Illustrative Vehicle Configurations



(a semitrailer or trailer). If the unit is a semitrailer, the number indicating the number of axles is preceded by an "S." Subsequent numbers indicate the number of axles associated with the remaining trailing units.

The Appendix provides a "cross walk" between the *Highway Cost Allocation (HCA) Study* vehicles and the *Comprehensive TS&W (CTS&W) Study* configurations.

Networks and Geographic Units

The configurations are evaluated in relation to various highway systems—the National Network (NN) for STAA vehicles, the National Highway System (NHS), and two limited systems of highways tailored for the operation of LCVs. The LCV networks were developed to meet the analytical requirements of the study. For purposes of this analysis, all configurations are assumed to operate nationwide. Analytical networks were required for the study to reflect the fact that some vehicle configurations have physical and operating characteristics that would make them unsuitable to operate on all highway systems.

County-to-county mileage tables were created for three different networks: the NN and two hypothetical LCV networks. All networks used the "National Transportation Atlas Data Base: 1995" from the DOT's Bureau of Transportation Statistics.

The use of specific roadway networks allows proposed changes to the TS&W 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 quickest travel time; (2) estimated travel time; (3) mileage on each highway functional class; (4) mileage in each State; and (5) non-network miles between origin/destination to the road network (i.e., drayage distance).

National Network for Large Trucks

The Surface Transportation Assistance Act (STAA) of 1982 required States to allow 48-foot semitrailers (or longer if grandfathered) and 28-foot double trailers (often referred to as "STAA vehicles") on specified highways. The Act directed the Secretary of Transportation to designate an NN for trucks that could accommodate vehicles with those trailer lengths. Today, with over 200,000 miles of roadway, the NN includes virtually all Interstate Highways (44,000 miles) as well as other highways. States are required to allow reasonable access for the STAA vehicles to and from the NN. Figure II-5 provides a map of the NN.

National Highway System

With the National Highway System Designation Act of 1995, Congress established the NHS. This system, which includes 156,986 miles, consists of the highways of greatest National interest, and includes the Interstate System, a large portion of the other principal arterial highways, and a small portion of mileage on the other functional systems. The NHS is depicted in Figure II-6.

Analytical Networks for Longer Combination Vehicles

Two networks were developed for the study to evaluate the impact of expanding LCV operations. These networks are not proposed or endorsed by the Department as LCV networks. They are for analytical purposes only.

The network developed to test the operation of long double trailer combinations, Rocky Mountain Doubles (RMDs) and Turnpike Doubles (TPDs), consists of 42,500 miles and provides for continuous east to west travel.

This network consists of access-controlled, inter-connecting segments of the Interstate system and other highways of comparable design and traffic capacity. The routes connect major markets and distribution centers.

The network designed to evaluate the impact of allowing triple-trailer combination vehicles to operate nationwide includes 65,000 miles of rural Interstate and other highways. Some urban Interstate highway segments are included for connectivity. This network includes many low traffic highways in the West and some four lane highways in the East. The network designed for the operation of triple-trailer combinations is larger than the network used to analyze long double combination operations because triple-trailer combination vehicles have more articulation points than RMDs and TPDs, and therefore fewer problems with offtracking.

Both networks likely are more extensive in some States than would be politically or practically feasible and thus tend to overestimate the impact of TS&W policy options addressing LCVs. Relatively extensive networks were analyzed in this study to estimate the upper end of likely impacts that might occur under each TS&W scenario. If less extensive networks were available, impacts would be smaller. Time and resource constraints did not allow sensitivity analyses to be conducted to evaluate different networks. The analytical networks for LCVs are shown in Figures II-7 and II-8.

Scenario Definitions

Three illustrative scenarios were identified for initial evaluation: (1) “Uniformity”, (2) “North American Trade”, and (3) “LCVs Nationwide”. A “Base Case” Scenario was evaluated for comparison.

Also analyzed are two scenarios that have been identified by Congress and other interested parties as of particular interest: (1) enactment of H.R. 551, “The Safe Highways and Infrastructure Protection Act of 1997” and (2) Nationwide operation of triple-trailer combinations. Assumptions in this latter scenario are not identical to those that might have been specified by proponents of that scenario, but are consistent with assumptions about triple-trailer operations in the Nationwide LCV scenario. Having consistent assumptions allows differences between the two scenarios to be readily compared.

The DOT anticipates that, over time, additional policy options will be advanced for analysis. The analytical

Figure II-5. National Network for STAA Vehicles

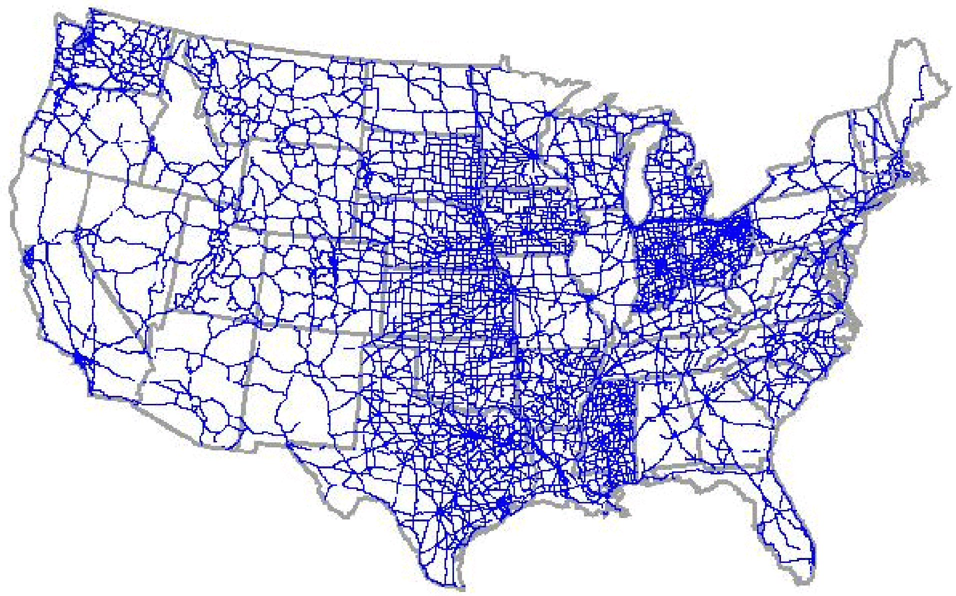


Figure II-6. National Highway System Map

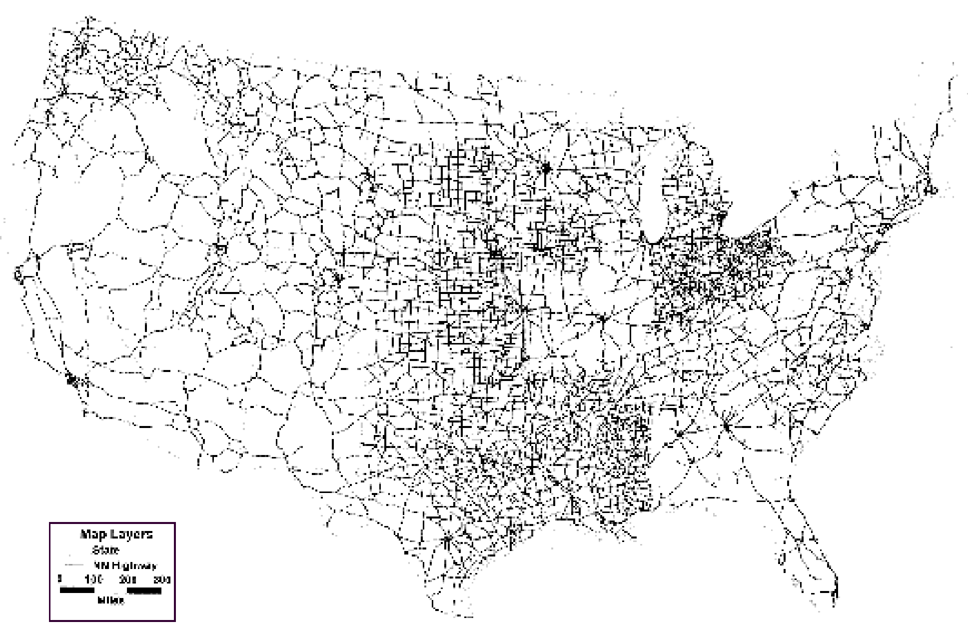
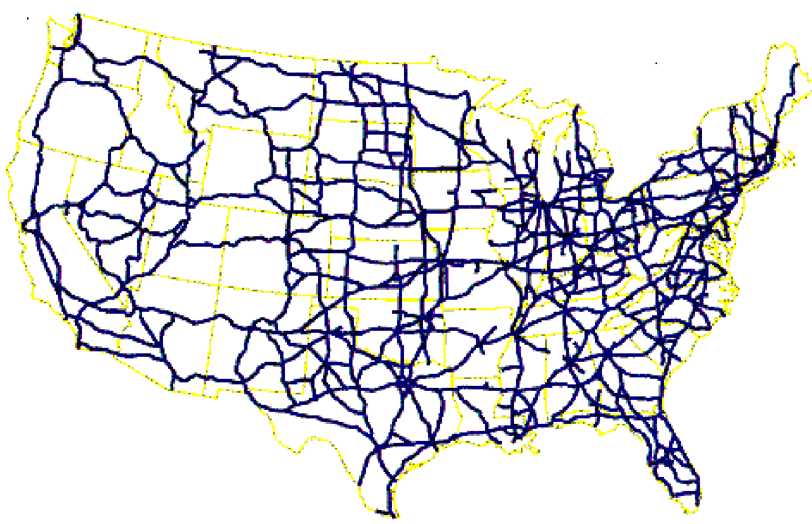


Figure II-7. Analytical Network for Long Double-Trailer Combinations

Figure II-8. Analytical Network for Triple-Trailer Combinations



framework developed for the study is sufficiently flexible to permit the evaluation of many different options, particularly those that are variations on the study's core illustrative scenarios.

These scenarios are described briefly below, and in detail, in Chapter III.

Base Case

The Base Case serves as a base line for the other scenarios and retains all features of current law. Figure II-9 shows key provisions of the base case. The base case includes the freeze on LCVs imposed by the Intermodal Surface Transportation Efficiency Act (ISTEA) which restricts the use of LCVs to the types of operations in effect as of June 1, 1991. The freeze was continued by the Transportation Equity Act for the 21st Century (TEA-21). The definition of an LCV, in that legislation and adopted for this study, is any combination of a truck tractor and two or more trailers or semitrailers which operates on the Interstate System at a GVW greater than 80,000 pounds. 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 a freeze on the length of the cargo- carrying units of combinations with two or more such units on the NN. Current Federal weight limits would remain on Interstate highways, as would existing grandfather rights. It should be noted that the Base Case assumptions may be somewhat conservative in the long run since States can change their TS&W limits on non-NN (or non-Interstate) highways. The Base Case also assumes that no change in technology, operating practices or pricing will take place between the base year (1994) and the analysis year (2000).

Uniformity Scenario

Figure II-9. Base Case Federal Truck Size and Weight Limits

Federal law regulates trucks by specifying basic truck size & weight standards and exempting certain situations from those standards by recognizing State grandfather rights and special permits. Current Federal law sets the following limits:

- 20,000 pounds for single axles on the Interstate;
- 34,000 pounds for tandem axles on the Interstate;
- Application of Federal Bridge Formula for other axle groups up to the maximum of 80,000 pounds gross vehicle weight on the Interstate;
- 102 inches for vehicle width on the National Network (NN) for large trucks;
- 48-foot (minimum) or longer, if grandfathered, for semitrailers in a semitrailer combination on the NN; and
- 28-foot (minimum) for trailers in a twin-trailer combination on the NN.

The Uniformity Scenario would eliminate current grandfather provisions that now allow some States to retain higher GVW and axle weight limits than the Federal limits on the Interstate System. The grandfather provisions are based on a State's weight limits that existed in 1956. This scenario would also extend Federal limits to the entire NN, resulting in nationally uniform weight limits on the NN.

North American Trade Scenario

The North American Trade Scenario focuses on changes that could enhance trade among the North American trading partners and other international trading partners as well. It assumes gross vehicle weights more comparable to those in Canada and Mexico. Key vehicles under this scenario are the six-axle tractor-semitrailer and an eight-axle "B-train" double. The "B-train", which is used in Canada and in the U.S. along the Canadian border, has a coupling mechanism between the first and second trailers with a single articulation point rather than two like conventional twin-trailer combinations. This gives the combination substantially greater stability than conventional twin trailer combinations. Both the six-axle tractor-semitrailer and the B-train double have tridem axles (see Figure II-10 for AASHTO's definition of a tridem axle). Currently, the weight allowed on a three-axle group is limited by the Federal Bridge Formula to weights below those allowed in Canada and Mexico. Two tridem-axle weights are evaluated in this scenario, 44,000 pounds and 51,000 pounds. The 51,000 pound tridem would allow gross vehicle weights of 97,000 pounds for six-axle tractor-semitrailers which is sufficient to allow 40-foot containers to be carried at the maximum international weight limits.

Because a tridem-axle weight limit of 51,000 pounds would have adverse infrastructure and safety impacts, a 44,000-pound tridem-axle weight limit was also analyzed. This weight limit would provide some, although reduced, benefits for international trade, but would limit potentially negative vehicle stability, control, and infrastructure impacts. Under these limits, a six-axle tractor semitrailer combination could operate at 90,000 pounds and the B-train double at 124,000 pounds. In addition, this scenario could increase productivity for short wheelbase straight trucks by allowing operations of four-axle vehicles at weights of either 64,000 pounds or 70,000 pounds.

Figure II-10. Tridem Axle Definition

Any three consecutive axles whose extreme centers are not more than 144 inches apart, and are individually attached to or articulated from, or both, a common attachment to the vehicle including a connecting mechanism designed to equalize the load between axles.

-The American Association of State Highway Transportation Officials

Longer Combination Vehicles Nationwide Scenario

The LCV Nationwide Scenario estimates the impact of expanding LCV operations to a nationwide network. Of particular concern with the potential expansion of LCV operations is the impact on safety, competitiveness of the rail industry, and productivity.

The 1991 ISTEA placed a freeze on LCV operations. The legislation allowed LCV operations that were legal under State law in effect on June 1, 1991 to continue, if the State so desired. TEA-21, passed in 1998, continued the ISTEA freeze. Currently, 20 States permit the operation of some type of LCV.

H.R. 551 Scenario

H.R. 551 calls for a phase-out of trailers over 53 feet in length (new trailers over 53 feet would not be permitted and existing equipment would be grandfathered). H.R. 551 also would freeze weight limits on Interstate and NHS facilities, preventing incremental increases in TS&W limits by the States. The effects of this provision, however, cannot be fully modeled because the base case also assumes no increases in State TS&W limits. Therefore, for practical purposes, the H.R. 551 Scenario yields impact results which are almost identical to the Base Case Scenario. However, the provision to phase-out trailers over 53 feet is evaluated.

Figure II-11. Weigh-Out versus Cube-Out Freight

For high-density (weigh-out) freight such as farm products and natural resources, a vehicle's maximum payload is controlled by truck weight limits. For low-density (cube-out) freight, such as computer equipment and snack foods, vehicle size limits constrain payload.

Triples Nationwide Scenario

The Triples Nationwide Scenario would permit triple-trailer combinations having three short (28- to 28.5-foot) trailers to operate at the same weights and on the same designated nationwide network as they are assumed to operate in the LCVs Nationwide Scenario. These weights are greater than weights at which triples typically operate today under existing grandfather weight limits. In some States that currently allow triples, the network is larger than the network of roads on which triples currently operate, and in some States the analytical network is smaller. Time and resource constraints did not permit evaluation of more than the one illustrative triples network.

Impact Areas

The effects of the alternative TS&W policies are presented in terms of each scenario's impact on various areas of interest:

- Freight Diversion
- Highway Agency Costs
  - Pavement Preservation
  - Bridge Protection
  - Roadway Geometry
- Safety
- Traffic Operations
- Environmental Quality and Energy Consumption
- Rail Industry Competitiveness
- Shipper Costs

Each impact area is briefly described below.

Freight Diversion

Truck size and weight limits determine the maximum payload that vehicles may carry. Figure II-11 explains the relationship between commodity density and maximum payload. In general, increases in TS&W limits will increase the tonnage and/or volume of freight that may be carried per vehicle per trip. Fewer trips would be required to carry the same amount of freight, thereby decreasing tractor vehicle-miles-of-travel (VMT) and reducing trucking costs. Alternatively, more restrictive TS&W limits would increase trips, tractor VMT, and trucking costs.

When the price of a good or service changes, demand may be affected. Comments to the docket suggested that rather than reducing truck VMT, previous increases in TS&W limits had increased VMT. A working paper was commissioned for this study to investigate the issue of "induced demand" and whether this would likely be a large or small impact. Based on relationships between total transportation costs and the relative changes that might be expected as the result of changes in TS&W limits, the paper concludes that any induced demand for trucking services because of the lower price would be small.

While the amount of new truck traffic that might be induced by changes in TS&W limits is expected to be relatively small, changes in truck costs and rates may cause a change in the selection of transport mode for some shipments that are not reflected in the induced demand analysis described above. For example, reductions in truck rates per unit of payload could induce some shippers to switch from rail to truck services. Further, changes in other shipper logistics costs impacted by TS&W variables (such as the size and frequency of shipments) may also influence intermodal (truck/rail) diversion. Examples of these costs include warehousing, order processing, and freight loss or damage.

The diversion analysis generates VMT by truck configuration and rail car miles for boxcars and intermodal traffic. This information is extremely important to the overall study because most impact assessment methods depend on estimates of VMT by truck configuration. Several state-of-the-art diversion models were developed for the study to predict the impact of TS&W changes on mode choice and truck configuration selection.

Highway Agency Costs

Pavement

Pavement wear (see Figure II-12) is of interest because deteriorated pavement increases user operating costs and necessitates public expenditures to correct pavement deficiencies. Pavement deterioration increases with axle weight and the number of axle loadings a pavement experiences, both of which may be affected by TS&W changes. The study relies on pavement deterioration models developed for the 1997 *HCA Study* to predict changes in pavement costs associated with the various TS&W scenarios.

Bridge

While the relationship between pavement deterioration and axle or axle group weight is well documented, the role of trucks with respect to bridge wear is not as well understood. Bridge engineers base new bridge designs on expected typical truck loading and include safety margins to ensure against failure. These margins are significant and reflect uncertainty about bridge materials, construction practices, actual loads, and the costs and consequences of bridge failure. Changes in TS&W limits may impact these safety margins, possibly increasing the number of bridges that must be replaced or posted with signs indicating bridge capacity.

State transportation agencies rate bridges using an "inventory rating" or an "operating rating" approach to determine when a bridge should be posted to prevent its use by certain vehicles. The inventory rating is more conservative than the operating rating, allowing a greater margin of safety. Past TS&W studies used the inventory rating, operating rating or some compromise assumption between the two, to indicate the requirement for bridge replacement, given changes in TS&W limits.

The current study uses the bridge stress criteria as established for the Federal Bridge Formula (FBF) to indicate bridge replacement requirements. This approach is more consistent with actual TS&W regulatory practice which is controlled by FBF, than is using either the inventory rating or operating rating to define bridge deficiencies. These issues are discussed in greater detail in Chapter VI.

Figure II-12. Factors Affecting Pavement Life

The life of a pavement is determined by a number of factors: vehicle loading (axle loads, tire footprint and suspension systems), traffic volume and mix, environment, subgrade condition, initial pavement design, initial construction practices, maintenance, and pavement age.

Roadway Geometry

In some cases, the scenario vehicles will perform differently than vehicles in the current fleet. For example, long double-trailer combinations have difficulty negotiating many interchange ramps and grade-level intersections. In addition, some require staging areas where they can be assembled or broken down, allowing pickup and delivery with shorter combinations. Such performance characteristics may necessitate modifications to existing roadway geometric design features.

Work commissioned for this study examined the relationship between the operating characteristics of the replacement configurations and the geometric elements of the current highway system. Geometric improvements required to accommodate the "worst" vehicles in the new scenario fleet were determined as were their associated costs. In addition, the cost of providing staging areas was estimated. Geometric costs are discussed in greater detail in Chapter VII.

Safety

Extensive research conducted for the study in the area of truck safety demonstrates that crash rates cannot be reliably predicted for many of the vehicle configurations considered in the alternative TS&W policy scenarios. Therefore, while changes in crash exposure (that is, VMT) by configuration are available, the change in the aggregate number of crashes for a given scenario cannot be reasonably estimated.

As discussed earlier in the section on freight diversion, changing TS&W limits may alter travel patterns. For example, depending on the scenario, the expanded operation of certain configurations could result in their operating in different regions of the country. Also, the vast majority of LCVs currently operating are restricted to certain highways. Quantifying the new safety profile for operations under the illustrative scenarios is extraordinarily difficult because historical crash rates cannot be reliably applied to new travel patterns, as they would reflect what would have occurred under existing operating conditions and not what could occur under new conditions.

Another factor complicating the estimation of crash rates, given changes to TS&W policies, is that the population of large commercial trucks, other than semitrailer and STAA double combinations, currently is a small portion of the truck fleet. Consequently, there is little data directly correlating TS&W factors to type, frequency, and cause of roadway crashes.

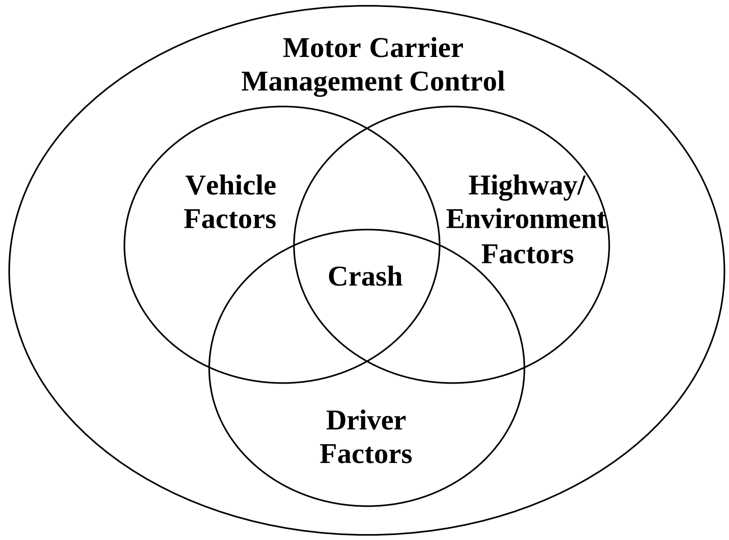
Further, TS&W effects must be isolated from other safety variables before precise numbers of accidents may be determined. The physical characteristics of vehicles play a role in motor carrier safety experience along with the important and interrelated factors of driver performance, roadway design, and traffic environment. Figure II-13 shows interrelationships between the major factors contributing to truck crashes.

However, valuable information about relative vehicle stability and control properties is available. Figure II-14 describes key vehicle stability and control considerations associated with TS&W changes. Work commissioned for the study indicates that differing vehicle stability and control properties combined with new truck travel patterns will affect crash rates and numbers. For example, all vehicles (including trucks) traveling over two-lane roads experience significantly increased crash risks compared to those traveling on the Interstate System and other higher design roadways. The majority of fatal crashes involving trucks occur on highways with lower geometric standards.
Also, higher traffic densities in populous areas exacerbate handling and stability problems with certain vehicle configurations.

Traffic Operations

The introduction of new truck configurations could have significant effects on the operations and the level of service on the highway network. The study estimates passenger car equivalents for a variety of truck configurations; also included are estimates of the differences in overall delay (expressed in vehicle- hours) that may occur with operation of the new truck configurations. These differences result primarily from changes in the number of trucks on the highways and their speeds relative to the automobile population. Chapter IX also discusses other operational impacts that are more difficult to quantify.

Figure II-13. Factors Contributing to Truck Crashes



Environmental Quality and Energy Consumption

Environmental impacts evaluated in the study include air and noise pollution. Procedures to estimate impacts of air and noise pollution that were developed for the 1997 *HCA Study* are used in this analysis. In general, environmental quality and energy consumption impact assessments are a function of VMT, although certain pollution impacts involve many other factors.

Figure II-14. Vehicle Stability and Control Considerations

Because of differences in vehicle stability and control, some larger and heavier trucks are more prone to rollover than are other trucks; some are less capable of successfully avoiding an unforeseen obstacle when traveling at highway speeds; some negotiate tight turns and exit ramps better than others; some can be more reliably stopped in shorter distances than can others; and some climb hills and maneuver in traffic better than others.

Motor vehicles produce emissions that damage the quality of the environment and adversely affect the health of human and animal populations. The economic cost of changes in air pollution levels resulting from alternative TS&W policy scenarios could not be estimated within the scope of this study. The Department continues to work with the Environmental Protection Agency to develop estimates that adequately reflect the latest understanding of the costs of motor vehicle emissions.

Noise emissions from motor vehicle traffic are a major source of annoyance, particularly in residential areas. For this study, noise costs were estimated using information on the reduction in residential property values caused by noise emissions. Estimates of noise emissions were developed using Federal Highway Administration noise prediction models.

The change in fuel consumption given alternative vehicle configurations is also of interest. This was estimated using engine performance models, for each scenario, based on fuel economy by vehicle weight. Total fuel consumption is strongly influenced by changes in VMT.

Rail Impacts and Shipper Costs

Beyond the issue of motor carrier productivity is that of shipper costs. If carriers are able to transport the same quantity of freight in fewer trips, their costs will go down. The motor carrier industry is considered sufficiently competitive for cost savings to be passed on to shippers as lower rates. This is generally true of the rail industry as well.

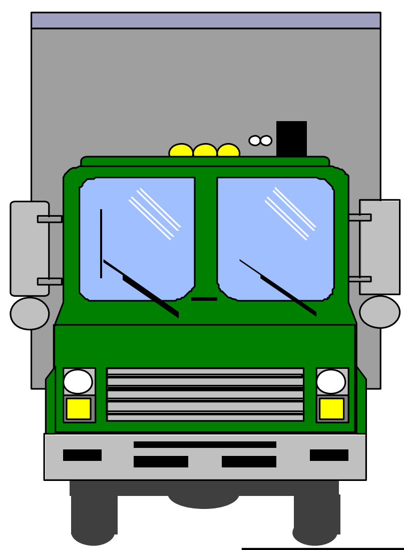
This analysis quantifies the magnitude by which costs to shippers will increase or decrease. Examined are (1) rail shippers that continue to ship by rail, (2) rail shippers that switch to truck, and (3) truck shippers that continue to ship by truck. All three groups of shippers will potentially experience changes in their rate structures as a result of changes in truck sizes and weights.

A shipper that can take advantage of more productive truck configurations could realize lower total transportation and logistic costs. However, rail shippers that could not economically switch to trucks might face increased costs as railroads spread fixed costs over a smaller shipper base.

Also, a portion of rail customers will experience lower rates resulting from rail industry attempts to maintain traffic in the face of lower truck rates. The rail impact analysis estimates the likely rate increases for remaining rail traffic necessary to cover fixed costs. In other words, the “contribution to fixed costs” lost because of diverted traffic would be recouped by increasing rates for the remaining rail traffic, potentially impacting future demand for rail service and, therefore, the financial status of the rail industry.

Thus changes in Federal TS&W limits may affect costs not only for shippers using trucks, but also for rail shippers as railroads respond to new market conditions.

CHAPTER III



Scenario Descriptions

Introduction

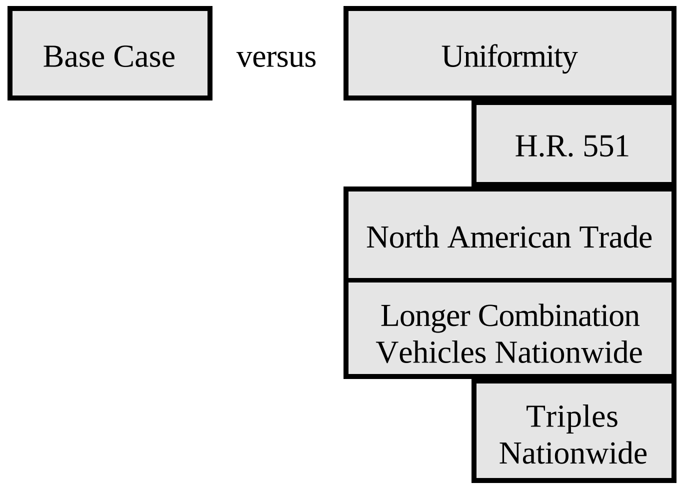
The outreach process described in Chapter I identified a number of truck size and weight (TS&W) issues of broad interest. Those issues were incorporated into a set of illustrative scenarios that reflected changes in various Federal TS&W regulations. Potential impacts of those scenarios were analyzed against base case impacts of maintaining current Federal TS&W regulations. Figure III-1 shows the five illustrative scenarios analyzed in this study:

- Uniformity
- North American Trade
- LCVs Nationwide
- H.R. 551
- Triples Nationwide

The H.R. 551 and Triples Nationwide scenarios are subsets of the Uniformity Scenario and the LCVs Nationwide Scenario respectively. They are indented in Figure III-1 to show this relationship.

In addition, a Base Case was established against which the illustrative scenarios are compared.

Figure III-1. Illustrative Truck Size and Weight Scenarios



These scenarios should not be construed as being indicative of the Department of Transportation's (DOT's) disposition toward a particular TS&W policy option. Rather, they were selected to illustrate potential impacts across a broad range of possible TS&W changes.

This chapter describes the illustrative scenarios in detail. The scenarios address a wide range of issues, and were specified to estimate the upper range of impacts that might be expected from various types of TS&W policy changes. Under different assumptions about the vehicle weights and dimensions that might be allowed under each scenario or the networks of highways that might be available for certain vehicles, the estimated impacts might be lower.

Base Case

The Base Case provides a point of reference for the scenario analyses. It represents the motor carrier and rail industries in the year 2000, absent any significant changes in Federal or State TS&W limits.

Introduction

The Base Case retains all features of current law. Federal size limits [102-inch maximum vehicle width, 48-foot minimum semitrailer length limits or longer if grandfathered (see Figure III-2), and 28-foot minimum trailer length limits for double-trailer combinations] remain on the Interstate System and other highways on the NN. Operation of commercial motor vehicle combinations with two or more cargo-carrying units on the NN are restricted to length limits in effect on June 1, 1991.

The current Federal weight limits on Interstate highways and bridges [20,000-pound single-axle, 34,000-pound tandem-axle, 80,000-pound gross vehicle weight (GVW) cap, and Federal Bridge Formula (FBF)] continue, as do existing grandfather rights. Operation of LCVs on the Interstate Highway System, is restricted by State law in effect as of June 1, 1991.

The analysis year for the study is 2000. Projections of the truck fleet and truck VMT are based on trends from 1994, the base year for both this study and the *1997 Federal Highway Cost Allocation (HCA) Study*. Based on a review of many studies, the fleet and VMT were projected to increase at an annual rate of 2.6 percent a year between 1994 and 2000.

Figure III-2. State Semitrailer Lengths on the NN

The Surface Transportation Assistance Act of 1982 mandated minimum semitrailer lengths of 48 feet. However, in those States having semitrailer lengths longer than 48 feet, these lengths became the (grandfathered) minimum.

Alabama	53'6"	Montana	53'0"
Alaska	48'0"	Nebraska	53'0"
Arizona	57'6"	Nevada	53'0"
Arkansas	53'6"	New Hampshire	48'0"
California	48'0" *	New Jersey	48'0"
Colorado	57'4" *	New Mexico	57'6"
Connecticut	48'0"	New York	48'0"
Delaware	53'0"	North Carolina	48'0"
District of Columbia	48'0"	North Dakota	53'0"
Florida	48'0"	Ohio	53'0"
Georgia	48'0"	Oklahoma	59'6"
Hawaii	48'0"	Oregon	53'0"
Idaho	48'0"	Pennsylvania	53'0"
Illinois	53'0"	Puerto Rico	48'0"
Indiana	48'6" *	Rhode Island	48'6"
Iowa	53'0"	South Carolina	48'0"
Kansas	57'6"	South Dakota	53'0"
Kentucky	53'0"	Tennessee	50'0"
Louisiana	59'6"	Texas	59'0"
Maine	48'0"	Utah	48'0"
Maryland	48'0"	Vermont	48'0"
Massachusetts	48'0"	Virginia	48'0"
Michigan	48'0"	Washington	48'0"
Minnesota	48'0""	West Virginia	48'0"
Mississippi	53'0"	Wisconsin	48'0"
Missouri	53'0"	Wyoming	57'4"

* King pin regulation applies
Source: 23CFR 658, Appendix B

Table 1. Base Year and Forecast Commercial Vehicle Fleet and Travel

Vehicle Class	Number of Vehicles			Vehicle Miles Traveled (in millions)		
	1994	2000	Percent Share of Truck Fleet	1994	2000	Percent Share of Truck Fleet
3-axle single unit truck	594,197	693,130	24.9	8,322	9,707	7.6
4-axle or more single unit truck	106,162	123,838	4.4	2,480	2,893	2.2
3-axle tractor-semitrailer	101,217	118,069	4.2	2,733	3,188	2.5
4-axle tractor-semitrailer	227,306	265,152	9.5	9,311	10,861	8.5
5-axle tractor-semitrailer	1,027,760	1,198,880	43.0	71,920	83,895	65.4
6-axle tractor-semitrailer	95,740	111,681	4.0	5,186	6,049	4.7
7-axle tractor-semitrailer	8,972	10,466	0.3	468	546	0.4
3- or 4- axle truck-trailer	87,384	101,934	3.6	1,098	1,280	1.0
5-axle truck-trailer	51,933	60,579	2.2	1,590	1,855	1.4
6-axle or more truck-trailer	11,635	13,572	0.5	432	503	0.4
5-axle double	51,710	60,319	2.2	4,512	5,263	4.1
6-axle double	7,609	8,876	0.3	627	731	0.6
7-axle double	7,887	9,201	0.3	542	632	0.5
8-axle or more double	9,319	10,871	0.4	650	759	0.6
Triples	1,203	1,404	0.0	108	126	0.1

Characteristics of the Base Case commercial vehicle fleet are consistent with those in the *HCA Study*. The *HCA Study* provides VMT for selected vehicle classes disaggregated by weight group, highway functional class, and State.

The rail base case was projected to the year 2000 using the “International and Domestic Freight Trends” report by DRI/McGraw-Hill and Reebie Associates. This report projects an annual growth rate for rail car miles of 2.2 percent to the year 2000. Rail intermodal car miles were projected to grow at 5.5 percent per year.

Scenario Specifications

The number of trucks estimated to be in the truck fleet and the extent of their use in 1994 and 2000 are shown in Table III-1 Only those trucks likely to be impacted by changes in TS&W limits were explicitly considered in the study. Table III-2 shows characteristics of how those vehicles are currently used.

The impact that base year (1994) truck operations would have on infrastructure costs (bridge, pavement, roadway geometry), safety, traffic operations, energy and environment, shipper costs, and rail industry competitiveness was compared to the impact that truck operations would have in 2000 if no significant TS&W policy changes occurred. This comparison shows how changes estimated to occur between 1994 and 2000, essentially due to growth in travel demand, would compare to impacts expected to result from TS&W policy changes in the year 2000 Base Case.

The Vehicles

The truck configurations analyzed in this study and their current use in terms of areas of operation, length of haul, types of commodities carried, and highways used are described in Table III-2. The maximum weights and dimensions allowed for these configurations in each State have been modeled by dividing the country into six regions (see Figure III-3) and selecting the median weights and dimensions for the configurations from among the States in the region (see Tables II-2 to II-4 in Volume II). The regions are: North-east (14 States), Southeast (9 States), Midwest (9 States), South Central (2 States), West (14 States), and California. Alaska and Hawaii have not been modeled as data were not available and they depend on marine links for connection to the major U.S. truck and rail networks.

The Networks

Single unit trucks (SUTs) and shorter single-trailer truck combinations have access to virtually all highways. "STAA" double trailer combinations and combinations with 48-foot semitrailers 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 offtracking.

Access Provisions

STAA combinations (vehicles authorized under the STAA legislation) are given access to terminals (points of loading and unloading) and service facilities (for food, fuel, rest, and repair) under State provisions that follow Federal regulations called for by the STAA. All States must allow access for STAA vehicles from and to the NN via any routes they can safely negotiate.

Uniformity Scenario

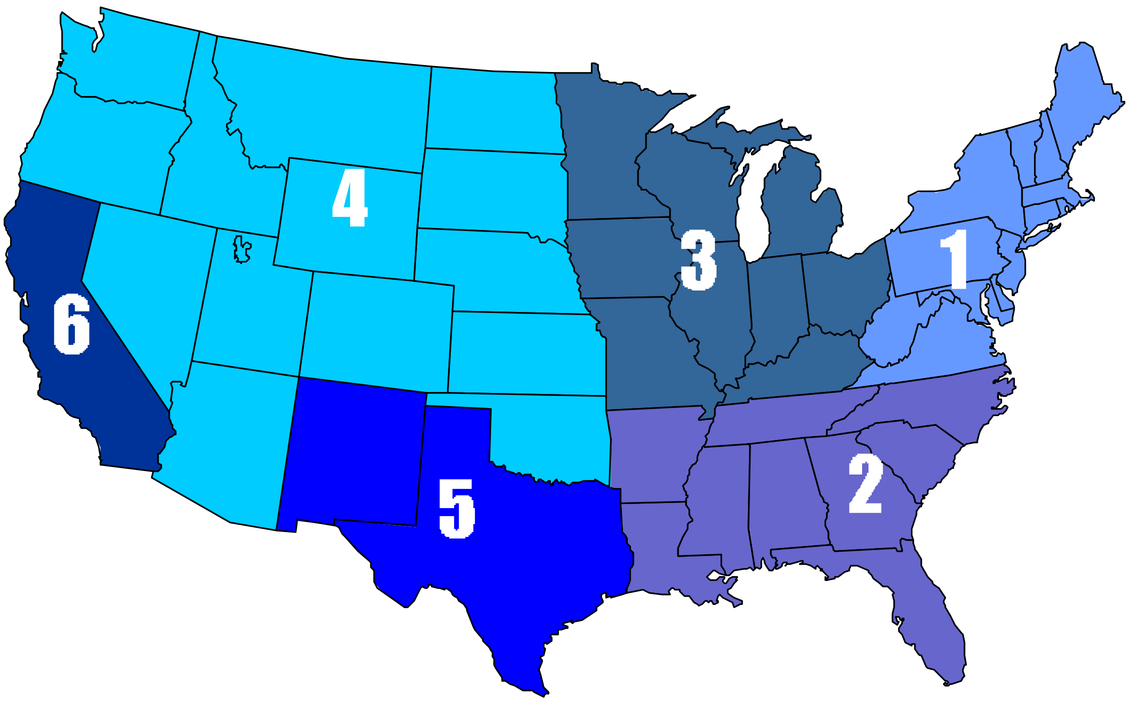
A myriad of TS&W regulations affects U.S. trucking operations. These differences reflect variations in economic and industrial activities, freight flow characteristics, infrastructure design and maintenance philosophies, system condition, traffic densities and modal options.
Many believe that grandfather rights create enforcement problems. Also, there is concern that vehicles with potentially damaging axle weights may be allowed to operate under grandfather provisions. Equity issues are also important in that carriers in one State are afforded valuable operating privileges that are denied to shippers and carriers (and the industries they represent) in neighboring States. Finally, safety and congestion issues related to large trucks are of increasing concern to auto, as well as truck drivers. This scenario is designed to test the impact of removing the grandfather provisions and

applying Federal weight limits to all highways on the NN. States that currently have higher weight limits on non-Interstate portions of the NN would have to lower those limits to the Federal limit, and the few States that have lower weight limits on non-Interstate portions of the NN would have to raise their limits.

Table 2. Current Use of Scenario Vehicles

Configuration Type	Number of Axles	Common Maximum Weight (Pounds)	Current Use
Single-Unit Truck	3	50,000 to 65,000	Single-unit trucks (SUT) are the most commonly used trucks. They are used extensively in all urban areas for short hauls. Three-axle SUTs are used to carry heavy loads of materials and goods in lieu of the far more common two-axle SUT.
	4 or more	62,000 to 70,000	SUTs with four or more axles are used to carry the heaviest of the construction and building materials in urban areas. They are also used for waste removal.
Semitrailer	5	80,000 to 99,000	Most used combination vehicle. It is used extensively 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 to 100,000	Used to haul heavier materials, commodities, and goods for hauls longer than those of the four-axle SUT.
STAA Double	5, 6	80,000	Most common multitrailer combination. Used for less-than-truckload (LTL) freight mostly on rural freeways between LTL freight terminals.
B-Train Double	8	105,500 to 137,800	Some use in the northern plains States and the Northwest. Mostly used in flatbed trailer operations and for liquid bulk hauls.
Rocky Mountain Double	7	105,500 to 129,000	Used on turnpikes in Florida, the Northeast, and Midwest and in the Northern Plains and Northwest in all types of motor carrier operations, but most often it is used for bulk hauls.
Turnpike Double	9	105,500 to 147,000	Used on turnpikes in Florida, the Northeast, and Midwest and on freeways in the Northern Plains and Northwest for mostly truckload operations.

Figure III-3. Truck Size and Weight Analysis Regions



Historical Perspective

Grandfather Provisions

Current TS&W law includes three grandfather provisions which allow higher State TS&W limits than those indicated in the Federal regulations. The first, adopted in 1956, is concerned with axle weights and gross weights.

The second, enacted in 1975, deals principally with bridge formulas and axle spacing tables. The most recent grandfather clause was created in 1991 and focuses on double-trailer or triple-trailer combination vehicles operating at weights greater than 80,000 pounds.

The Transportation Equity Act for the 21st Century did not change existing grandfather provisions. It did however, establish new grandfather dates, by special exceptions to the rules, for Maine and New Hampshire.

The Federal-Aid Highway Act of 1956 imposed axle and GVW limits for trucks operating on the Interstate System. Because some States already allowed motor carrier operations at higher axle or gross weights, a grandfather clause was included in the legislation to preclude a rollback in those States.

The Federal-Aid Highway Amendments of 1974 (enacted in 1975) mandated that maximum weights for axle groups would be determined by a formula designed to protect bridges. A new grandfather provision was included in the 1975 legislation that allowed

States to continue to use alternative bridge formulas or axle spacing tables that allowed weights greater than the new Federal formula. The grandfather provisions in the 1956 and 1975 legislations have been interpreted to include exemptions for both permitted and non-permitted vehicles. Figure III-4 explains divisible and non-divisible permitting regulations and practices.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 froze the weight, length, and routes of LCVs operating on the Interstate System as well as the lengths and routes of commercial vehicle combinations with two or more cargo carrying units operating on the NN. With this legislation, operations of LCVs, defined as any combination of a truck tractor and two or more trailers or semitrailers which operate on the Interstate System at a GVW greater than 80,000 pounds, are restricted to the types of vehicles and routes in use on or before June 1, 1991.

Uniformity Legislation

The STAA of 1982 included provisions that created more uniform TS&W standards nationwide. The act provided that Federal-aid funds would be withheld from States that enacted maximum weight limits lower than the maximums specified by Federal law. These limits are 20,000 pounds for single axles, 34,000 pounds for tandem axles, and GVWs determined by the FBF, subject to an 80,000-pound maximum limit.

It raised the maximum vehicle width limit from 96 inches to 102 inches, and, as amended, applied this limit to the NN, subsequently designated by the Federal Highway Administration and States, as required by the STAA of 1982.

It also set minimum length limits of 48 feet (or longer if grandfathered) for semi-trailers in a single-trailer combination and 28 feet for trailers in a double-trailer combination. It required the States to allow trailers these lengths or longer on their NN routes. However, the States are permitted to allow longer trailers. The STAA also required the States to provide reasonable access for these STAA vehicles between the NN and terminals and service facilities.

Scenario Specifications

This scenario examines the impact of establishing State truck weight limits at the current Federal limits for all trucks operating on the NN. All State grandfather rights would be eliminated. Non-divisible load permits would continue. Off the NN, vehicles would continue to operate at current State-regulated weights.

The Vehicles

Under the Uniformity Scenario, single unit trucks (SUTs) were analyzed as follows: (1) the maximum GVW for three-axle trucks would be 51,000 pounds and (2) the maximum GVW for four-axle trucks would be reduced to 56,500 pounds. These weights assume short wheelbase vehicles, with weights determined by FBF. This assumption may overstate the impact of this scenario because longer wheelbase vehicles could continue to operate at higher weights. Also, manufacturers would probably build longer wheelbase vehicles to

Figure III-4. Divisible and Non-divisible Load Permits

States grant special permits exempting eligible motor carrier operations from Federal gross vehicle weight (GVW), axle weight and bridge formula limits. Federal law authorizes all States to issue permits for non-divisible loads, and 21 States allow the operation of overweight divisible loads under grandfathered special permits. The interpretation of divisible versus non-divisible loads, however, varies from State to State.

In 1994, the Federal Highway Administration defined a non-divisible load or vehicle as one that exceeds "applicable length or weight limits which, if separated into smaller loads or vehicles, would (1) compromise the intended use of the vehicle . . . , (2) destroy the value of the load or vehicle . . . , or (3) require more than eight work hours to dismantle using appropriate equipment. . . ." (Part 658 of Title 23, Code of Federal Regulations).

However, because the definition is not commodity-specific and because States are left to interpret the definition in application, there is ambiguity about what loads qualify as non-divisible and, therefore, may be treated specially. For example, some States consider equipment that has been spot-welded to be divisible, while other States categorize such equipment as non-divisible. Further the burden of proof as to the effort required for dismantling lies with the applicant, and there is substantial variation between States as to the amount of proof required to demonstrate that dismantling a load requires more than eight hours of work.

The weights that can be allowed under non-divisible load permits are not restricted by Federal regulation. These permits are usually issued for a specific route, often for an individual trip. They may be issued for very high GVWs, but the number of axles required generally goes up with GVW. Examples of non-divisible loads include manufactured homes, boats, cranes, mining equipment, major pieces of machinery, construction equipment, and power plant components.

In contrast to non-divisible loads, divisible load permits apply to all other material. They are generally issued for regular operations at a specified GVW, usually on a quarterly or annual basis. These permits apply to either entire systems or specified roads and often include restrictions concerning seasons and weather extremes. About half of the States have claimed grandfather clause authority to issue divisible load permits for operations over 80,000 pounds GVW on the Interstate.

Many States allow divisible load permits for specific commodities that are important to the economic health of their State. It is often argued, however, that exemptions are also instituted operate at higher gross weights.

All SUT unit and combination vehicle types would be affected because States would not have grandfather rights to allow operation of trucks with GVWs or axle loads greater than federally set limits. For example, a seven-axle truck-trailer combination, currently allowed under grandfather provisions in some States at a GVW of 105,500 pounds would be restricted to an 80,000-pound limit on the NN. In those rare cases where weight limits are lower on the NN as compared to Interstate Federal limits, this scenario assumes that the weights would be increased. However, it should be noted that the modeling capability underlying the study is not sufficiently sensitive to this particular case.

The new limits would prohibit all LCVs from operating above 80,000 pounds, rendering them impractical for weight limited loads but not cube-limited loads. For example, a seven-axle triple-trailer combination currently operating under grandfather provisions, at 115,000 pounds, would be required to operate under the 80,000-pound limit.

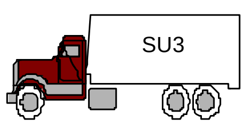
The Network

The analysis network assumed for testing this scenario was the NN.

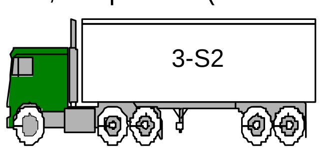
Access Provisions

Access provisions are

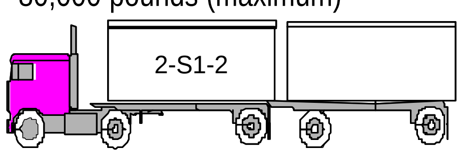
Figure III-5. Uniformity Scenario



Three-axle single unit
51,000 pounds (maximum)



Five-axle semitrailer combination
80,000 pounds (maximum)



Five-axle STAA double-trailer combination
80,000 pounds (maximum)

Main Feature

- **Extend Federal gross vehicle weight limits on States beyond the Interstate to National Network (eliminates grandfather provisions)**

Available Highways

- **National Network for Large Trucks**

Access Provisions

- **Current Federal and State provisions** assumed unchanged from the Base Case.

North American Trade Scenarios

The North American Trade Scenarios are focused on trade among the North American trading partners. Such trade could be facilitated by allowing the operation of six-axle tractor-semitrailer combinations at 97,000 pounds, which is sufficient to carry a container loaded to the International Standard Organization (ISO) limit on Interstate highways without a special permit (as would be required under today's regulations).

To provide for the operation of a six-axle tractor semitrailer combination at 97,000 pounds, a tridem weight limit of 51,000 pounds was tested. Currently, the weight allowed on a three-axle group is limited by the FBF. Introduction of a tridem weight limit would potentially impact the four-axle SUT as well as the eight-axle B-train double combination.

While the 97,000 pound six-axle tractor semitrailer combination and the eight-axle B-train combination would have benefits in terms of trade, a tridem-axle weight limit of 51,000 pounds would have adverse bridge and safety impacts, especially for the short wheelbase 4-axle SUT. The three scenario vehicles were also tested with tridem axle weight limits of 44,000 pounds. A 44,000-pound tridem axle weight limit could provide a productivity increase for the scenario vehicles while limiting vehicle stability and control as well as infrastructure impacts.

A tridem-axle weight limit of 44,000 pounds would assume 20,000 pounds on the steering axle for an SUT, allowing up to 64,000 pounds GVW. For a six-axle semitrailer combination, 12,000 pounds is assumed for the steering axle and 34,000 pounds on the drive tandem, which would allow up to 90,000 pounds GVW for this configuration. For the eight-axle B-train combination operating at a GVW of 124,000 pounds, 12,000-pounds is assumed on the steering axle, 34,000 pounds on the drive axle, 44,000 pounds on the tridem axle of the first trailer and 34,000 pounds on the tandem axle of the second trailer.

A tridem-axle weight limit of 51,000 pounds would assume 20,000 pounds on the steering axle for an SUT, allowing up to 71,000 pounds GVW. For a six-axle semitrailer combination, 12,000 pounds is assumed for the steering axle and 34,000 pounds on the drive tandem, which would allow up to 97,000 pounds GVW for this configuration. For an eight-axle B-train combination operating at a GVW of 131,000 pounds, 12,000 pounds is assumed on the steering axle, 34,000 pounds on the drive axle, 51,000 pounds on the tridem axle of the first trailer and 34,000 pounds on the tandem axle of the second trailer.

Background: Policy Related Issues

North American Trade

The United States, Canada, and Mexico signed the North American Free Trade

Agreement (NAFTA) on December 17, 1992. Among other objectives, NAFTA is intended to promote competitiveness in the global economy and to provide for greater efficiency in transportation among the North American trading partners. By eliminating unnecessary barriers, the international transport of goods and services will be more efficient.

Figure III-6 compares the vehicle mix of the Canadian, American, and Mexican commercial vehicle fleets. The six-axle tractor semitrailer configuration is widely used in both Canada and Mexico. This vehicle is practical in Canada and Mexico because they have tridem-axle weight limits for a 12-foot spread that are considerably higher than the U.S. Federal limits (see Table III-3). The Canadian tridem-axle weight limit ranges from 46,297 pounds to 52,911 pounds, depending on how far apart the axles are spread. Mexico's tridem-axle weight limit is 49,604 pounds. Unlike Canada and Mexico which establish tridem-axle weight limits by regulation, the U.S. does not legislate a tridem limit, rather it is specified by the FBF.

There are also significant differences in the single- and tandem-axle weight limits among the United States, Canada and Mexico. Table III-4 compares single- and tandem-axle weight limits in the three countries. The United States and Canada have very similar weight limits for single axles. Mexico, however, is 10 percent higher for tandem-trailer axles and 20 percent higher for tandem drive axles than its NAFTA partners. In the case of tandem axles, there is an almost 9,000-pound difference between Mexico's limit of 42,990 pounds for a truck or truck-tractor tandem-axle and the U.S. Federal limit of 34,000 pounds. Canada has an intermediate limit of 37,479 pounds.

This scenario tests the impact of allowing the six-axle tractor semitrailer at weights of up to 90,000 pounds (assuming a 44,000-pound tridem-axle weight limit) or 97,000 pounds (assuming a 51,000-pound tridem-axle weight limit). This would be accomplished by allowing a higher tridem-axle weight limit and raising the maximum GVW limit.

International Container Traffic

International containers are a significant and growing feature of contemporary freight transportation. Over the 10-year period between 1987 and 1996, worldwide container port traffic grew 124 percent. In the United States, container movements grew 62 percent during the same period of time (see Table III-5).

An international container enters the United States through a marine port and is usually transported to a rail terminal or its final destination via truck. These containers can cause a vehicle to exceed the Federal axle and/or vehicle weight limits. When

Figure III-6. Comparative Fleet Profiles -- Canada, United States, and Mexico

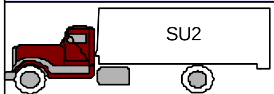
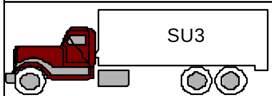
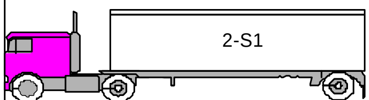
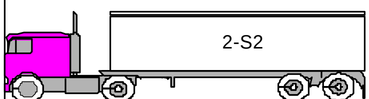
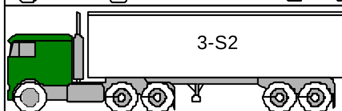
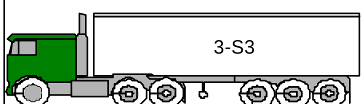
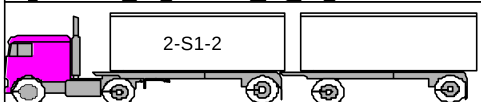
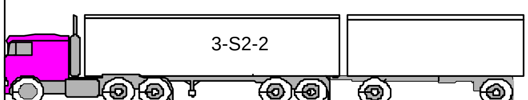
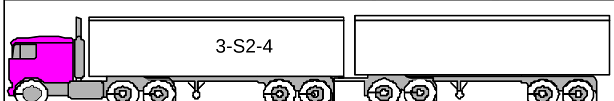
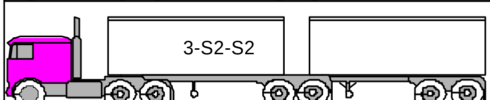
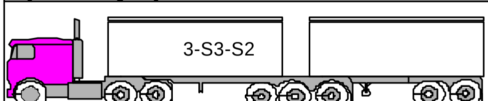
Truck Configuration	Canada	United States	Mexico
 SU2	9.7%	35.5%	8.3%
 SU3	2.3%	4.9%	15.3%
 2-S1		1.6%	
 2-S2		5.5%	
 3-S2	51.0%	42.2%	35.2%
 3-S3	18.5%	3.0%	37.3%
 2-S1-2		2.7%	
 3-S2-2	5.2%	0.3%	
 3-S2-4		0.4%	2.5%
 3-S2-S2	5.3%		
 3-S3-S2	7.9%		
Other Configurations	0.1%	3.9%	1.4%

Table III-3. Tridem Axle Weight Limits at Various Axle Spacings

Axle Set	Canada	United States		Mexico
		Federal	State Max*	
8 feet	46,297	34,000	44,000	49,604
8+ feet	46,297	42,000	58,400	49,604
10 feet	50,706	43,500	58,400	49,604
12 feet	52,911	45,000	59,400	49,604

* Grandfathered weights

Table III-4. Maximum Single and Tandem Axle Weight Limits – Canada, United States, Mexico

Axle Set	Canada	United States		Mexico
		Federal	State Max*	
Steering Axle	12,125	-	13,000	14,330
Single Trailer Axle	20,062	20,000	22,500	22,046
Single Drive Axle	20,062	20,000	22,500	24,251
Tandem Trailer Axle	37,379	34,000	44,000	39,683

containers, particularly 40-foot containers, are loaded to the weight limits established by the ISO—the principal international agency that sets standards for containers—they are generally too heavy for trucks governed by U.S. weight limits. Many of the NAFTA and European Community countries allow higher weights than the United States. is demonstrated in Table III-6.

A 20-foot marine container can be loaded to a gross weight of 44,800 pounds by ISO standards and may cause a bridge formula violation in the United States. A 40-foot container can be loaded up to an ISO weight of 67,200 pounds and may cause U.S. axle, bridge and gross weight limits to be violated.

The Federal Highway Administration allows, at State discretion, sealed shipping containers moving in international commerce to be carried at GVWs over 80,000 pounds under non-divisible load permits (see Figure III-7). However, this arrangement further exacerbates the variability in U.S. weight limits. This creates difficulties for foreign shippers that may not be

Table III-5. Container Port Traffic

Year	US Ports	World
1987	14,048	65,844
1988	15,252	73,810
1989	15,922	79,816
1990	16,651	85,957
1991	17,348	93,108
1992	18,627	102,906
1993	19,176	112,439
1994	20,230	128,320
1995	21,347	135,000
1996	22,788	147,348

Source: Containerization International, Yearbook, 1984-1997.

Thousands of Twenty-foot equivalent units

familiar with the variance in gross vehicle and axle load limits from State to State.

Four-Axle Straight Trucks

A tridem-axle weight limit such as assumed in this scenario could also benefit short-wheelbase vehicles such as dump, refuse, ready mix concrete, farm and construction vehicles. Evidence indicates that FBF is overly conservative for short-wheelbase vehicles.

Tridem-axle weight limits of 44,000 pounds and 51,000 pounds are tested for four-axle SUTs. Although the new limits provide for only somewhat higher payloads relative to what can be carried today, these short wheelbase truck operations would be able to carry the weight on a much shorter wheelbase without excessive infrastructure impacts, particularly for bridges. As expected, the tridem-axle weight limit of 44,000 pounds is relatively more infrastructure friendly than would be the 51,000-pound limit.

It should be noted that, in many States, these SUTs have grandfathered limits above the Federal limits. For example in Maryland and the District of Columbia, three-axle dump trucks with a special registration permit may operate at weights up to 65,000 pounds regardless of their wheelbase. In the Eastern coal producing States, trucks for hauling coal generally are allowed to operate legally on designated highways or with a permit at weights above the Federal limits.

Figure III-7. Non-divisible Load Permits for International Containers

The Federal Highway Administration made a policy decision in the early 1980's to allow goods transported in international containers to be treated as non-divisible loads. Not all States utilize this provision. Some States require that U.S. Customs service container seals be broken and a portion of the contents be removed when overweight containers are detected.

Table 6. International Standards Organization Container Capacity

	Configuration	Weight Container Plus Cargo (pounds)	20-foot Containers Which may be Legally Transported	40-foot Containers Which may be Legally Transported
United States (without permit)	Five-Axle Semitrailer	80,000	1	0
	Six-Axle Semitrailer	80,000	1	0
Canada	Five-Axle Semitrailer	87,000	1	0
	Six-Axle Semitrailer	102,500	1	1
	Eight-Axle B-Train Double	137,800	1	1
Mexico	Five-Axle Semitrailer	97,000	1	1
	Six-Axle Semitrailer	106,900	1	1
	Nine-Axle Double	146,600	2	1
European Community	Five-Axle Truck Trailer	88,200	1	0
	Five-Axle Semitrailer	97,000	1	1
	Six-Axle Semitrailer	97,000	1	1

Scenario Specifications

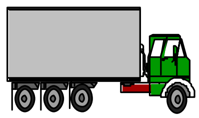
The Vehicles

Figure III-8 summarizes assumptions in the North American Trade Scenario. The scenario tests the impact of introducing tridem-axle weight limits of 44,000 pounds and 51,000 pounds. These limits are applied to the four-axle SUT, the eight-axle B-train double combination and the six-axle semitrailer combination. The tridem-axle group has nine feet between the first and last axle in the group. If the axles were to be spread more than this, pavement wear would increase while bridge stress would decrease. Conversely, if the nine feet were shortened, bridge stress would increase, while pavement wear would decrease.

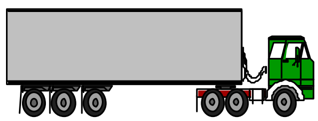
The four-axle SUT with a 44,000-pound tridem-axle weight limit would be allowed to operate at a maximum GVW of 64,000 pounds and with a 51,000-pound tridem-axle weight limit, at 71,000 pounds GVW.

The eight-axle double trailer combination is assumed to operate with two 33-foot trailers. This vehicle, operating at weights in excess of 80,000 pounds, would most likely operate with a “B-train” connection (see Chapter 8 on Safety Impacts). These vehicles are assumed to operate at weights of 124,000 pounds GVW with a 44,000-pound tridem-axle weight limit, and 131,000 pounds GVW with a 51,000-pound tridem-axle weight limit.

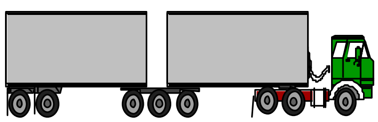
Figure III-8. North American Trade Scenarios



Four-axle single unit truck
64,000 pounds or 71,000 pounds maximum weight



Six-axle tractor-semitrailer
90,000 pounds or 97,000 pounds maximum weight



Eight-axle B-train double
124,000 pounds or 131,000 pounds maximum weight

Main Features

- **Combination vehicles widely used in Canada and Mexico**
- **Introduces tridem-axle weight limits**

Available Highways

- **Current National Network for STAA vehicles**

Access Provisions

- **Current Federal and State provisions**

The maximum GVW allowed for a six-axle semitrailer would increase to 90,000 pounds or 97,000 pounds with tridem-axle weight limits of 4,000 pounds or 51,000 pounds, respectively.

The Network

The analysis network for the six-axle tractor semitrailer and the eight-axle B-train double is the NN. Rocky Mountain Doubles (RMDs) and Turnpike Doubles (TPDs) are assumed to operate on their current routes. However, for analytical purposes, the trips for RMDs and TPDs have been routed through that portion of the 42,500-mile long-doubles network which is available in the 14 westernmost States, excluding Texas, New Mexico, California, Alaska and Hawaii. For triples, the roadway network that is modeled is the "LCV region" of the 65,000-mile network in the same States. For analysis purposes, the short-haul SUTs are not modeled using the study networks. In actual practice, these vehicles may travel anywhere, without restrictions. A more complete discussion of the analytical approach is contained in Chapter IV.

Access Provisions

The scenario assumes access provisions as in the Base Case, which implies access for eight-axle B-train combinations (with 33-foot trailers) to and from the NN.

Longer Combination Vehicles Nationwide Scenario

The ISTEA of 1991, which responded to public concerns regarding the safety of LCVs as well as concerns regarding rail competitiveness, included language to prevent the expansion of LCVs into States that did not permit them before June 1, 1991 (see Figure III-9).

The LCV Nationwide

Figure III-9. 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 (CMVs) having two or more cargo units on the National Network for Large Trucks. A CMV is a motor vehicle designed or regularly used for carrying freight, or merchandise, 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 or from lifting restrictions that governed LCV operations as of that date. Such restrictions may include route-, vehicle- and driver- specific requirements.

Scenario explores the impact of lifting the ISTEA freeze. New Federal limits would be established and a network of highways upon which these vehicles would be allowed to operate would be designated.

Figure III-10 illustrates the common LCV combinations: the RMD, the TPD, and the triple-trailer combination. A diagram of the eight-axle B-train double is also provided, although this vehicle, given current TS&W laws, is far less common than the other LCVs. The figure also provides, for comparison, typical non-LCV vehicles.

The reader will note that a tractor, twin 28-foot trailer combination weighing less than or equal to 80,000 pounds is not considered an LCV. This vehicle, the STAA double (sometimes referred to as a Western double), is allowed to operate in all States and in 1994 accounted for approximately 2.5 percent of all truck combinations and 4.5 percent of all truck combination VMT.

Figure III-11 illustrates that LCV usage is a regional phenomenon. Of the 21 States that allow the operation of LCVs, all but five are west of the Mississippi River. Some of the eastern turnpike States (e.g., those allowing LCV operations only on turnpike facilities) have allowed LCVs for about 35 years. Some western States have permitted LCVs for fewer than 15 years.

LCV operations are generally controlled through special divisible load permits. (See Figure III-12). These permits typically, but not always, include limitations specific to LCVs and may dictate equipment maintenance

Figure III-10. Comparison of Longer Combination Vehicles With Conventional Trucks

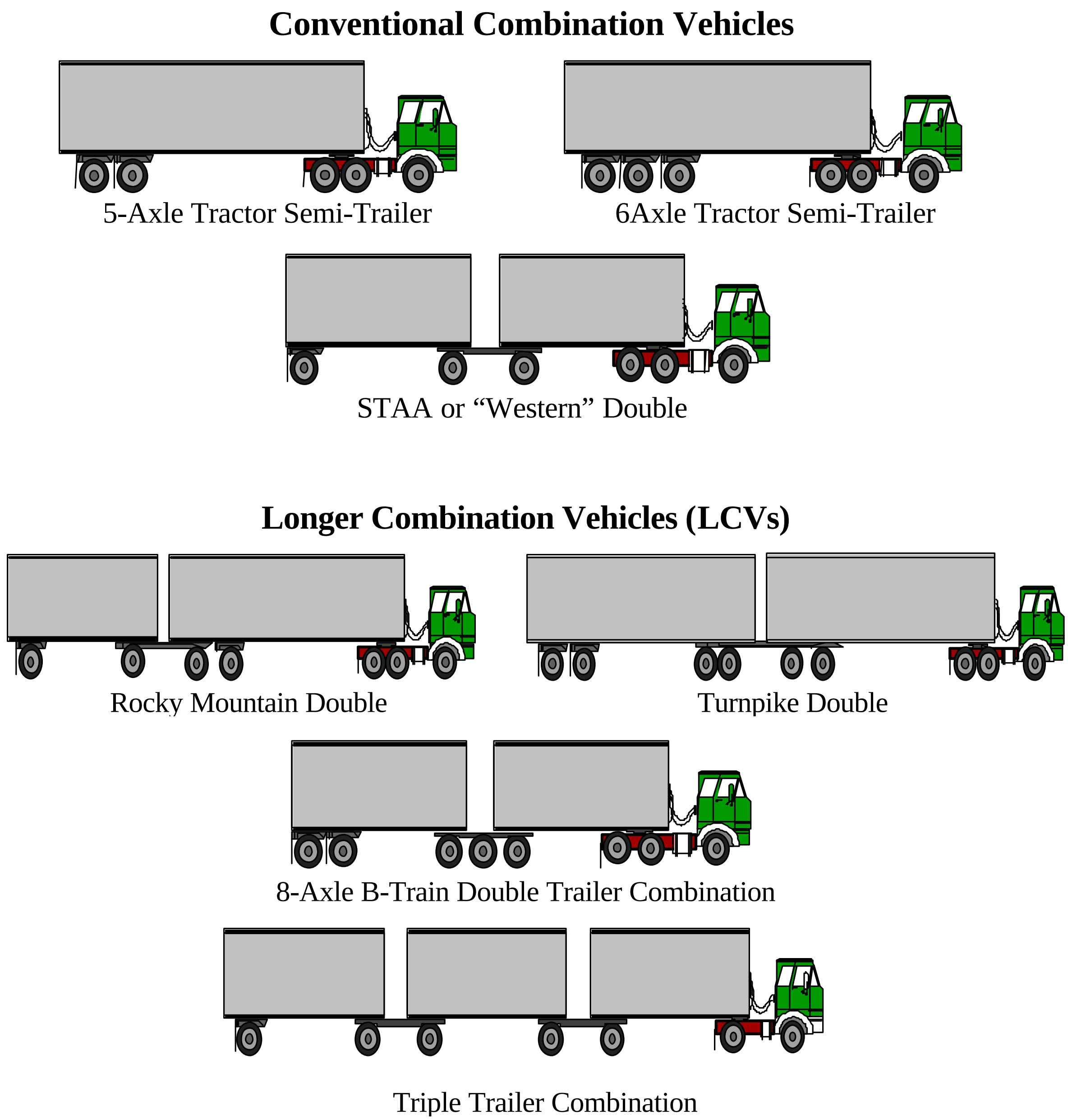
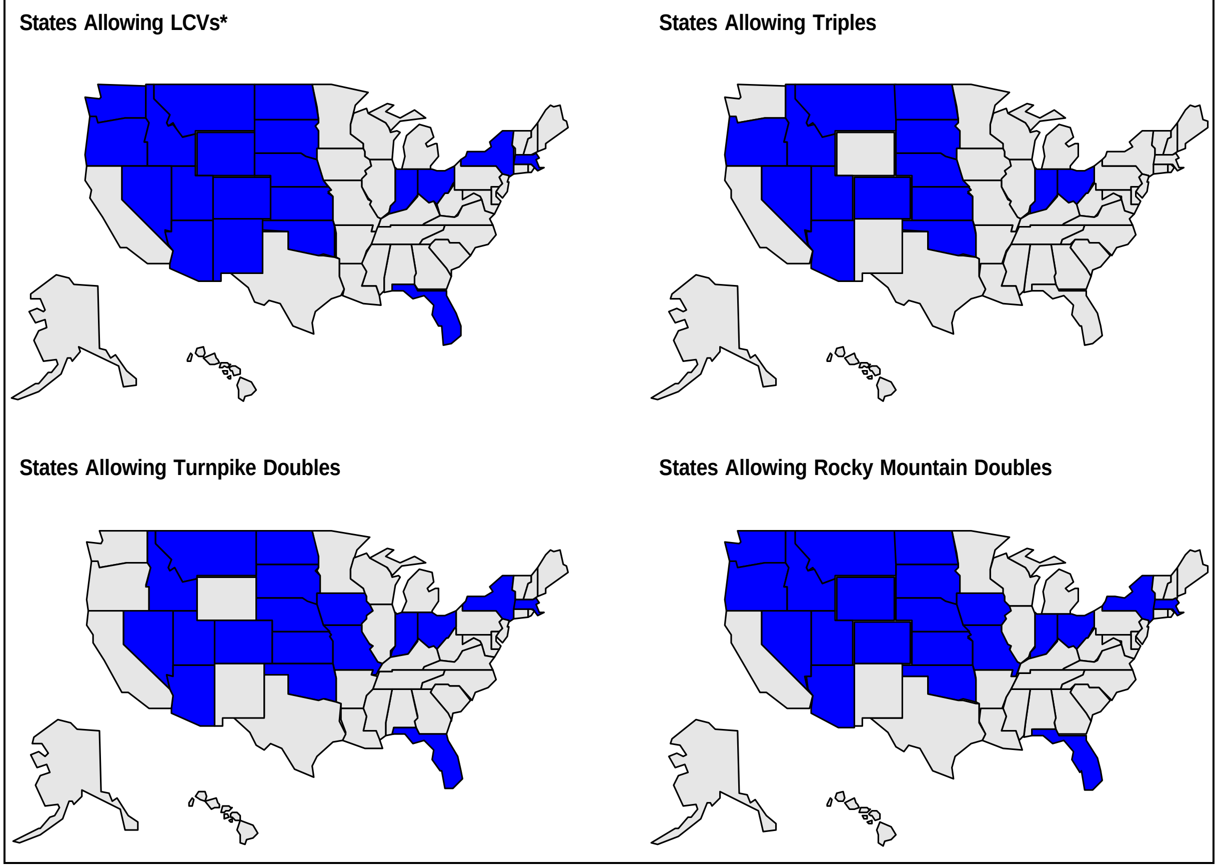


Figure III-11. States Allowing Various Longer Combination Vehicles



practices, driver qualifications, and route selection, among other factors.

Most State LCV restrictions also include length and weight provisions. In the majority of LCV States, maximum vehicle lengths for LCVs are between 110 feet for double-trailer combinations and 115.5 feet for triple-trailer combinations; maximum weights range up to 147,000 pounds for TPDs in Florida and 131,060 pounds in Montana.

Background: Vehicle Descriptions

This section provides descriptions of the most prevalent LCVs operating today. It should be noted, however, that eight-axle B-train combinations at weights over 80,000 pounds are allowed to operate in the northern plains States and the Northwest. They are used mostly in flat bed trailer operations and for liquid bulk hauls. These combinations are not prevalent.

Rocky Mountain Doubles

The RMD consists of a three-axle truck-tractor with a long front trailer (40- to 53-foot) and a shorter (20- to 28.5-foot) rear trailer. A few toll road authorities in the east and

Figure III-12. Special Permits for Longer Combination Vehicles

Most States that allow Longer Combination Vehicles (LCVs) require special permits for their operation. These permits generally certify that (1) drivers have adequate and specialized training and experience, (2) the equipment is sufficient for handling heavier loads, (3) the carrier is properly insured, and (4) the vehicle is properly maintained and meets safety standards. State permits may be issued for single trips or on an annual basis.

In addition to these permit provisions, many States have special equipment requirements for LCV operations. These may include splash and spray suppression devices (such as mud flaps) and axle requirements. Other restrictions could include operating requirements such as minimum speeds, designated lanes, mandated distances to complete passing maneuvers and, load sequencing of the combination's trailers. Many States impose special driver requirements that are more extensive than those required for conventional trucks. These requirements may include minimum age limits and special training.

Special LCV permits often include route restrictions. Typically, these routes have, at a minimum, 12-foot lane widths, low to moderate grades, adequate space for executing turning maneuvers at intersections and curves, bridge load-bearing capacities necessary to tolerate heavier loads, suitable passing lanes, and a positive crash history.

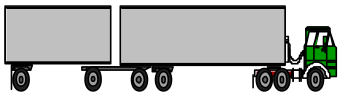
midwest began to issue permits for RMDs in 1959. Western States followed in the late 1960s. Today, RMDs operate over an extensive network of highways and toll roads in 21 States (six turnpike States and 14 western States). RMDs are generally used for general freight and short resource hauls. They are useful in freight delivery to more than one point on a route, because one trailer can be dropped at an intermediate point.

Turnpike Doubles

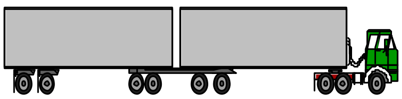
The TPD combination consists of a tractor towing two long trailers of equal length, typically from 40 feet to 53 feet in length. In the 1960s, several eastern States began permitting the use of these vehicles. Today, 19 States allow such operations. The TPD combination is allowed in all but three of the States in which RMDs are allowed to operate. These operations are generally, but not always, limited to Interstate and toll road facilities.

Compared to other LCVs, TPDs have more cubic capacity and can carry higher weights. TPDs are particularly well suited to operations where freight is moved from origin to destination without intermediate pick-up or delivery.

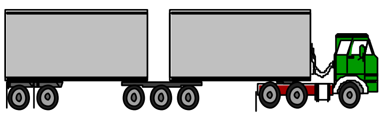
Figure III-13. Longer Combination Vehicles Nationwide Scenario



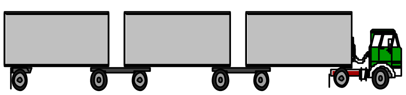
7-axle Rocky Mountain Double
Maximum weight – 120,000 pounds



9-axle Turnpike Double
Maximum Weight – 148,000 pounds



8-axle B-train Double
Maximum weight – 124,000 pounds
(33-foot trailers)



Triple-trailer combination
Maximum weight – 132,000 pounds

<u>Main Feature</u>

- **Broad national LCV operations**

<u>Available Highways</u>

- **RMDs and TPDs – 42,000 mile analysis network**
- **Triples – 60,000 mile analysis network**
- **8-axle B-train double – National Network for STAA vehicles**

<u>Access Provisions</u>

- **RMDs and TPDs – none off the analysis network**
- **Triples – State issued permits**
- **8-axle B-train doubles – current Federal and State provisions**

Triples

A triple-trailer combination generally consists of a two- or three-axle truck-tractor and three trailers in tow. Each trailer is usually 28 feet to 28.5 feet in length. Triple-trailer combinations are usually restricted to maximum GVWs from 105,000 pounds to 129,000 pounds. Triples are permitted to operate in 14 States on limited networks (on highways in 11 States and on toll roads in three States). They are usually restricted to Interstate facilities and four-lane highways with low traffic volumes.

In 1994, total VMT for triple-trailer combinations was 108 million miles out of 99,177 million miles traveled by all combination vehicles. The predominant users of triples are the less-than-truckload (LTL) industry and major package express carriers. This configuration allows the driver to drop off and pick up individual units at multiple points in a given run. In addition, LTL loadings generally fill up the trailer volume before they reach GVW limits. Therefore, they benefit from the additional cubic capacity.

Scenario Description

The LCVs Nationwide Scenario estimates the impact of lifting the LCV freeze to allow LCV operations on a nationwide network. The LCVs would be afforded higher GVW limits (see Figure III-13). All other Federal size and weight controls would remain. The scenario assumes that all States would uniformly adopt the new limits, and therefore captures the maximum impact.

The Vehicles

The longest and heaviest configuration tested in this scenario is the nine-axle TPD. It would be allowed to operate at weights of up to 148,000 pounds GVW and have up to twin 53-foot trailers. The other LCVs would also realize weight increases with the seven-axle RMD being allowed to operate at 120,000 pounds, the eight-axle B-train double at 124,000 pounds and the seven-axle triple-trailer combination at 132,000 pounds. RMDs are assumed to operate with 53-foot and 28.5-foot trailers. TPDs are assumed to operate with two 53-foot trailers. The eight-axle B-train is assumed to operate with two 33-foot trailers.

The Networks

The analysis of this scenario required use of all of the analytical networks described in Chapter II. The 42,500-mile long-double network was used to simulate travel by the RMD and TPD combinations. The more extensive (65,000-mile) analytical network was used to evaluate the operation of triple-trailer combinations. The eight-axle B-train double combination would be permitted to operate on the same network as STAA doubles which is the NN.

Access Provisions

Because of poor offtracking (cornering) performance, the analysis does not allow long double-trailer combinations (TPDs and RMDs) off the designated analytical 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.

Staging areas are assumed at key rural interchanges and the fringes of major urban areas. Work completed for this study (see Chapter VII, Roadway Geometry) indicates that staging areas would be needed every 16 miles on rural freeways. On non-freeway rural highways, staging areas would be needed about every 50 miles. Urban staging area requirements are estimated to range from 2 to 14, depending upon the number of LCV routes approaching a given area. Typically, the analysis indicates that six staging areas are required for each urban area. However, some urban areas require significantly more, such as Dallas which would need twelve.

Trucks with trip origins or destinations in urban areas would use urban fringe staging areas, while through trucks would use the Interstate or other freeway system to their destination. The cost of these facilities is set forth in Chapter VII.

Triple-trailer combinations are allowed direct access, under a State-issued permit, to and from the network without disconnecting the trailers.

H. R. 551 Scenario

H.R. 551, "The Safe Highways and Infrastructure Preservation Act," was first introduced in 1994 during the 103rd Session of Congress, and again in 1997, as H.R. 551, during the 105th Session. The bill would federalize certain areas of truck regulation that are now State responsibilities. This scenario is a subset of the Uniformity Scenario described earlier.

H.R. 551 contains three provisions related to Federal TS&W limits: (1) it would phase out trailers longer than 53 feet, (2) it would freeze State grandfather rights, and (3) it would freeze weight limits (including divisible load permits) on non-Interstate portions of the NHS. However, only the first provision was analyzed.

H.R. 551 Provisions and Background

Phase Out of Trailers Longer than 53 Feet

The proposed legislation would repeal provisions of the STAA of 1982 which grandfathered all trailer lengths longer than 53 feet that were in lawful operation in 1982. States would be prohibited from registering new trailers, containers or other cargo-carrying units longer than 53 feet for operation on the Interstate and those classes of qualifying NHS highways as designated by the Secretary of Transportation. Existing trailers, semitrailers and other cargo units longer than 53 feet or those manufactured up to one year after the date of enactment would be allowed to operate indefinitely.

This section of H.R. 551 is intended to prevent the proliferation of very long semitrailers. It has been asserted that trailers longer than 53 feet are relatively more dangerous than shorter trailers because of off-tracking and swing-out lane encroachment. Further, some maintain that if these longer trailers jackknife they are more likely to hit other vehicles.

As shown in Table III-7, ten States currently permit the operation of semitrailers that are over 53 feet long. Six of the ten States limit the operation of these longer trailers to the NN (which includes the Interstate).

Termination of State Determination of Grandfather Rights

H.R. 551 includes a provision, closely modeled on the ISTEA LCV freeze, which would codify and freeze all Interstate System grandfather rights. The proposed legislation requires the FHWA to publish a list of vehicles or combinations which were lawfully operating at weights over the Federal Interstate weight limits before January 1, 1997. This list would be by route, commodity and weight.

Table III-7. States Routinely Allowing Semitrailers Longer Than 53 Feet

State	Length Limit
Alabama	57 feet
Arkansas	53 feet 6 inches
Arizona	57 feet 6 inches
Colorado	57 feet 4 inches
Kansas	59 feet 6 inches
Louisiana	59 feet 6 inches
New Mexico	59 feet 6 inches
Oklahoma	59 feet 6 inches
Texas	59 feet
Wyoming	60 feet

State authority to determine weight limits under the 1956 or 1975 grandfather clause—as provided for by the Symms Amendment (see Figure III-14)—would be repealed. The freeze would not prohibit any of the existing exceptions to Federal limits, but would constrain States to the existing limits. This would apply to both permitted and non-permitted limits.

Freeze on National Highway System Weights

H.R. 551 proposes a freeze on non-Interstate NHS weight limits, greatly expanding Federal authority to regulate truck weight limits. The freeze would also apply to divisible load permits. At present, States establish vehicle weight limits for their highways other than those on the Interstate System.

For roads, where vehicle weight limits are determined by the Federal government, the proposed weight limit freeze would increase the number of road miles from 44,000 miles (the current Interstate System) to almost 156,000 miles (the NHS). This proposal would effectively eliminate all State flexibility to allow higher vehicle weights.

Scenario Specifications

Figure III-15 summarizes key provisions of this scenario. The scenario has been proposed to preclude States from raising their TS&W limits prospectively. A review of changes in State TS&W laws over the past ten years revealed that such increases have not occurred except in a limited number of cases involving specific commodities or truck configurations. For example, the kinds of divisible load permits have not changed appreciably over the last ten years. However, the number of permits issued has increased (see Table III-8).

This observation is not surprising since the ISTEA freeze has been in place since 1991. The analytical implication, in terms of this study, is that the only feature of the H.R. 551 proposal that can be modeled is the limitation on trailer length. It is

Figure III-14. The Symms Amendment

The Surface Transportation Assistance Act (STAA) of 1982 provided more uniform truck size and weight standards across the country by requiring States to raise weight limits that were lower than the Federal standard. Prior to this there was no Federal legislative provision that would prevent the States from enforcing lower limits.

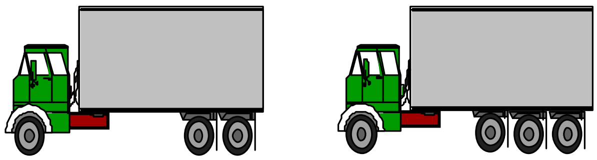
The STAA of 1982 also gave States added authority to determine their own grandfather rights. A provision introduced by Senator Symms, allowed the States to determine which "vehicles or combination thereof... could be lawfully operated within such State on July 1, 1956." Some States have argued, based on this legislation that they are the sole arbiters of their grandfather rights. As a result of this legislation, ten States have claimed grandfather

Table 8. State Permitting of Overweight Loads – 1985-1995

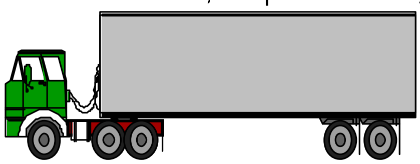
Year	Divisible Single	Divisible Multiple	Divisible Total	Nondivisible Single	Nondivisible Multiple	Nondivisible Total	Total Permits
1985	62,810	90,832	153,642	1,072,776	46,451	1,119,227	1,272,869
1986	53,976	96,193	150,169	1,149,625	59,274	1,208,899	1,359,068
1987	51,824	102,759	154,583	1,136,649	67,132	1,203,781	1,358,364
1988	64,955	112,801	177,756	1,151,732	61,222	1,212,954	1,390,710
1989	67,194	136,267	203,463	1,205,394	76,687	1,282,081	1,485,544
1990	73,270	140,697	213,967	1,321,261	88,362	1,409,623	1,623,590
1991	163,228	160,914	324,142	1,259,176	66,848	1,326,024	1,650,166
1992	184,711	162,040	346,751	1,347,773	92,734	1,440,507	1,787,258
1993	160,847	166,865	327,712	1,325,802	104,870	1,430,672	1,758,384
1994	157,114	198,236	355,350	1,426,143	116,934	1,543,077	1,898,427
1995	169,013	211,502	380,515	1,543,270	106,746	1,650,016	2,030,531

Source: FHWA Annual Inventory of State Practices, Overweight Vehicles–Penalties and Permits, FY85-FY94; and FY95 Annual State Certifications

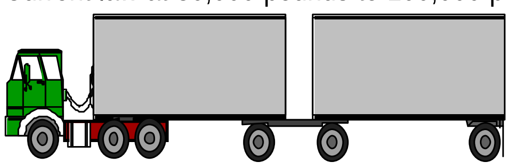
Figure III-15. H.R. 551 Scenario



Two to four-axle single unit truck
Current law at 54,000 pounds to 70,000 pounds



Five to six-axle tractor-semitrailer
Current law at 80,000 pounds to 100,000 pounds



Five to six-axle STAA double trailer combination
Current law at 80,000 pounds

Main Features

- **Phases in elimination of semitrailers over 53 feet long**
- **Assumes status quo weights**

Available Highways

- **National Highway System**

Access Provisions

- **Current Federal and State provisions**

impossible to predict what States might do in the future with respect to changing their TS&W limits, since a meaningful historical trend does not exist.

The Vehicles

H.R. 551 would phase out all semitrailers longer than 53 feet. These trailers are used primarily to transport low-density freight that benefit from the additional cubic capacity. The proposed legislation would not impact other equipment.

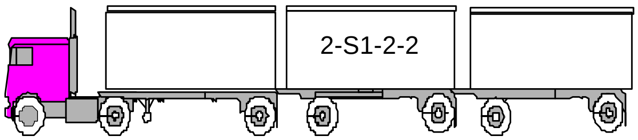
Because the longer trailers in use today would be grandfathered, the analysis assumes that these trailers would remain in use indefinitely. The analysis also assumes that the additional increment of freight that longer trailers would have hauled in the 2000 analysis year will have to be carried in the shorter, 53-foot trailers.

The Network

This scenario does not include any change to the status quo. It is notable, however, that an NHS weight-limit freeze would not create an incentive to increase weight on roads off the NHS because relatively little freight is transported between origins and destinations for which non-NHS routes are practical.

Access Provisions

Figure III-16. Triples Nationwide Scenario



Seven-axle triple-trailer combination
132,000 pounds (maximum)

Main Feature

- **Broad national operation of triple-trailer combinations and new weight limits for triple-trailer combinations**

Available Highways

- **65,000-mile system**

Access Provisions

- **State issued permits**

Current Federal and State access requirements would remain in effect.

Triples Nationwide Scenario

This scenario, a subset of the LCVs Nationwide scenario, would permit the operation of triple-trailer combinations across the country.

Scenario Specifications

Figure III-16 summarizes key provisions of this scenario.

The Vehicles

The Triples Nationwide Scenario focuses on the seven-axle triple-trailer combination which will be permitted to operate nationwide at a GVW of 132,000 pounds.

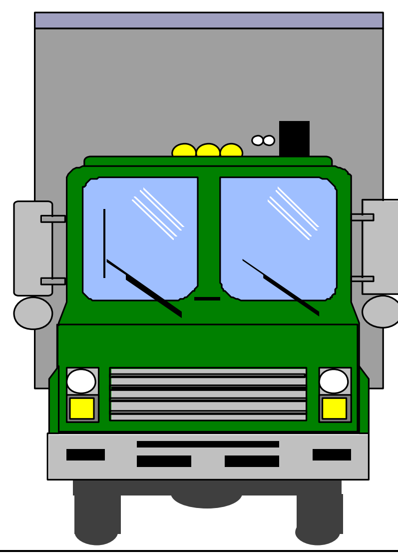
The Networks

This scenario was tested using the 65,000-mile analytical network developed to test triple-trailer combinations. The reader is referred to Chapter II for a discussion of this network.

Access Provisions

Current State access provisions would remain in effect. Triple-trailer combinations are assumed to have direct access to and from the network without disconnecting the trailers, in accordance with State issued permits. Therefore, there is no requirement for staging areas.

CHAPTER IV



Freight Distribution

Introduction

This chapter presents a discussion of the methodology used to evaluate changes in shipper decisions when faced with a change in trucking costs. Of particular interest to this study is the shift of freight from one truck configuration to another, and from one gross vehicle weight (GVW) group to another. Also of concern is the shift in freight between rail and truck.

This information, expressed in truck vehicle-miles-of-travel (VMT) and rail car miles, is important in estimating not only shipper cost savings, but also impacts on pavements, safety, energy consumption, air quality, and noise levels.

Analytical Approach

Figure IV-1 provides an overview of the analytical approach used to estimate the truck VMT and rail car mile impacts of changes in Federal truck size and weight (TS&W) limits. The general structure of the analytical approach is depicted on the left-hand side of Figure IV-1.

The analytical approach incorporates the most appropriate and current data and state-of-the-art modeling techniques. Data are analyzed via modeling techniques with explicit user-controlled assumptions. The next section discusses the data, the model, and assumptions used to generate each scenario's VMT and rail car miles.

Rail and Truck Base Case Traffic

As indicated in Chapter III, the analysis year for this study is 2000 and the base year is 1994. The base year provides the link between the Department of Transportation's (DOT's) *1997 Federal Highway Cost Allocation (HCA) Study* and this *1999 Comprehensive TS&W (CTS&W) Study*. The *HCA Study* provides 1994 and Year 2000 VMT for the study vehicles, disaggregated by weight group (presented in 5,000-pound increments), highway functional class, and State. The base year data for the rail car mile traffic comes from the Surface Transportation Board's (STB's) 1994 Waybill Sample (see Figure IV-2).

The Year 2000 truck VMT and rail car miles were projected by applying estimated growth rates to the 1994 base year data. Annual truck VMT growth is projected at 2.6 percent, consistent with the *HCA Study*. Growth estimates for rail shipment car miles were developed by DRI/McGraw Hill ("International and Domestic Freight Trends," May 1996).

DRI/McGraw Hill estimates that absent any changes to the Nation's TS&W limits, rail carload car miles will increase 2.2 percent annually, and rail intermodal car miles will increase 5.5 percent annually.

The truck and rail freight diversion analysis may be divided into three groups: (1) truck-to-truck, (2) rail-to-truck, and (3) truck-to-rail. The following two sections focus on truck-to-truck and rail-to-truck diversion. Current analytical and data constraints preclude the estimation of truck-to-rail diversion. Although a decrease in TS&W limits may cause some truck traffic to divert to rail, this diversion is likely to be relatively minor.

Figure IV-1. Analysis of Scenario Vehicle Miles of Travel and Car Miles

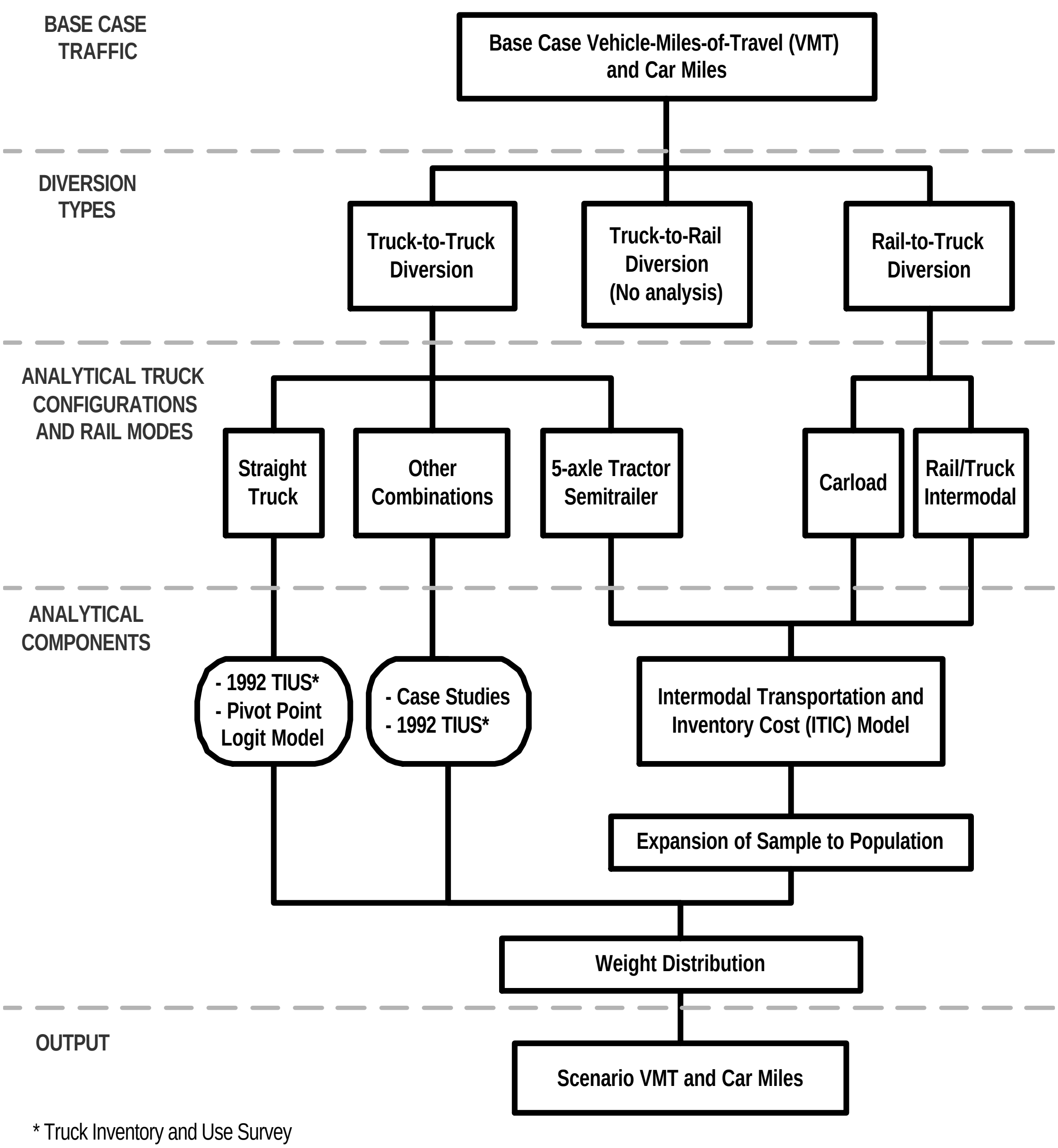


Figure IV-2. The Surface Transportation Board's Waybill Sample

The Waybill is the railroad's bill of lading and contains a great deal of detailed information. The sample includes 2.5 percent of all railroads' Waybill records. The Surface Transportation Board's complete Waybill database contains 192 data items for each record. The data items used in this study include:

- location codes for the origin and destination of each shipment,
- commodity shipped,
- rail equipment used,
- shipment weight,
- shipment revenue,
- originating, terminating and intermediate railroads, and
- junction points between railroads.

Diversion

Truck-to-Truck Diversion

Diversion of freight from one truck configuration to another accounts for a substantial share of the total change in truck VMT associated with TS&W policy options. The analysis of truck-to-truck diversion is divided into single-unit trucks (SUTs), five-axle tractor semitrailers and other combination trucks. These subdivisions are based on the availability of data.

Single-unit and other combination truck analyses rely on aggregate weight distribution and operational characteristics data. Analysis of the five-axle tractor semitrailer utilizes a shipment-by-shipment data set which includes weight distributions and operational characteristics.

Single Unit Trucks

Three- and four-axle SUTs tend to operate at, near or above the current Federal weight limits. These trucks generally transport freight in short-haul operations of 200 miles or less. Often SUTs are designed to perform a specific task. Common examples of SUTs are dump trucks, garbage haulers, and transit mixers.

The diversion analysis for SUTs depends on weight distributions from the *HCA Study* and relative changes in payload ton-mile costs for the impacted traffic. The analysis is discussed further in the Analytical Models Section.

Five-Axle Tractor Semitrailer

The five-axle tractor semitrailer is the most common combination vehicle, comprising the largest and fastest growing segment of combination trucks. These vehicles account for 78 percent of the combination truck fleet and are growing at a rate of 3.8 percent per year. As outlined in Figure IV-3, the five-axle tractor semitrailer encompasses a large variety of operations and body types.

Figure IV-3. Five-Axle Tractor Semitrailers

Five-axle tractor semitrailers encompass many different body types. Forty-four percent of five-axle tractor semitrailers are vans, 22 percent are platforms, 10 percent are dump bodies, 7 percent are tank trucks and 17 percent are other body types. Thirty-eight percent of the five-axle tractor semitrailers operate short-haul, under 200 miles. An example of this type of truck is a platform or low-boy trailer used to deliver building supplies. These operations tend to be affected by increases in truck weight more than truck size, since they handle high density (heavier weight) materials. Sixty-two percent of the five-axle tractor semitrailers operate long-haul, over 200 miles. An example of this type of truck is a van trailer used to deliver merchandise from a manufacturer to a retailer's warehouse. These operations tend to be impacted by increases in truck size more than truck weight, as packaged finished goods are low density (lighter weight).

Freight diversion to or away from the five-axle tractor semitrailer accounts for the largest changes in VMT for each scenario. Figure IV-4 highlights the types of truck configurations into which freight from a five-axle tractor semitrailer could shift in the model simulation process. This analysis was performed using the Intermodal Transportation and Inventory Cost (ITIC) model which is described in detail later in this chapter.

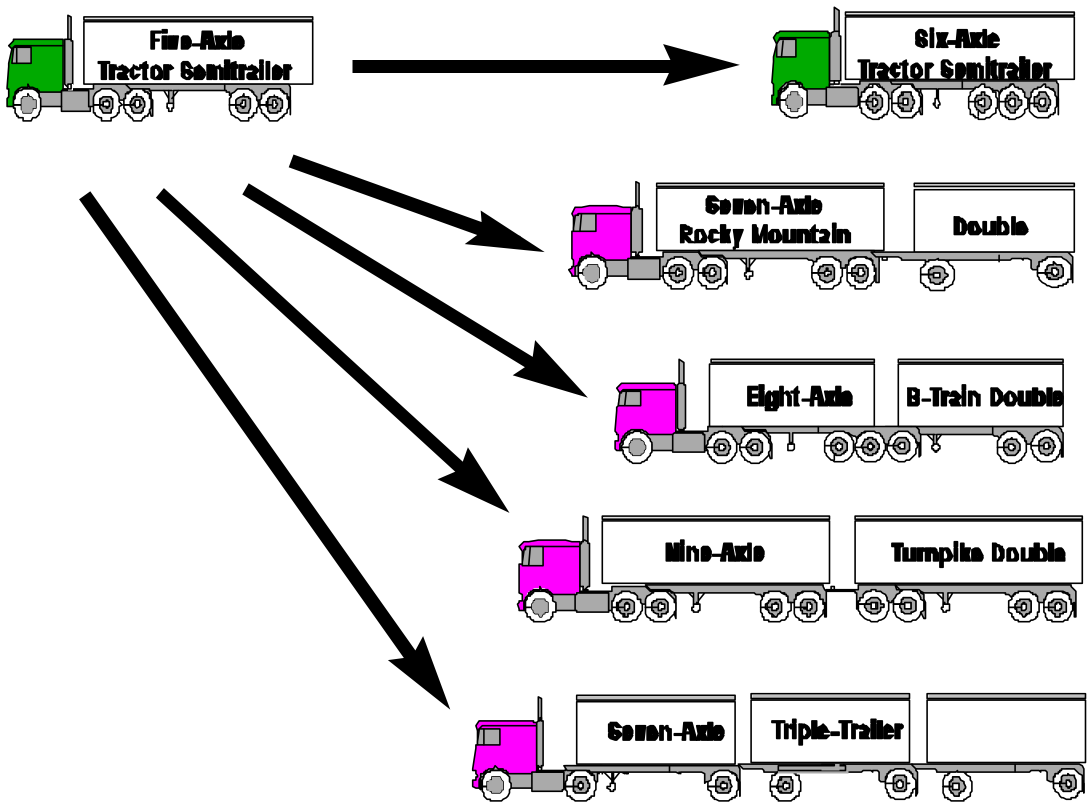
Other Combinations

In the case of other combination trucks, the ITIC Model cannot be used because a shipment-by-shipment data sample is not available. Instead, diversion associated with these vehicles is estimated using operating weight distributions from the *HCA Study* and the 1992 Truck Inventory and Use Survey (TIUS). Diversion of freight to and from the following vehicle types is estimated:

- Five-axle double-trailer combinations;
- Six-axle double-trailer combinations;
- Six-axle tractor semitrailer combinations;
- Seven-axle Rocky Mountain Double (RMD) trailer combinations;
- Eight-axle double-trailer combinations;
- Nine-axle Turnpike Double (TPD) trailer combinations; and
- Seven-axle triple-trailer combinations.

These vehicles vary widely in their use. For example, the five- and six-axle double-trailer combinations are principally used by less-than-truckload (LTL) carriers. LTL carriers combine shipments from several sources to create full truckload (TL) shipments. These packages generally are

Figure IV-4. Five-Axle Tractor Semitrailer Diversion Options



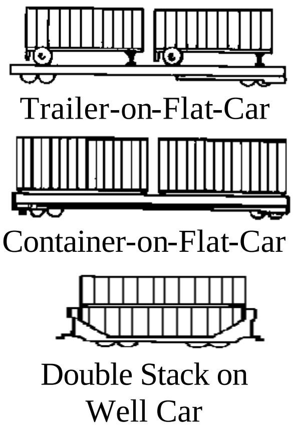
light and fill the truck's cubic capacity before approaching its weight limit. Such operations would benefit from an increase in vehicle size, not weight. Often, the opposite is true for seven-axle RMDs hauling raw materials under special State permits in some Western States. These trucks operate at grandfathered State weight limits which exceed the Federal limit of 80,000 pounds and would likely be used more widely if Federal weight limits were increased.

Rail-to-Truck Diversion

Given an increase in TS&W limits some rail traffic would divert to the newly allowed truck configurations. The diversion analysis focuses on truck-competitive rail shipments, for example, paper products that currently travel on both rail and truck. In rail-truck competitive markets, the increase in TS&W limits would reduce truck transportation costs, causing some shippers to reevaluate their choice of mode.

However, a large portion of rail shipments are not truck competitive and are unlikely to shift to truck, regardless

Figure IV-5. Rail Intermodal Equipment



*Drawings not to scale.

of changes in TS&W limits. Two-thirds of rail shipments are bulk commodities moving in large quantities. For example, coal is often moved as a single shipment of over 40 rail cars.

Rail shipments are classified as either rail intermodal or rail carload. The distinction between the two is made because of operational differences which are discussed in the following sections.

<u>Rail Intermodal</u>

Rail intermodal freight is transported in containers or trailers. Each container or trailer is placed on a rail flat car or well car. Figure IV-5 shows three common rail intermodal types: (1) trailers loaded on a flat car; (2) containers loaded on a flat car; and (3) containers loaded in a double stack configuration on a well car. Rail inter-modal traffic is referred to as trailer-on-flat-car/container-on-flat-car (TOFC/COFC).

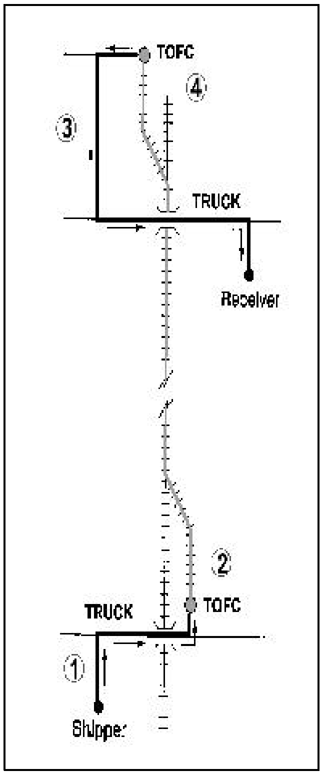
Intermodal shippers include: (1) large transoceanic carriers who move hundreds of containers with each voyage; (2) for-hire trucking companies who move conventional truck trailers on rail; (3) LTL carriers; and (4) intermodal marketing companies who consolidate small numbers of usually domestic containers and trailers from many small shippers.

Rail intermodal carriers serve the same markets as truck carriers, often competing for the same freight. Figure IV-6 shows an example of TOFC service. First, a TOFC shipment leaves the shipper via truck and travels over-the-road to the railroad. Second, the railroad lifts the trailer onto a rail car. Third, the trailer travels, by rail, to the rail intermodal facility closest to its final destination. Fourth, the railroad lifts the trailer off the rail flat car where a truck tractor attaches to the trailer and delivers the shipment, over-the-road, to the receiver. If the price of using trucks became less expensive relative to rail intermodal, then the trailer might complete the move over-the-road without using the railroad.

<u>Rail Carload</u>

The 1994 Waybill Sample indicates that rail carload traffic accounts for 86 percent of all tons hauled by the railroads; the remaining 14 percent being TOFC/COFC. Rail carload traffic operations include over ten different equipment types. Examples include: (1) box cars, generally used for dry and packaged goods; (2) hoppers, usually used for bulk raw materials and grain; and (3) tanks, usually used for liquid chemical and petroleum products. Figure IV-6 provides illustrations of each of these equipment types. Among the carload body types, the box car competes the closest with truck.

Figure IV-6. Trailer-on-Flatcar/Container-on-Flatcar Operations



Analytical Models

The previous section provided an overview of the types of traffic that could be impacted by a change in TS&W limits. This section provides the estimation techniques used to determine truck VMT and rail car miles given a change in TS&W policy.

For purposes of analysis, truck traffic is divided into short-haul and long-haul. This section begins with a discussion of the short-haul truck analysis. The short-haul analysis uses a model which predicts the distribution of payload ton-miles for the affected configurations and weight groups given changes in relative operating costs.

The long-haul truck VMT and rail car mile analysis use the ITIC Model, which will be discussed in more detail following the short-haul truck model presentation. The final section discusses the estimation of the post-diversion weight distribution for the affected truck configurations.

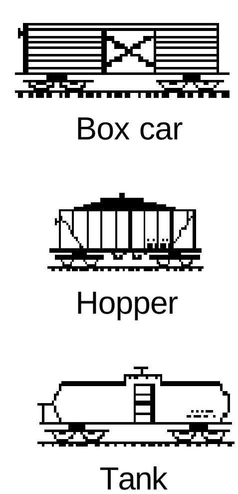
Short-haul Truck Analysis

The short-haul truck analysis focuses on the heavily loaded SUTs and those combination trucks which operate under 200 miles, on a typical haul.

The first step in the SUT analysis is to identify the relevant configurations which are affected by the Federal weight limits. For example, in the North American Trade Scenarios, which assume an increased tridem-axle weight limit, the four-axle SUTs would attract freight from the three-axle SUTs.

Next, the analysis determines the proportion of three- and four-axle SUT VMT which would be impacted by the scenario. A review of the weight distributions from the *HCA Study* shows those three- and four-axle SUTs with operations at or above the Federal weight limits. This is assumed to be the VMT where trucks operate at 85 percent to 110 percent of the Federal maximum GVW. The likelihood of this traffic diverting depends on the relative change in operating costs between the current configuration and the four-axle SUT with a higher GVW.

Figure IV-7. Rail Carload Equipment



*Drawings not to scale.

Short-haul combination trucks are assumed to have diversion which mirrors the diversion of the long-haul combination trucks.

Long-haul Truck and Rail Analysis

The long-haul truck and rail analysis utilizes a unified approach in estimating diversion. The analysis accounts for both the change in transportation cost (as was done for the short-haul analysis) and the impact on inventory costs. For freight traveling over 200 miles, it is important to include the changes in inventory costs which could offset potential savings (or costs) of diverting to a different mode or configuration.

Model Decision Making Process

The long-haul diversion decision is captured in the ITIC Model. The framework of the ITIC Model is shown in Figure IV-8. The ITIC Model is used to evaluate truck-to-truck, rail carload-to-truck and rail intermodal-to-truck diversion. The model comprises two modules, one for transportation costs and one for inventory costs. The inventory cost module is the same for both rail and truck observations. However, the transportation cost module is different for truck and rail because the two modes are represented by different data sets. Figure IV-9 describes factors affecting truck and rail mode choice decisions.

The model determines whether a shipment will divert by estimating the total logistics cost (transportation cost plus inventory cost) to move the shipment by the various modes and truck configurations. If the total cost is lower for a proposed truck configuration, the shipment will divert. The inventory and transportation cost estimation procedures are detailed in the following sections.

<u>Inventory Cost</u>

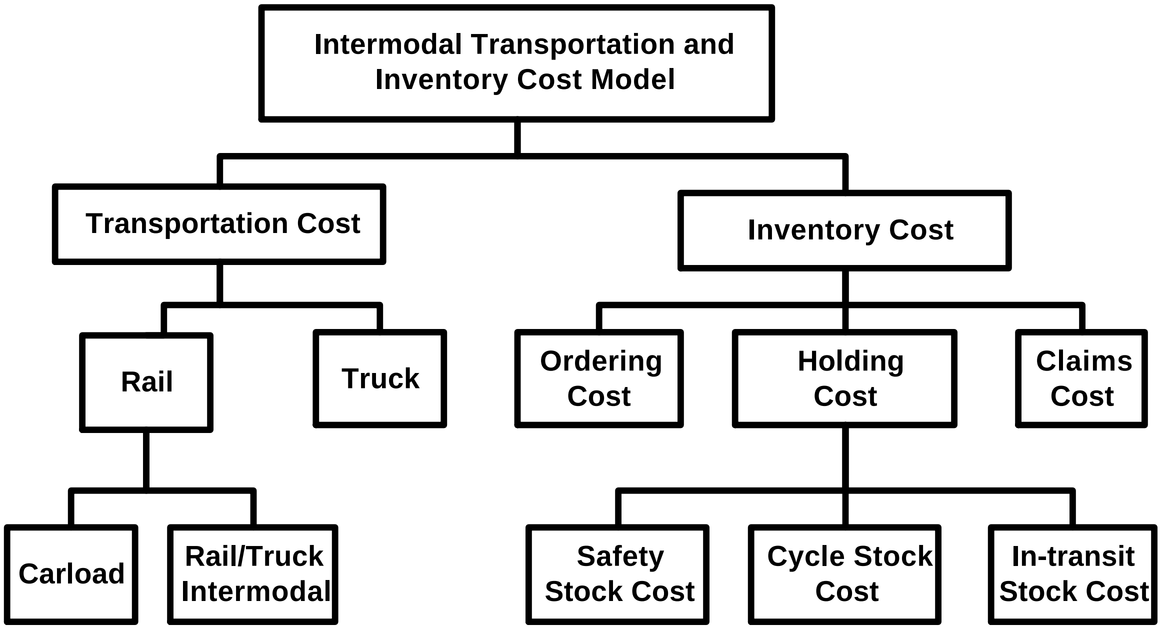
"Inventory cost" is the cost of maintaining stock for either a manufacturing process or to meet customer demands. Inventory costs are calculated in the same manner for both truck and rail moves. Three broad components comprise inventory cost: holding cost, claims cost, and order cost.

Inventory holding cost, which is synonymous with the cost of warehousing inventory, includes the costs associated with safety, cycle, and in-transit stock. Safety stock protects shippers against potential shipping delays. Safety stock requirements are determined by the lead time for each shipment (the sum of the shipment transit time and wait time) and the shipper's estimate of relative modal reliability.

The second element of inventory holding cost is the cycle stock cost, or the average stock on-hand between shipments. The final element is the in-transit stock cost, which is the cost of capital dedicated to purchase the goods.

The second inventory cost component is the claims cost. This is the annual cost of insurance for loss and damage. It includes a penalty for the opportunity cost of funds tied-up during settlement. The final component of the inventory cost is the shipment order cost. This is the cost of

Figure IV-8. Intermodal Transportation and Inventory Cost Model



administering the paperwork and placing an order.

Transportation Cost

"Transportation cost" refers to the cost to the shipper of moving goods from origin to destination. The transportation cost is calculated differently for truck and rail shipments. For truck shipments, it is calculated by multiplying the cost-per-mile by the shipment distance.

For rail shipments, the transportation cost for carload and intermodal shipments varies slightly with intermodal shipments having an additional truck or drayage cost. The transportation cost for rail carload shipments is reported as "revenue" in the Waybill Sample. However, the ITIC Model assumes that if necessary, to avoid losing a shipment, railroads may reduce their rates down to their variable costs. This means the railroads are willing to forgo any contribution to their capital infrastructure and profit to retain a shipment before allowing that shipment to divert to truck. Issues arising from this discounting assumption are discussed in Chapter XI.

Intermodal shipments have an additional truck cost component for each rail move. The railroad cost reflects the cost to haul the shipment over the railroad, while the truck cost is the charge for moving the shipment from the shipper to the railroad and from the

Figure IV-9. Truck and Rail Mode Choice

Shippers choosing between truck and rail often consider a trade-off between price and service. In terms of price-per-ton-mile, rail service is almost always less expensive than truck service. In terms of service quality, truck service offers door-to-door delivery and typically faster deliveries. The price versus convenience trade-off is close in those markets where there is significant competition between rail and truck. In these "rail-truck competitive markets" shippers routinely make choices between truck and rail service.

The most competitive rail-truck service is intermodal. Intermodal service uses equipment that makes part of the journey by highway in trailers or containers, so anything that goes in a truck trailer or container could move intermodally. An equivalent statement can be made for box cars, but box cars are less used for general merchandise shipments. Paper, auto parts, and lumber account for the preponderance of box car traffic.

Other rail traffic is either low-value goods where shippers are more concerned about the price of shipping than the convenience of door-to-door service, or goods of such a nature that rail has a formidable cost advantage over highway movement. Coal, grain, and most chemicals fall into this latter category. Shippers of these commodities use trucks only for comparatively short distances or when rail service is temporarily unavailable, and even then only for short moves.

railroad to its final destination. The railroad cost component is calculated in the same manner as the transportation cost for rail carload and the truck cost component is calculated in the same manner as the transportation cost for trucks.

Limitations

In the interest of simplicity, the ITIC Model applies an "all-or-nothing" rule to determine if a shipment will divert. In other words, if the cost of transporting a given freight shipment from the Waybill Sample is one cent cheaper on an alternative truck configuration or mode, the shipment is predicted to divert. By extension, all similar shipments that the sample shipment represents would also be assumed to divert. This approach is likely to overstate the potential for diversion. If the difference in costs between truck configurations or modes is slight, it is unlikely that the full amount of that type of freight shipped in a year, would automatically divert.

The model only generally captures the service considerations that are a part of each shipper's decision making process. Service considerations, such as spoilage, are not available in a form suitable for the ITIC Model.

In addition, the commodity descriptions in the data sets

Figure IV-10. Intermodal Transportation and Inventory Cost Model Development

Development of the Intermodal Transportation and Inventory Cost (ITIC) Model involved several stages of sensitivity testing and expert reviews. An expert group was established to evaluate, in detail, the diversion approach and results. This group, comprised of experts in truck and rail operations, inventory and diversion modeling, reviewed both interim and final products.

The group examined the model structure, underlying theory and the reasonableness of the analytical output. The product of this review process was a detailed understanding of the determinants that influence mode selection in the ITIC Model.

In addition, the review process highlighted limitations of the model and areas requiring further development.

may be too generic to determine the service level to be assigned. For example, if a shipment consisted of "food and kindred products," it is impossible to tell whether this is fresh or canned peaches. Therefore, in the case of fresh peaches, the model would assume incorrectly that the shipment is not perishable. Perishable goods would have short delivery deadlines, which could decrease the diversion of a shipment from a semi-trailer to a long double-trailer combination (RMD or TPD) or a triple-trailer combination. This is because more time would be required for a shipper to coordinate the movement of trailers with different service requirements.

The analysis year of the study is 2000. The potential diversion of traffic between truck classes and between truck and rail is estimated assuming that shippers and carriers could immediately change their operations to take advantage of differences in relative transportation costs among modes. In practice it would take many years for all carriers to adapt their fleets to take best advantage of revised TS&W limits. Likewise, it is assumed that the highway infrastructure needed to accommodate truck configurations that may operate under revised TS&W regulations is immediately available. Again, in practice, it would take many years before all bridge and geometric design improvements were made. Thus the study assumes that conditions approaching a long-run equilibrium are achieved instantly. Similar assumptions have been made in previous TS&W studies by the Department and others.

Input Data

Truck

This section discusses the truck data set required for the ITIC Model. Because a single data set which captures all the relevant variables is not available, different sources are used to capture over-the-road shipments, transportation cost, line-haul miles, repositioning miles and commodity attributes. The sample of over-the-road shipments is based on the 1993-1994 Association of

American Railroads' North American Transportation Survey (NATS). The survey collected 24,639 responses. Because each respondent was asked about their current and previous shipment, the sample contained data on 49,278 shipments. For this analysis, short-haul shipments of less than 200 miles were deleted leaving a data set of 47,135 shipments. Also excluded were shipments by autorack trucks, since the study's scenarios do not specifically analyze those vehicles.

Figure IV-11. Diversion of Freight Transported in Short Double-Trailer Combinations

Because a sample of shipments by five- and six-axle double-trailer combinations does not exist, the diversion analysis relied upon the 1992 Truck Inventory and Use Survey, as well as industry observation. The survey shows that 70 percent of the short double-trailer combinations are used in less-than-truckload (LTL) operations. The diversion analysis assumes that to increase the efficiency of the fleet, current LTL double-trailer operations would divert to triple-trailer operations. An additional assumption is made that the other 30 percent of short double-trailer combinations have operations similar to LTL carriers and would also experience cost savings from adding an additional trailer.

The NATS data provide shipment information for origin and destination pairs, truck body type and commodity hauled. For modeling purposes, it is assumed that there are two body types, van and tank, although body type is more detailed in the survey.

The NATS data do not include truck configuration information, such as the number of axles, trailers or trailer length. The data do not distinguish between a five-axle tractor semitrailer, a short double, or an LCV. According to the 1992 TIUS report, 80 percent of all trucks operating over 200 miles are five-axle tractor semitrailers. Therefore, it is assumed that all the shipments represented in NATS are traveling in five-axle tractor semitrailers. This assumption does not affect the overall distribution of VMT among vehicle classes because base case traffic by configurations other than the five-axle tractor semitrailer is analyzed separately.

There were three adjustments to the NATS data. The data were adjusted for trip length to avoid the bias associated with sampling mostly long trips in the survey. The second adjustment was for partial loads. The NATS did not include a question on whether the trailer was fully loaded. Responses to previous roadside surveys were used to estimate partial loads. The final adjustment was to expand the sample of truck moves to the total truck VMT. The diversion results were expanded to the *HCA Study* total VMT by configuration, State and highway functional class.

Four variables were added to the shipment records in the NATS data set:
(1) transportation cost;
(2) line-haul miles;
(3) repositioning miles; and
(4) commodity information.
The truck transportation cost-per-mile is based on a

Figure IV-12. ITIC Model Calibration

A Base Case Scenario, which assumes current Federal truck size and weight (TS&W) rules, was analyzed using the Intermodal Transportation and Inventory Cost (ITIC) Model. The results were evaluated to see how accurately the model determined the truck configuration and mode choice of shipments under current Federal TS&W limits. Since shipper decision making results are known for the Base Case Scenario, this provides a good test case by which to verify the model results.

The carload and truck input data sets were separately analyzed with the ITIC Model. In the base case, if the model selected a mode different from the mode reported in the data set, the shipment was called a “misassigned” record. For example, if a carload rail observation “diverted” to a five-axle tractor semitrailer then that record was said to have “misassigned” since the model did not predict that rail carload was the preferred mode.

In the truck analysis, the misassigned records were less than one percent of the input records. This means that in virtually all cases, the ITIC Model correctly predicted the truck configuration consistent with the input data set.

In the rail carload analysis, 6,563 records were misassigned in the base case; that is the model incorrectly predicted that the shipment would travel by truck. This was equal to 2.53 percent of the carload shipment records in the sample set. This level of error is good for a complex model such as ITIC.

Most, 56 percent, of the misassigned carload records involved transportation equipment. In fact, almost one-half of the total transportation equipment records in the carload sample were misassigned. Apparently, the model does not capture, or is not sufficiently sensitive to, all of the relevant mode choice considerations characterizing the transportation equipment market. The next most common misassigned commodity was pulp and paper, accounting for 12 percent of the misassigned records.

The misassigned records could result from model error or the absence of a critical variable. However, it is also possible that these misassigned shipments are very truck/rail competitive; and therefore highly susceptible to diverting. Deleting the records may result in underestimating diversion. The same conclusion holds if the shipments represent shipper error, i.e., if the shipper lacked complete information about all the relevant costs, and elected to ship by rail even though trucks would have been more advantageous.

In this analysis the misassigned records have been removed from the vehicle-miles-of-travel estimates. This could potentially lead to an understatement of rail diversion.

report by Jack Faucett Associates (August, 1991), "The Effect of Size and Weight Limits on Truck Costs." The report summarizes cost-per-mile information by body type, truck configuration and payload. The modeling approach assumes motor carrier rates may be closely approximated by a per-mile rate.

Line-haul and repositioning miles are also added to the NATS shipment data. The line-haul miles were computed for each truck configuration using the networks presented in Chapter II and the origin and destination cities included in NATS. An estimate of repositioning miles was added to the line-haul distance to reflect the distance a truck would likely travel before obtaining a return shipment.

The final additional data variables provide commodity attribute information on price-per-pound, annual use rate, and shipping density for a commodity. Estimates of the commodity price-per-pound were obtained from the Bureau of Census' 1993 Commodity Flow Survey (CFS) Report.

Rail

The primary source of railroad data is the STB's 1994 Waybill Sample. Records for the following were excluded:
(1) shipments under 200 miles, since short rail moves are not competitive with truck; (2) coal shipments traveling more than 500 miles, since this heavy bulk freight is not directly competitive with trucks;
(3) autorack shipments, since autoracks are not explicitly analyzed in the illustrative scenarios; and
(4) movements of locomotive and empty rail equipment.

The ITIC Model uses the following Waybill Sample variables: origin and destination pairs, commodity shipped, annual tons shipped, number of railroads, equipment type, sample-to-population expansion factors and the variable cost for the rail shipments.

Of the variables just described, the most important for estimating freight diversion is the railroad's variable cost. It is more important than rail revenue since the ITIC Model assumes that each shipment by rail can be discounted down to the railroad's variable cost before the freight would divert to truck. However, rail revenue is important to the rail viability analysis in Chapter XI, "Rail Impacts."

The variable cost for rail shipments is estimated by the STB via an accounting procedure that uses railroad-by-railroad data to compute variable cost for sixteen equipment types.

An expert review of the Waybill and the ITIC Model's analysis of the Waybill records revealed that the variable cost field could not be used in the ITIC Model for intermodal shipments.

The variable cost for intermodal shipments was estimated using an accounting procedure similar to the STB's method. The costs were expanded from an estimation of selected intermodal city pairs which represented a cross-section of annual tons-per-year and mileage groups. The costing method was adjusted for train length, rail yard dwell time, and number of containers or trailers-per-rail car, among other factors specific to each city pair.

Four variables were added

to the Waybill records:
(1) commodity information;
(2) truck repositioning miles;
(3) truck line-haul; and
(4) pick-up and delivery cost for intermodal shipments. The commodity attribute information is price-per-pound and shipping density for each commodity. Estimates of the commodity price-per-pound were obtained from the Bureau of Census' 1993 CFS Report.

For each rail shipment, the distance to move the shipment by the various truck configurations was added to the rail database. This provided a means of comparing the rail line-haul distances with the truck line-haul distances. The truck line-haul miles were computed in the same manner described under the truck data section.

The pick-up and delivery cost for intermodal shipments is the cost of getting the container or trailer to and from the railroad network. The distance that the intermodal shipment travels by truck was estimated using the population density for each Business Economic Area as designated by the Census Bureau.

Weight Distribution

The final step in producing each scenario's VMT estimate is to determine the operating weight distribution (by percent of VMT) for each configuration. The operating weight distribution is derived using the scenario payload-ton-miles and the 1994 weight distribution from the *HCA Study*. For example, the solid line in Figure IV-12 shows the 1994 weight distribution for four-axle SUTs. The horizontal axis shows the 5,000-pound weight groups and the vertical axis shows the percent of four-axle SUT VMT in each weight group. Notice that the distribution is bimodal with one peak at the empty or tare weight and one at the average loaded weight. The dashed line in the exhibit shows the new weight distribution for the Uniformity Scenario. It is assumed to follow a distribution similar to the base 1994 distribution.

Figure IV-13. Weight Distribution Example - Base Case and Uniformity Scenario for Four-Axle Single Unit Truck

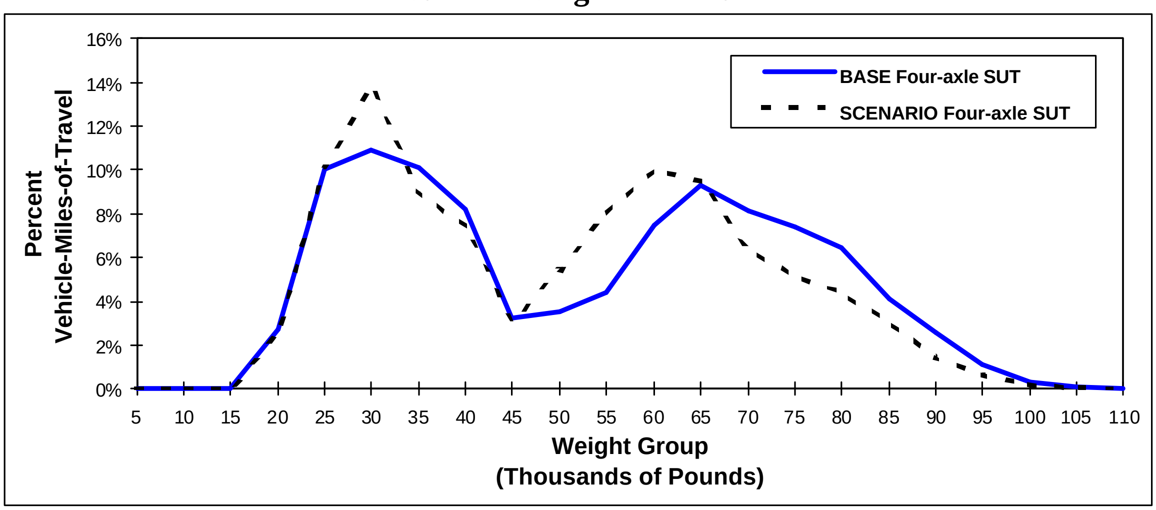


Figure IV-14. Use of the Intermodal Transportation and Inventory Cost Model in Analyzing the Uniformity Scenario

Although the Intermodal Transportation and Inventory Cost Model is used to analyze truck-to-truck and rail-to-truck diversion for the majority of the scenarios, it is not used to analyze the Uniformity Scenario. This scenario requires a level of precision beyond the current truck data set.

The Uniformity Scenario requires evaluation of State grandfathered limits. The input data is not broad enough to capture trucks traveling on roads coming under State grandfather exemptions.

There are two steps in determining the new weight distributions. First, the average loaded weight peak is adjusted for the new payload-ton-miles. Second, the empty weight peak is adjusted by the ratio of empty-to-loaded miles: (1) for short-haul (less than 200 miles), the ratio is one empty mile for every loaded mile; or (2) for long-haul, the repositioning miles from the ITIC Model are used to estimate the ratio of empty-to-loaded miles.

Assessment of Scenario Impacts

Uniformity Scenario

The Uniformity Scenario tests the impact of eliminating State grandfather authority and establishing current Federal TS&W limits on the National Network (NN) for Large Trucks. It would result in decreased weight limits in States that have grandfathered axle or gross vehicle weights that currently exceed Federal limits, or higher weights on non-Interstate portions of the NN that currently have lower limits than Federal limits.

For this scenario, the primary analytical input to estimate truck-to-truck diversion was the *HCA Study's* distribution of VMT by State, functional class, and 5,000 pound weight group. The analysis indicates that the weight distribution shifts toward the higher functional class highways in States where grandfather rights exist. Figure IV-15 outlines how freight currently traveling in trucks with grandfather exemptions would likely respond to the elimination of these exemptions.

Potential diversion from truck-to-rail was not addressed in this scenario. As previously discussed, the capability to estimate railroad rates for a given truck move does not currently exist.

Figure IV-16 shows the impact of the Uniformity Scenario on SUTs, truck-trailer, and tractor semitrailer combinations. Figure IV-17 shows the impact on multi-trailer combination trucks.

Figure IV-18 shows the VMT impact for the total heavy commercial truck fleet for the Year 2000. As the charts indicate, the configurations most significantly affected are those with six or more axles. These are the configurations that State grandfather rights allow to operate above the 80,000-pound Federal limit.

The six-axle tractor semitrailer is projected to experience a 42 percent decrease in VMT from 6,059 million miles to 3,519 million miles. VMT for the seven-axle tractor semitrailer would decrease 74 percent from 546 million miles to 141 million miles. These operations divert to the five-axle tractor semitrailer.

Double-trailer combinations with seven or more axles also experience significant freight diversion. The analysis indicates that the seven-axle double-trailer combination would decrease 54 percent, from 632 million miles to 290 million miles. The VMT associated with the eight- and nine-axle double-trailer combinations would decrease 74 percent from 759 million miles to 198 million miles. The analysis indicates that freight from these operations would divert to five-axle tractor semitrailer combinations.

Figure IV-15. Uniformity Scenario - Likely Truck Configuration Impacts

Original Truck Configuration		Likely Reaction to the Scenario
Three-axle single unit	ö	Less payload in a three-axle single unit
Four-axle single unit	ö	Less payload in a four-axle single unit
Five-axle tractor semitrailer	ö	Less payload in a five-axle tractor semitrailer
Six-axle tractor semitrailer	ö	Change to a five-axle tractor semitrailer
Six-axle double-trailer combination	ö	Change to a five-axle tractor semitrailer
Seven-axle double-trailer combination	ö	Change to a five-axle tractor semitrailer
Eight-axle (or more) double-trailer combination	ö	Change to a five-axle tractor semitrailer
Triple-trailer combination	ö	Change to a five-axle tractor semitrailer
Five-axle truck-trailer	ö	Less payload in a five-axle truck-trailer
Six-axle truck-trailer	ö	Less payload in a six-axle truck-trailer
Five-axle double-trailer combination	ö	Less payload in a five-axle double-trailer combination

Figure IV-16. Impacts of Uniformity Scenario on VMT by Single Unit Trucks, Truck-Trailers, and Tractor-Semitrailers

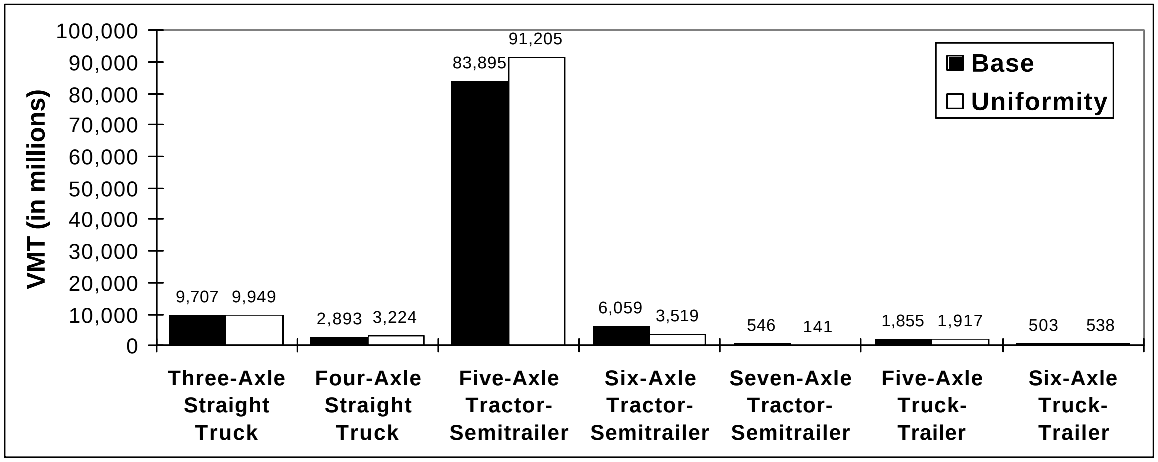
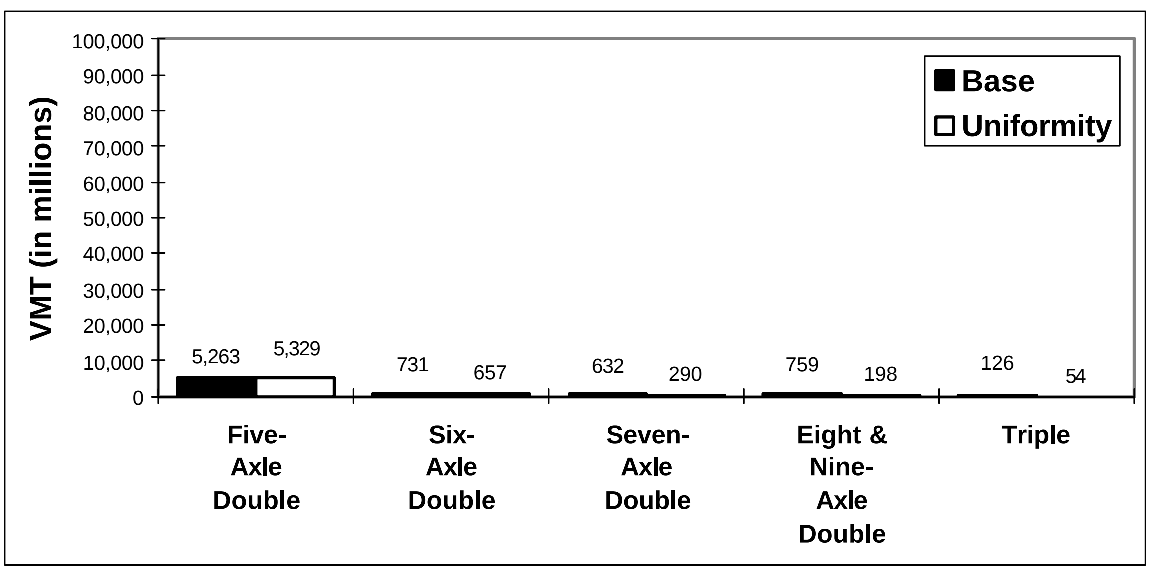


Figure IV-17. Impacts of Uniformity Scenario on Multitrailer Combination VMT



North American Trade Scenarios

There are two North American Trade Scenarios: the first tests a 44,000-pound tridem axle and the second tests a 51,000-pound tridem axle. These axle weights are tested on two common vehicles -- the four-axle SUT and the six-axle tractor semitrailer -- and one vehicle that is not widely used in the U.S.-- a twin 33-foot eight-axle double-trailer combination.

44,000-pound Tridem Axle

This scenario specifies the maximum legal GVWs for the four-axle SUT at 64,000 pounds, the six-axle tractor semitrailer at 90,000 pounds and a twin 33-foot eight-axle double-trailer combination at 124,000 pounds.

Figure IV-19 outlines assumptions regarding how freight currently traveling in the affected configurations would respond to the new tridem axle weight limit.

Figures IV-20 and IV-21 summarize the analysis results. Total heavy commercial truck VMT for the Year 2000 decreases by 11 percent. The three-axle SUT VMT is reduced by 12 percent, from 9,707 million miles to 8,529 million miles. VMT for the four-axle SUT increases 24 percent, from 2,893 million miles to 3,595 million miles. The five-axle tractor semitrailer VMT is reduced by 73 percent, decreasing from 83,895 million miles to 22,274 million miles. This represents the freight traveling near or above the 80,000-pound Federal weight limit or filling a 53-foot trailer. That freight diverts to: (1) the six-axle tractor semitrailer which experiences a 3 percent increase in VMT, from 6,049 million miles to 6,209 million miles; or (2) the eight-axle double-trailer combination whose VMT increases from 683 million miles to 49,003 million miles.

Figure IV-18. Total VMT, Base Case Vs. Uniformity Scenario

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	128,288
Uniformity Scenario	132,351
Percent Change	3.2%

Truck-to-Truck Diversion

All truck freight traveling near or above the Federal TS&W limits is impacted by this scenario. Weigh-out commodities such as frozen foods, logs, pulp, paper, building materials, chemicals, fuels, and raw materials divert to the higher payload tridem axle configurations, and cube-out commodities such as processed food, farm produce, textiles, furniture and manufactured goods divert to the higher cube twin 33-foot eight-axle double-trailer combination. The diversion caused by cube-out freight moving to the highest cube truck is larger than the diversion

Figure IV-19. Likely Truck Configuration Impacts for North American Trade Scenario

Original Truck Configuration		Likely Reaction to the Scenario
Three-axle single unit	ö	Change to a four-axle single unit
Four-axle single unit	ö	More payload in a four-axle single unit
Five-axle tractor semitrailer	ö ö	Change to a six-axle tractor semitrailer Change to a eight-axle double-trailer combination
Six-axle tractor semitrailer	ö	More payload in a six-axle tractor semitrailer
Eight-axle (or more) double-trailer combination	ö	More payload in a eight-axle double-trailer combination

Figure IV-20. Impact of North American Trade Scenario (44,000 lb. Tridem Axle) on VMT By Different Vehicles

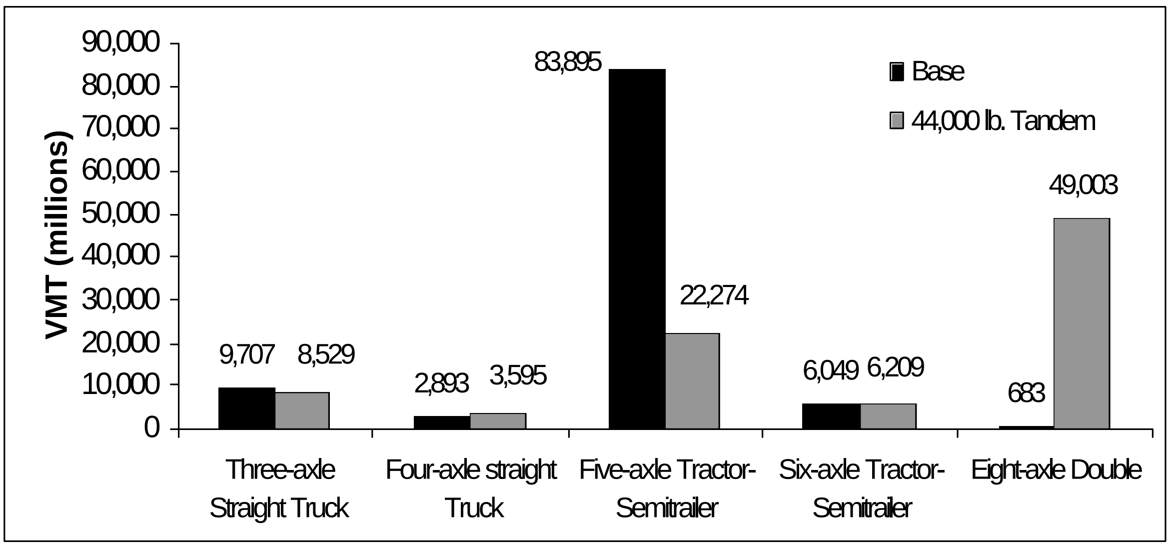


Figure IV-21. Impact of North American Trade Scenario (44,000 pound Tridem Axle) on Total Heavy-Truck VMT

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	128,288
44,000-Pound Tridem Axle Scenario	114,671
Percent Change	-10.6%

caused by the weigh-out freight because most long-haul truck shipments cube-out before they weigh-out.

Rail Carload-to-Truck Diversion

Freight accounting for 5 percent of the current rail carload car miles is estimated to divert to trucks. The shipments that would benefit from the heavier payload truck configurations are short moves such as pulp, paper and allied products, food and kindred products, lumber and wood products, primary metal industry products, waste and scrap.

Rail Intermodal-to-Truck Diversion

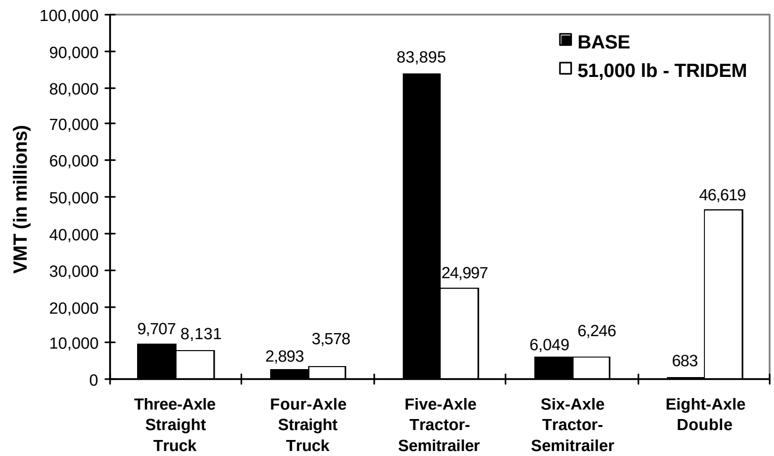
Freight accounting for 2 percent of current rail intermodal car miles is estimated to divert to truck. The amount of diversion is low because this scenario also allows heavier payloads for intermodal trailer- or container-on-rail. The TOFC/COFC container can be heavier because when unloaded and shipped by highway it may move on a six-axle tractor-semitrailer weighing 90,000 pounds.

Two types of intermodal traffic were tested for potential diversion to trucks. The first were containers that were 33 feet or less and weighed between 20,650 pounds and 42,650 pounds. These shipments were tested for diversion to the 124,000-pound eight-axle double-trailer combination. The length was limited because the eight-axle double-trailer combination comprises twin 33-foot trailers (for further explanation see Figure IV-24). The weight was limited because two containers weighing 20,650 pounds each could have traveled on a five-axle double-trailer combination under the current weight limit, if that had been the most economical alternative. Two containers weighing more than 42,650 pounds each would be too heavy for the eight-axle double-trailer combination under this scenario.

Shipments weighing more than 45,000 pounds were tested for potential diversion to the 90,000-pound six-axle tractor semitrailer. The weight was limited because a shipment less than 45,000 pounds could have traveled in a five- or six-axle tractor semitrailer with a GVW of 80,000 pounds.

Even with restrictions on the type of shipment analyzed, the model may

Figure IV-22. Impacts of North American Trade Scenario (51,000 pound Tridem Axle) On VMT by Different Vehicles



over estimate diversion of containers. Many of these containers are moved in bulk by large shipping companies. The added cost of tracking individual containers moving on trucks would outweigh any small savings. The Waybill data set does not specify these grouped container moves.

51,000-pound Tridem Axle

This scenario specifies the maximum legal GVWs for the four-axle SUT at 71,000 pounds, the six-axle tractor semitrailer at 97,000 pounds and a twin 33-foot eight-axle double-trailer combination at 131,000 pounds.

The same types of shifts among truck configurations shown in Figure IV-19 for the 44,000-pound tridem axle scenario would also apply to the 51,000 pound scenario.

Figures IV-22 and IV-23 summarize the analysis results. Total heavy commercial truck VMT for the Year 2000 is estimated to decrease 11 percent. These results are similar to the results for the 44,000-Pound Tridem Axle Scenario because most of the diverting freight is cubing-out and shifting to the twin 33-foot eight-axle double-trailer combination.

Three-axle SUT VMT is reduced by 16 percent, from 9,707 million miles to 8,131 million miles. Four-axle SUT VMT increases by 24 percent, from 2,893 million miles to 3,578 million miles. The five-axle tractor semitrailer

Figure IV-23. VMT for Base Case and North American Trade Scenario (51,000 pound Tridem Axle)

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	128,288
51,000-Pound Tridem Axle Scenario	114,632
Percent Change	-10.6%

Figure IV-24. Rail Intermodal Input Data

It is assumed that the current intermodal trailer or container sizes would not change with changes in truck size and weight limits. For example, under the North American Trade Scenarios which analyze heavier twin 33-foot eight-axle double-trailer combinations, rail intermodal shippers would not change container sizes. This means that only 8 percent of the rail intermodal [trailer-on-flat-car/container-on-flat-car (TOFC/COFC)] shipments were analyzed for potential diversion to the eight-axle double-trailer combination. However, the remaining 92 percent were analyzed for potential diversion to the six-axle tractor semitrailer.

The first obstacle in testing alternative sizes of intermodal trailers or containers was determining the impacts on all the participants in the intermodal transportation stream. Container ships and rail flat car and well car loadings would need to change to accommodate new 33-foot containers. This would have implications for pricing and ultimately the choice of container size.

The second consideration limiting the ability to analyze container or trailer size changes is the lack of TOFC/COFC commodity data. The Waybill records do not contain specific commodity information; typically they indicate “freight all kinds” or “TOFC shipment.” The Intermodal Transportation and Inventory Cost Model requires the commodity’s weight per-cubic-foot to determine the loading in an alternative trailer.

In the absence of TOFC/COFC density data, an assumption was made that all shipments are constrained by cubic capacity. The shipment weight on each Waybill record shows the majority of the TOFC/COFC shipments do not weigh-out. That is, the payload plus the tare weight of the tractor or tractor plus trailer is less than the current Federal limit of 80,000 pounds. Given the assumption that TOFC/COFC shipments cube-out, the shipper would want to use the highest cube container or trailer possible. This *a priori* makes the 40- and 45-foot containers or trailers more economical than 33-foot containers or trailers.

VMT declines by 70 percent, decreasing from 83,895 million miles to 24,997 million miles. The diverted freight was traveling near or above the 80,000-pound Federal weight limit or cubically filling a 53-foot trailer. That freight shifts to either: (1) the six-axle tractor semitrailer which has a 3 percent increase in VMT, from 6,049 million miles to 6,246 million miles; or (2) the eight-axle double-trailer combination which realizes a 6,726 percent increase in VMT from 683 million miles to 46,619 million miles.

Truck-to-Truck Diversion

The configurations and commodities impacted are the same as in the 44,000-Pound Tridem-Axle Scenario. The additional weight for the tridem axle in this scenario has a minor impact on the weight distribution since most truck freight cubes-out before it weighs-out.

Rail Carload-to-Truck Diversion

Freight accounting for 7 percent of the current rail carload car miles diverts to trucks. The shipments which would benefit from the truck configuration changes are shorter moves of such commodities as pulp, paper and allied products, food and kindred products, lumber and wood products, primary metal industry products, and waste and scrap.

Rail Intermodal-to-Truck Diversion

Under this scenario, freight accounting for 3 percent of current rail intermodal car miles diverts to truck. The amount of diversion is limited because this scenario also allows a heavier intermodal trailer or container.

Two types of intermodal traffic were tested for potential diversion to truck. The first were containers that were 33 feet or less and weighed between 20,650 pounds and 46,150 pounds. These shipments were tested for diversion to the eight-axle double-trailer combination at 131,000 pounds. The length was limited because the eight-axle double-trailer combination is comprised of twin 33-foot trailers (for further explanation see Figure IV-24). The weight was limited because two containers weighing 20,650 pounds each could have traveled on a five-axle double-trailer combination under the current weight limit, if that had been the most economic alternative. Two containers weighing more than 46,150 pounds each would be too heavy for the eight-axle double-trailer combination under this scenario. The second type of shipment examined included those weighing more than 45,000 pounds. This traffic was tested for potential diversion to the six-axle tractor semitrailer at 97,000 pounds. The weight was limited because shipments less than 45,000 pounds could have traveled in a five- or six-axle tractor semitrailer at 80,000 pounds.

Even with the restrictions on the type of shipment analyzed, the model may overestimate diversion of containers. Many of these containers move in bulk by large shipping companies. The added cost of tracking individual containers moving on trucks would outweigh any small savings. The Waybill data set does not specify these grouped container moves.

Longer Combination Vehicles Nationwide Scenario

This scenario has a large impact on truck travel because the proposed configurations are both larger and heavier than trucks in common use today. Also, interconnected, nationwide road networks are assumed to be available for the scenario vehicles.

Of all the LCVs, the one of most interest is the nine-axle TPD at 148,000 pounds. This is the longest and heaviest configuration tested in the scenario. A large amount of freight shifts to TPDs from existing trucks, rail carload and rail intermodal. Figure IV-25 outlines assumptions regarding how freight currently traveling in the affected configurations would respond to the new LCVs.

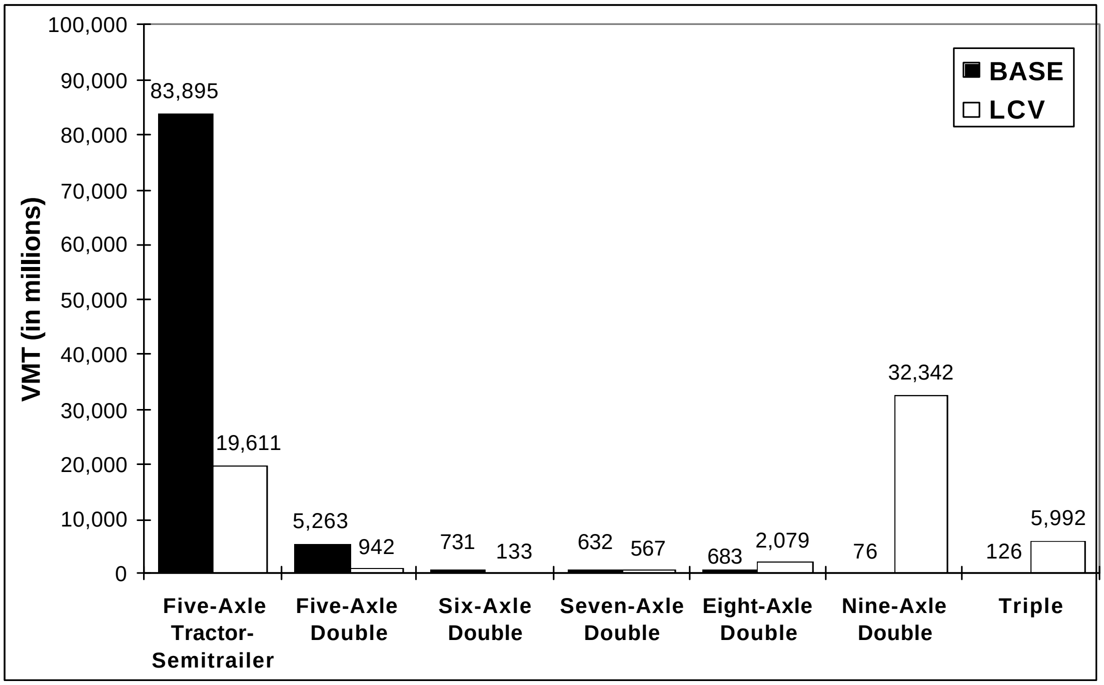
Figures IV-26 and IV-27 summarize the analysis results. Total heavy commercial truck VMT for the Year 2000 is estimated to decrease 23 percent under the scenario assumptions. This large change in VMT is caused by the diversion of freight from the five-axle tractor semitrailer to the nine-axle TPD. The initial five-axle tractor semitrailer VMT decreases 77 percent from 83,895 million miles in the base case to 19,611 million miles after the scenario has taken effect. At the same time the nine-axle TPD VMT increases from 76 million miles to 32,342 million miles. This growth in nine-axle TPD VMT includes the diversion from rail carload and intermodal to truck.

The other major shift in this scenario is from five- and six- axle double-trailer combinations to triple-trailer combinations. The VMT for five- and six-axle double-trailer combinations declines

Figure IV-25. Likely Truck Configuration Impacts of the LCV Nationwide Scenario

Original Truck Configuration		Likely Reaction to the Scenario
Five-axle tractor semitrailer	ö	Change to a seven-axle Rocky Mountain Double (RMD)
	ö	Change to a eight-axle double-trailer combination
	ö	Change to a nine-axle Turnpike Double (TPD)
	ö	Change to a triple-trailer combination
Five-axle double-trailer combination	ö	Change to a triple-trailer combination
Six-axle double-trailer combination	ö	Change to a triple-trailer combination
Seven-axle double-trailer combination	ö	More payload in a seven-axle RMD
Eight-axle double-trailer combination	ö	More payload in an eight-axle double-trailer combination
Nine-axle TPD	ö	More payload in a nine-axle TPD
Triple-trailer combination	ö	More payload in a triple-trailer combination

Figure IV-26. Impacts of LCV Nationwide Scenario on VMT by Different Vehicles



82 percent while the VMT for triple-trailer combinations increases 4,655 percent from 126 million miles to 5,992 million miles.

The following sections discuss the impact of truck-to-truck, rail carload-to-truck and rail intermodal-to-truck modal choices.

Truck-to-truck Diversion

<u>Five-Axle Tractor Semitrailer</u>

As noted in the scenario description the long doubles are restricted to operating on a limited network and must be assembled and disassembled at staging areas for travel to origins and destinations. The model assigns costs for staging area operations and costs for the drayage in single-trailer combinations for travel to origins and destinations. Nevertheless,

Figure IV-27. Total VMT for Base Case and LCV Nationwide Scenario

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	128,288
LCVs Nationwide Scenario	98,562
Percent Change	-23.2%

a significant share of freight currently using a five-axle tractor semitrailer is predicted to divert to the nine-axle TPD under assumptions in the scenario. Introducing the nine-axle TPD is equivalent to reducing by half the number of tractors and drivers needed to pull the same number of 53-foot trailers. This translates into an almost two-for-one savings over the transportation cost of a five-axle tractor semitrailer.

The analysis results show that virtually all freight currently using fully loaded five-axle tractor semitrailers would shift to the nine-axle TPD. Partial loads act as a constraint on diversion. It is assumed that 15 percent of the current five-axle tractor semitrailers are partially loaded and would not divert to the nine-axle TPD. As indicated earlier, the 15 percent is based on a trend analysis from previous truck surveys.

If the allowable weights for the TPD were lower or the network upon which they can operate were less extensive, a smaller share of shipments from five-axle tractor-semitrailers could be expected to divert to the TPD. Also, additional research is required to assess whether the logistics costs assumed in the model for using TPDs reflect all shipper and carrier considerations.

Five-Axle and Six-Axle Double-Trailer Combinations

These trucks are used primarily for moving LTL shipments. LTL shipments are consolidated from small shipments and usually have multiple origins and destinations. The LTL carriers use a hub-and-spoke system and short 28-foot doubles to combine shipments for the long-haul portion of the trip and then use the single 28-foot van or a specialized two-axle van for delivery.

These carriers would shift their long-haul traffic to triple-trailer combinations, in place of current double-trailer combinations. The analysis assumes that all but 15 percent of the VMT for five- and six-axle double-trailer combinations would shift to triple-trailer combinations. The remaining 15 percent is assumed to be partial loads which would still travel as double-trailer and not triple-trailer combinations. As for the TPDs, if the assumed gross vehicle weights were lower or the network/access provisions less liberal, less diversion to triples would be expected.

Seven-Axle Rocky Mountain Double

The results of the analysis indicate that little freight would divert from the five-axle tractor semitrailer to the seven-axle RMD. Most freight diverts to the nine-axle TPD which can hold both more volume and weight. The analysis assumes that there is a shift to heavier payloads among the current fleet of seven-axle RMDs.

Rail Carload-to-Truck Diversion

Freight accounting for 9 percent of rail carload car miles is estimated to divert to trucks, based on the scenario assumptions. The shipments which divert to the heavy payload truck configurations are shorter moves of such commodities as pulp, paper and allied products, food and kindred products, lumber and wood products, primary metal industry products, waste and scrap. Even though the analysis of this scenario indicates significant increases for truck weights, there is still limited diversion of carload traffic to trucks.

Figure IV-28. Operating Restrictions

This study did not assume operating restrictions beyond a restricted roadway network for Longer Combination Vehicles (LCVs). This analytical assumption does not necessarily match what would occur given implementation of the scenario because some operating restrictions would certainly apply to the operation of LCVs. For example, metropolitan areas might restrict their hours of operation to avoid conflicts with rush hour traffic. This study does not estimate the costs for monitoring compliance with the restricted roadway or the costs of any additional operating restrictions.

Rail Intermodal-to-Truck Diversion

Freight accounting for 31 percent of current rail intermodal car miles is estimated to divert to truck under the LCVs Nationwide Scenario. Only long-haul traffic over high density corridors would continue to operate on rail. For example, high volume lanes such as Los Angeles to Chicago would continue to operate but lower volume lanes such as Atlanta to New York would not operate. This is because the railroad's variable cost-per-trailer or container is much lower on the high volume lanes.

The analysis of freight diversion from rail intermodal to truck was accomplished in two steps. The first group of intermodal traffic tested for diversion included containers of 33 feet or less. Similar to the North American Trade Scenarios, these were tested for potential diversion to the eight-axle double-trailer combination assuming no change in the freight loaded into a container or trailer. The current payload must be more than that which would currently fit on a five-axle double-trailer combination, two 20,650-pound containers, but less than two containers each at 42,650 pounds which is more than the hypothesized eight-axle double-trailer combination could carry.

All the remaining rail intermodal Waybill observations were tested for diversion to the nine-axle TPD. Much of the current rail intermodal cost advantage vanished when compared to the TPD. As was the case when comparing the TPD to the five-axle tractor semitrailer, the two-to-one transportation cost advantage of hauling two trailers with one tractor causes significant freight diversion.

H.R. 551 Scenario

This scenario tests the impact of limiting any further increases in the number of trailers over 53

Figure IV-29. Impact of Long-Doubles Network and Access Provisions

One of the reasons freight diverts to the nine-axle turnpike double from the five-axle tractor semitrailer is the extensive roadway network for longer double-trailer Longer Combination Vehicles (LCVs, "long doubles"). The long doubles network is 42,500 miles. Although, this is only one quarter of the National Network for Large Trucks, the long doubles network includes freeways in every State. The result is a road network that connects to each major city with limited connections to urban centers. Therefore, long doubles travel about the same number of miles as would a standard five-axle tractor semitrailer to carry a given shipment.

The other factor contributing to the popularity of the nine-axle turnpike double is the liberal access assumed to and from the 42,500-mile network. Previous studies have forced long doubles to use as few as 50 staging areas nationwide for assembling and breaking-down the combination. This study assumes that staging areas would be provided every 15.6 miles on rural freeways and about every 50 miles on non-freeway rural highways. Trucks with trip origins or destinations in an urban area would use urban fringe staging areas. These rules imply 2,455 rural and 830 urban fringe staging areas. This assumption substantially increases the roadway geometry cost, (see Chapter 7), but decreases miles traveled for long doubles and the miles to and from the network.

The staging area costs are included in Chapter 7, "Roadway Geometry." They are not included in the truck operating costs used by the Intermodal Transportation and Inventory Cost Model because it is unclear what services would be offered and whether the staging areas would be managed by the government or by private industry. The diversion analysis assumes all of the network interchange facilities are in place by the study analysis year (2000). These improvements, of course, could not happen immediately so the diversion estimates must be considered to be long-term changes, assuming that all infrastructure improvements are made and the network, staging area, and access provisions are as liberal as assumed in this scenario.

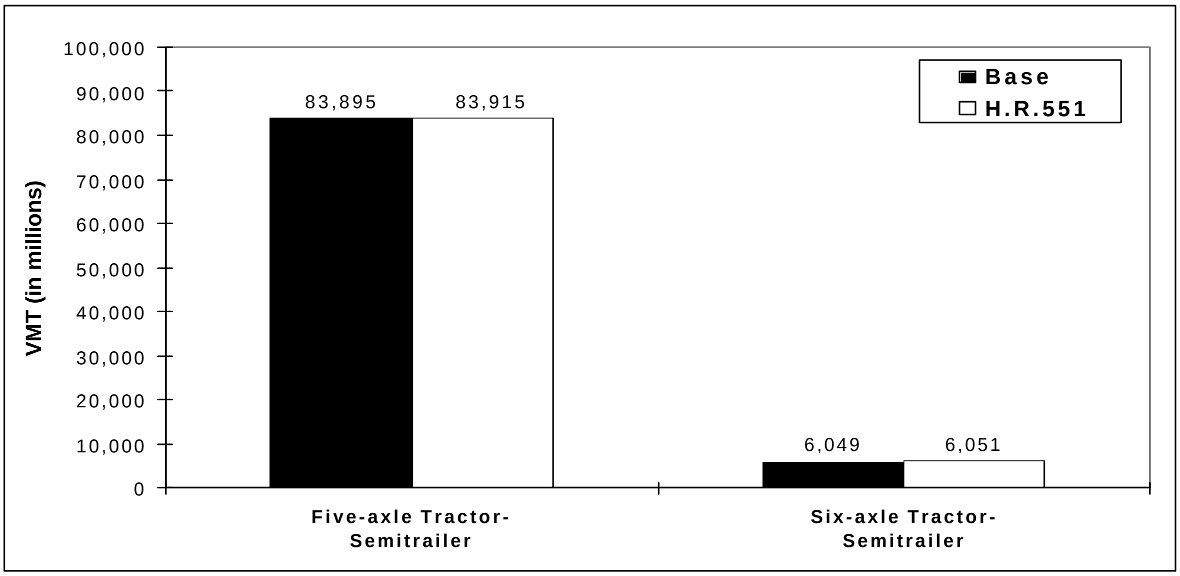
feet. This changes the cubic capacity of some five- and six-axle tractor semitrailers. However, underlying the analysis is an implicit assumption that current trailers over 53 feet would continue to operate through the analysis Year 2000. The analysis assumes that there would be no impact on rail traffic, since the change affects only cube-limited freight. Most shippers currently use rail for heavy bulk shipments and deploy trucks for lighter shipments that fill the cube or volume of a trailer.

Figure IV-30 outlines assumptions regarding how freight currently traveling in trailers over 53 feet would likely respond to limitations on these

Figure IV-30. Likely Truck Configuration Impacts, H.R. 551 Scenario

Original Truck Configuration		Likely Reaction to the Scenario
Five-axle tractor semitrailer	ö	Less payload in a five-axle tractor semitrailer
Six-axle tractor semitrailer	ö	Less payload in a six-axle tractor semitrailer

Figure IV-31. Impacts of H.R. 551 Scenario on VMT by Different Vehicles



configurations.

Figures IV-31 and IV-32 summarize the diversion estimates for this scenario. Total heavy commercial truck VMT for the Year 2000 increases less than one-half a percent. Since the current population of trailers over 53 feet is very small, the impact of this scenario is minor on a national scale. The only two configurations impacted are the five- and six-axle tractor semitrailers.

Triple-Trailer Combination Nationwide Scenario

This scenario tests the impact of allowing seven-axle triple-trailer combinations to operate at 132,000 pounds nationwide. This vehicle is the scenario's configuration with the most cargo space and GVW. Therefore, any freight which could benefit from more space or more weight will divert to the triple-trailer combination.

Figure IV-32. Impacts of Triples Nationwide Scenario on Total Truck VMT

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	128,288
Triples Nationwide Scenario	102,400
Percent Change	-20.2%

The analysis shows that substantial amounts of truckload traffic could divert from five-axle tractor-semitrailers to triple-trailer combinations under the liberal payload and access assumptions in this scenario. Five- and six-axle double-trailer combination LTL traffic would also divert as in the LCVs Nationwide Scenario. However, unlike the LCVs Nationwide Scenario, rail intermodal does not experience a substantial loss of traffic. The shift from rail intermodal is limited because each triple-trailer combination can only handle containers up to 28 feet in length and the majority of rail intermodal traffic is transported in containers or trailers 40 feet or longer.

Figure IV-34 outlines assumptions regarding how freight currently traveling in the impacted configurations would likely respond to the wider availability of triple-trailer combinations. Figures IV-35 and IV-36 summarize the resulting truck VMT.

Total heavy commercial truck VMT for the Year 2000 is estimated to decrease 20 percent due to

Figure IV-33. Use of the Intermodal Transportation and Inventory Cost Model to Analyze the H.R. 551 Scenario

Although the Intermodal Transportation and Inventory Cost Model is used to analyze truck-to-truck and rail-to-truck diversion for the majority of the scenarios, it is not used to analyze the H.R. 551 Scenario. This scenario requires a level of precision beyond the current truck data set.

The H.R. 551 Scenario requires data on the population of trailers over 53 feet. This small portion of the population, 1.16 percent of combination vehicle trailers (Truck Inventory and Use Survey, 1992), is not measured in the North American Truck Survey.

Figure IV-34. Likely Truck Configuration Impacts of Triples Nationwide Scenario

Original Truck Configuration		Likely Reaction to the Scenario
Five-axle tractor semitrailer	ö	Change to a triple-trailer combination
Five-axle double-trailer combination	ö	Change to a triple-trailer combination
Six-axle double-trailer combination	ö	Change to a triple-trailer combination
Triple-trailer combination	ö	More payload in a triple-trailer combination

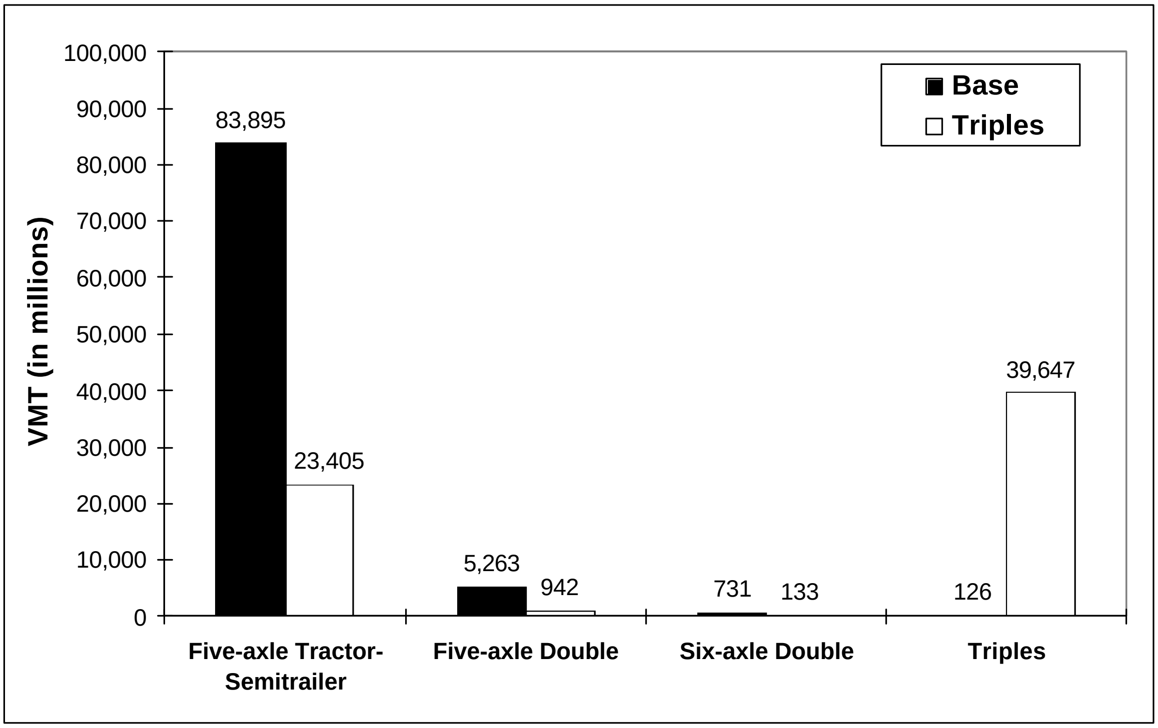
the change in truck operations from the five-axle tractor semitrailer to the triple-trailer combination. The five-axle tractor trailer's VMT decreases 72 percent from 83,895 million miles to 23,405 million miles. Significant traffic also shifts from five- and six-axle doubles to the triples combinations. Total triple-trailer combination VMT increases 31,366 percent from 126 million miles to 39,647 million miles. The following sections discuss the effects of truck-to-truck, rail carload-to-truck and rail intermodal-to-truck diversion.

Truck-to-Truck Diversion

Five-Axle Tractor Semitrailer

Significant freight shipped in five-axle tractor semitrailers is predicted to shift to the seven-axle triple-trailer combination under scenario assumptions. The triple-trailer combination offers both more cargo space and weight. As in the LCV analysis, it is assumed that 15 percent of the current five-axle tractor semitrailers are partially loaded and would not divert to the seven-axle triple-trailer combination. Little truckload freight currently is shipped in triples because other LCV doubles configurations are typically available in States that currently allow triples. Shippers and carriers might have to make significant adaptations to use triples for truckload shipments, but the line haul cost advantage of triples at 132,000 pounds compared to five-axle tractor-semitrailers is significant enough that many shippers and carriers could be expected to make those adaptations. If allowable weights were lower, access less liberal, or other alternative configurations available to haul truckload freight at comparable weights, triples likely would continue to be used primarily for LTL shipments.

Figure IV-35. Impact of Triples Nationwide Scenario on VMT by Different Vehicles



Five-and Six-axle Doubles

These trucks are used primarily for moving LTL shipments and all but 15 percent of this long-haul traffic is predicted to shift to triple-trailer combinations.

Rail Carload-to-Truck Diversion

Freight accounting for 5 percent of rail carload car miles is predicted to divert to triples under this scenario. The shipments which divert to the triple-trailer combination are short moves of such commodities as pulp, paper, and allied products, food and kindred products, lumber and wood products, primary metal industry products, and waste and scrap. Even though the scenario specifies significant increases for truck weights, there is limited diversion of carload freight to trucks.

Rail Intermodal-to-Truck Diversion

Freight accounting for one percent of current rail inter-modal car miles would divert to trucks. This is significantly less than the LCVs Nation-wide Scenario because the triple-trailer combination vehicle comprises short 28-foot trailers. Only TOFC/COFC shipments currently traveling in 28-foot 28-foot trailers or

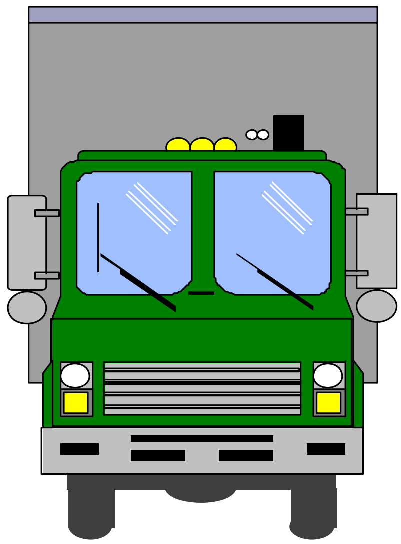
Figure IV-36. Impacts of Triples Nationwide Scenario on Total Truck VMT

Scenario	Vehicle-Miles-of-Travel (in millions)
Base Case	128,288
Triples Nationwide Scenario	102,400
Percent Change	-20.2%

shorter containers or trailers were tested for diversion to the triple-trailer combination. This may be overly restrictive but without knowing the dimensions of the freight traveling in the longer containers or trailers it is impossible to accurately predict if it could be accommodated by a 28-foot or shorter box and the comparable rail variable cost.

CHAPTER V

Pavement



Introduction

The States spend billions of dollars each year to maintain their highway systems. The *1997 Status of the Nation's Surface Transportation System: Conditions and Performance Report to Congress* indicates that $470 billion will be required over the next 20 years just to maintain the condition of the system. Changes in truck size and weight (TS&W) policy, especially if they include new axle weight limits, could have a major impact on pavement quality and performance characteristics and, therefore, future investment requirements.

The condition and performance of a highway pavement depend on many factors including:

- Pavement structure, materials, and layer depth;
- Construction quality (including uniformity of pavement layers) and maintenance practices;
- Weather—amount of precipitation and freeze-thaw cycles;
- Subbase characteristics that underlie the pavement;
- Magnitude, spacing, and frequency of axle loads; and
- Dynamic interaction between pavement conditions and vehicle speed, number of tires per axle, tire pressures, and suspension characteristics.

The factors most relevant to a national level TS&W study are the magnitude, spacing and frequency of axle loads. These factors along with information on surface roughness, base strength, pavement materials and structure, and weather conditions have been considered in this study. Tire, wheel, and suspension parameters important to estimating pavement damage were not considered in this study. This analysis is concerned with the incremental change in pavement costs caused by the scenario vehicles relative to the damage caused by the current fleet. Since there is no reason to expect these wheel, tire pressure, and suspension parameters to differ between the various existing and proposed configurations, these factors are not critical in estimating pavement impacts of TS&W scenarios.

The elements of dynamic truck-pavement interaction have been the focus of considerable research in recent years (such as the Organization for Economic Cooperation and Development's "Dynamic Interaction Vehicle-Infrastructure Experiment"). However, current information on these dynamic interactions is inconclusive with respect to TS&W policy and their effects appear to be of secondary importance relative to static axle loads.

Axle load and frequency information have been estimated based on vehicle-miles-of-travel (VMT) information for various classes of highway vehicles, which includes the number of axles, from the *1997 Highway Cost Allocation (HCA) Study*. The *HCA Study* VMT estimates by vehicle class and weight group were modified for the alternative TS&W policies through the freight diversion analytical process (see Chapter IV).

Pavement and subbase data by highway section were taken from the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) database to which was added State specific weather, soil, and base thickness data. The HPMS data base, the most comprehensive national database currently available, includes detailed characteristics on about 100,000 sections of U.S. highways.

Basic Principles

Truck-Pavement Interaction

In terms of vehicle-specific characteristics, pavement wear increases with axle weight, the number of axle loadings, and the spacing within axle groups, such as for tandem- or tridem-axle groups. Pavement impacts are also influenced by vehicle suspensions, tire pressure, and tire type. However, the analysis conducted for this study does not quantify these secondary, vehicle-specific characteristics because they are less important to pavement deterioration than pavement type and axle weight. Further, there is no reason to assume that these characteristics are different, in general, for one truck configuration versus another.

The gross vehicle weight (GVW) of a vehicle is not the prime determinant of a vehicle's impact on pavements. Rather, pavements are stressed by loads on individual axles and axle groups directly in contact with the pavement. Of course, the GVW, along with the number and types of axles and the spacing between axles, determines the axle loads. Over time, the accumulated strains (the pavement deformation from all the axle loads) deteriorate the pavement structure, eventually resulting in cracking of both rigid and flexible pavements and permanent deformation or rutting in flexible pavements. Eventually, if the pavement is not routinely maintained, the axle loads, in combi-nation with environmental effects, such as pavement moisture, accelerate cracking and deformation. Figure V-1 explains pavement fatigue in more detail.

Pavement Life Consumption

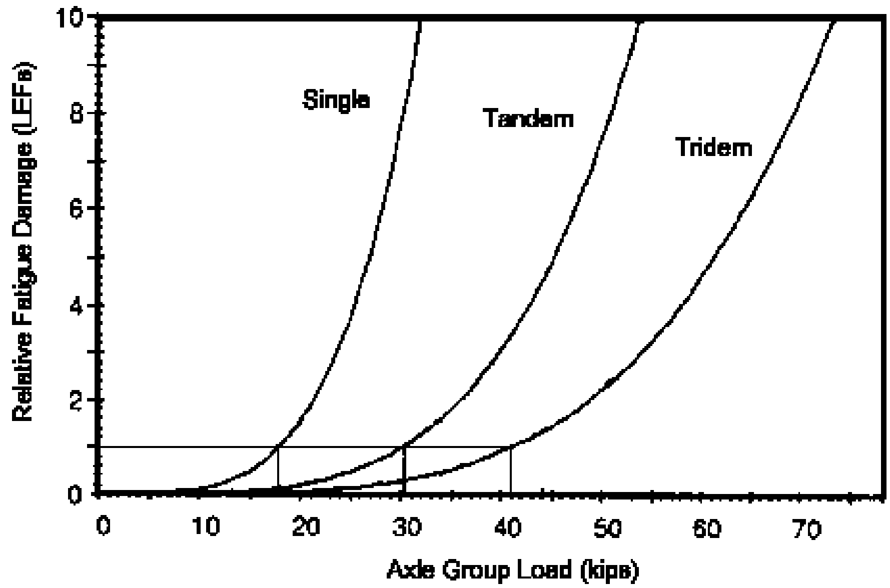
Proper pavement design relative to loading is a significant factor, which varies by highway system. The incremental effect on pavement deterioration increases sharply as the axle load increases. A fourth power relationship between axle load and pavement deterioration has been the rule of thumb since the American Association of State Highway Officials' road test conducted during the late 1950s (see Figure V-2). Such a relationship means that if axle loads are doubled from say 10,000 pounds to 20,000 pounds, the impact on the pavement will increase by

Figure V-1. Pavement Fatigue

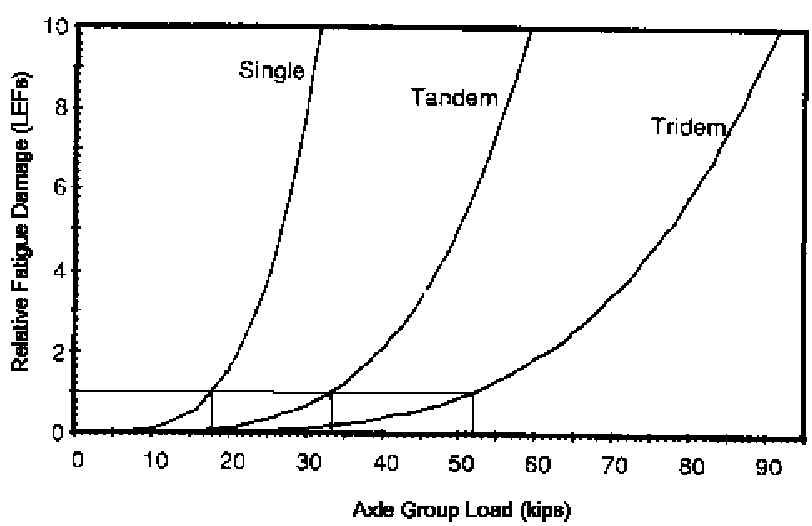
The break-up of pavements is usually caused by fatigue. Fatigue or fatigue cracking is caused by many repeated loadings and the heavier the loads the fewer the number of repetitions required to reach the same condition of cracking. It is possible, especially for a thin pavement, for one very heavy load to break up the pavement in the two wheel paths. To account for the effect of different axle weights, the relative amount of fatigue for an axle at a given weight is compared to that of a standard weight axle. Historically this standard axle has been a single-axle with dual tires and an 18,000-pound load.

FigureV-2. Impact of Axle Load on Fatigue in Flexible and Rigid Pavements

FLEXIBLE PAVEMENT



RIGID PAVEMENT



Source: Gillespie, et. al. "Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance," NCHRP Report 353, Transportation Research Board, Washington, DC, 1993.

a factor of approximately 16. More recent research has shown that the influence of load on pavement deterioration varies depending on the nature of the pavement distress. For instance the influence of axle load on pavement rutting is somewhat different from the relationship to cracking. In general, however, the relationship between axle load and pavement deterioration may be closer to a third power than a fourth power relationship. Thus doubling axle load may increase pavement deterioration by a factor of eight rather than 16, but still a very significant difference.

Adding one or two axles to a single axle to make a tandem- or tridem-axle group allows higher gross vehicle weights without increasing pavement damage. These axle groups reduce pavement consumption by spreading the load along more of the pavement. This effect is more significant for flexible than for rigid pavements (see Figure V-4), although Figure V-3 shows the difference is not large.

The spread between two consecutive axles in a tandem- or tridem-axle group also affects pavement life or performance; the greater the spread the more each axle in a group acts as a single axle. Spreading axles within a group increases the fatigue damage in flexible pavements. Rigid pavements are affected differently by axle spread. Over short distances, rigid pavements act like bridges, and consequently, pavement damage is reduced by spreading axles.

Tables V-1 through V-3 compare the relative pavement consumption of various axle groups and truck configurations evaluated in the study at the maximum allowable weights that would be allowed in the various scenarios. These

Figure V-3. The AASHO Road Test

In the late 1950's the then American Association of State Highway Officials (now the American Association of State Highway and Transportation Officials) conducted pavement deterioration tests at Ottawa, Illinois. The measure of pavement deterioration used was the Present Serviceability Rating (PSR). The tests found that, with increasing axle load, pavements deteriorated at a rate that was roughly equivalent to the relative weight increase raised to the fourth power. It is important to note that the analysis methods used in the AASHO road test were purely empirical and were not based on physical properties of the pavement structures. Furthermore all tests were conducted at a single site with a limited number of pavement designs, soil characteristics, environmental conditions, etc. More recent research drawing upon physical properties of construction materials and pavement emphasizes that pavements deteriorate in different ways and that the relationship of axle load to various types of pavement deterioration are not uniform. For most pavement distresses the relationship between axle load and pavement deterioration is less than a fourth power, and the overall relationship between axle load and pavement deterioration may be closer to a third power rather than a fourth power relationship. Recent reviews of the original AASHO road test data also have concluded that the data show approximately a third power relationship.

Figure V-4. Flexible Versus Rigid Pavements

High-type pavements include a weather-resistant surface and are classified as either flexible or rigid. Flexible pavements are surfaced with bituminous (or asphalt) materials. The total pavement structure "bends" or "deflects" in response to a load. Also, a flexible pavement structure is usually composed of several layers that absorb most of the deflection. Rigid pavements are made from portland cement concrete (PCC) and are substantially "stiffer" than flexible pavements. Some, PCC pavements have reinforcing steel to help resist cracking due to temperature changes and repeated loading.

Only 11 percent of all hard surfaced highways have rigid or composite pavements (rigid pavements with flexible overlays). The remaining have flexible pavements. About 50 percent of the Interstate System mileage has rigid or composite pavement. Flexible pavements are expected to serve from 10 years to 15 years. In contrast, rigid pavements may serve 30 years or more. However, when a flexible pavement requires major rehabilitation, the work is generally less expensive and quicker to perform than for rigid pavements.

comparisons are based on the effects of the axle groups and their loads relative to a 18,000-pound single axle load. These relative effects are expressed in load equivalency factors (LEFs) that may be defined as the number of repetitions of a reference load and axle combination (such as the 18,000-pound single axle) that is equivalent in pavement life consumption to one application of the load and axle configuration in question. LEFs are useful in distilling the effects of different vehicle types into a single measure for comparison purposes. However, actual LEFs vary by pavement type, thickness, and distress type.

Table V-1 shows LEFs for three of the more significant pavement distress types by axle group and weight derived from theoretical pavement damage models. Rigid and flexible pavement LEFs for fatigue were interpolated from Figure V-2. These theoretical values show relative relationships among axle load, axle type, pavement type, and pavement distress, but they do not show the influence of environmental factors and thus should not be used in specific applications. As discussed later in this chapter, the pavement analysis in this study did not use the theoretical LEFs shown in Table V-1, but rather used distress models that take into account differences in pavement type and thickness and environmental factors. The theoretical LEFs, however, are useful in demonstrating fundamental relationships of interest to TS&W considerations.

To estimate pavement impacts of different vehicle configurations at different weights, LEFs can be estimated for each group of axles and then summed to derive a total LEF for the vehicle. LEFs for each vehicle would be different for their travel on flexible pavement than for travel on rigid pavement, and they also differ depending on the type of pavement distress. Table V-2 shows total LEFs for various scenario vehicles at their maximum allowable weights under the illustrative scenarios.

Table V-1. Theoretical Load Equivalency Factors for Various Axle Groups and Loads for Major Types of Rigid and Flexible Pavement Distress

Axle Group	Load (pounds)	Load Equivalency Factors *		
		Rigid Pavement Fatigue (10-inch thickness)	Flexible Pavement (5-inch wearing surface)	
			Fatigue	Rutting
Steering Axle Single tires	12,000	0.6	1.4	1.3
	20,000	3.1	4.0	2.2
Single Axle Dual tires	17,000 (STAA double)	0.9	0.9	0.9
	20,000	1.6	1.5	1.1
Tandem Axle	34,000	1.1	1.6	1.9
Spread Tandem-Axle (10-foot Spread)	40,000	1.4	3.0	2.2
Tridem-Axle (9-foot spread)	44,000	0.6	1.4	2.4
	51,000	1.0	2.5	2.8

* Based on 18,000 pound single axle with dual tires

Source: Gillespie, et. al. "Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance,"

Table V-2 clearly shows the benefits of adding axles to vehicles. The LEFs for the four-axle SUT at 64,000 pounds are lower than those for the three-axle SUT at 54,000 pounds. Likewise, differences in axle configuration also are clearly illustrated in Table V-2 when one compares LEFs for the conventional five-axle tractor-semitrailer, the five-axle tractor-semitrailer with spread axles on the rear, and the five-axle STAA double.

The conventional tractor-semitrailer with tandem axles on the rear of the semitrailer has lower LEFs than a similar vehicle with the rear axles spread by 10 feet so they act like two single axles rather than like a tandem axle group. The STAA double with five single axles has greater LEFs than the two tractor-semitrailer combinations except for flexible pavement rutting where all three vehicles have similar impacts.

Two sets of LEFs are shown in Table V-2 for the seven-axle triple combination, one typical of less-than-truckload (LTL) operations and one at the maximum allowable weight assumed for triples in the study scenarios. The lower weight assumes 17,000-pound single axles and the second, 20,000-pound axles. This 3,000-pound difference in axle weights increases rigid pavement fatigue by 70 percent, flexible pavement fatigue by 53 percent, and flexible pavement rutting by 18 percent.

Table V-3 presents impacts of different vehicle configurations from a different perspective. It shows the total LEFs that would be accumulated by different vehicle configurations in hauling 100,000 pounds of freight. Total LEFs, and thus total pavement impacts, vary considerably by configuration and weight. The eight-axle B-train combination with a gross weight of 124,000 pounds and the six-axle tractor-semitrailer at 90,000 pounds would cause the least pavement impact to carry 100,000 pounds of freight, while the two SUTs and the triple at 132,000 pounds would have the greatest impact.

To realistically compare how pavement impacts change with changes in weight limits, it cannot be assumed that it is always cheaper to use the larger configurations, or that they always operate at their maximum allowable weights.

Analytical Approach

Alternative weights for current truck configurations were analyzed in terms of their interaction with highway infrastructure features. The configurations included were single-unit or straight trucks and single- and multitrailer truck combinations. Pavement types analyzed include flexible (asphaltic concrete) and rigid (portland cement concrete).

The methods used to assess the potential pavement impact of alternative TS&W policy scenarios on pavement life consumption involved two phases. The first phase included new research on tridem-axle impacts. Of particular interest was the relationship between axle loads, axle spacings and pavement deterioration. The goal was to develop optimum axle load and spacing criteria that also took into account potential bridge impacts.

The second phase included the development of pavement impact cost estimates based on the pavement cost model used for the *HCA Study* analysis. A number of revisions were made to that model to make it more sensitive to TS&W policy options.

Tridem-axle Impact Research

In the United States, the allowable load on a group of three axles connected through a common suspension system (a tridem-axle) is determined by the Federal Bridge Formula (FBF) rather than a limit set by law (or regulation). In Europe, Canada, Mexico, and other jurisdictions, tridem axles are given a unique load limit in the same way the United States specifies unique single- and tandem-axle limits without the use of a bridge formula. This is not to say that these unique tridem limits are not bridge-related. In Canada, for example, the tridem limits vary as a function of spacing, based on bridge loading limitations—not pavement limitations.

Tridem axles could be considered as a way to increase truck load capacity while reducing pavement damage (see Figure V-5).

Table V-2. Theoretical Load Equivalency Factors for Scenario Vehicles

Configuration	Gross Vehicle Weight (pounds)	Number of Axles in Each Group (S=Steering Axle)	Load Equivalency Factors ***		
			Rigid Pavement Fatigue (10-inch thickness)	Flexible Pavement (5-inch wearing surface)	
				Fatigue	Rutting
Three-Axle Single Unit Truck	54,000	S,2	4.2	5.6	4.1
Four-Axle Single Unit Truck	64,000	S,3	3.6	5.4	4.6
	71,000	S,3	4.1	6.5	5.0
Five-Axle Semitrailer	80,000	S,2,2	2.8	4.6	5.1
Five-Axle Semitrailer (10-foot Spread)	80,000	S,2,2 (spread)	3.1	6.0	5.4
Six-Axle Semitrailer	90,000	S,2,3	2.2	4.4	5.6
	97,000	S,2,3	2.7	5.5	6.0
STAA Double (five-axle)	80,000	S,1,1,1,1	4.2	5.0	4.9
B-Train Double (eight-axle)	124,000	S,2,3,2	3.3	6.0	6.5
	131,000	S,2,3,2	3.8	7.1	6.9
Rocky Mt.Double (seven-axle)	120,000	S,2,2,1,1	6.0	7.6	7.3
Turnpike Double (nine-axle)	148,000	S,2,2,2,2	5.0	7.8	7.3
Triple (seven-axle)	114,000 (LTL operation)*	S,1,1,1,1,1,1	6.0	6.8	6.7
	132,000 (TL operation)**	S,1,1,1,1,1,1	10.2	10.4	7.9

*LTL= Less-than-truckload
**TL=Truckload
*** Based on 18,000-pound single axle with dual tires

There already has been a switch from three-axle to four-axle SUTs by many heavy bulk freight haulers, and as noted above, significant pavement cost savings may be possible. The 80,000-pound GVW limit poses a constraint on adding axles to five-axle combinations because, under the GVW limit, the extra axle would reduce the payload.

An evaluation of a specific

Table V-3. Theoretical Load Equivalency Factors Per 100,000 Pounds of Payload

Configuration	Gross Vehicle Weight (pounds)	Empty Weight (pounds)	Payload Weight (pounds)	No. Of Vehicles per 100,000 pounds of payload	Load Equivalency Factors: Rigid Pavement Fatigue (10-inch thickness)	Flexible Pavement (5-inch wearing surface): Fatigue	Flexible Pavement (5-inch wearing surface): Rutting
Three-Axle Single Unit Truck	54,000	22,600	31,400	3.18	13.4	17.8	13.0
Four-Axle Single Unit Truck	64,000	26,400	37,600	2.66	9.6	14.4	12.2
	71,000	26,400	44,600	2.24	9.2	14.6	11.2
Five-Axle Semitrailer	80,000	30,500	49,500	2.02	5.7	9.3	10.3
Five-Axle Semitrailer (10-foot Spread)	80,000	30,500	49,500	2.02	6.3	12.2	10.9
Six-Axle Semitrailer	90,000	31,500	58,500	1.71	3.8	7.5	9.6
	97,000	31,500	65,500	1.53	4.1	8.4	9.2
STAA Double (five-axle)	80,000	29,300	50,700	1.97	8.3	9.9	9.7
B-Train Double (eight-axle)	124,000	38,700	85,300	1.17	3.9	7.0	7.6
	131,000	38,700	92,300	1.08	4.1	7.7	7.5
Rocky Mt.Double (seven-axle)	120,000	43,000	77,000	1.30	7.8	9.9	9.5
Turnpike Double (nine-axle)	148,000	46,700	101,300	0.99	5.0	7.7	7.2
Triple (seven-axle)	114,000 (LTL operation)*	44,500	69,500	1.44	8.6	9.8	9.6
	132,000 (TL operation)**	44,500	87,500	1.14	11.6	11.8	9.0

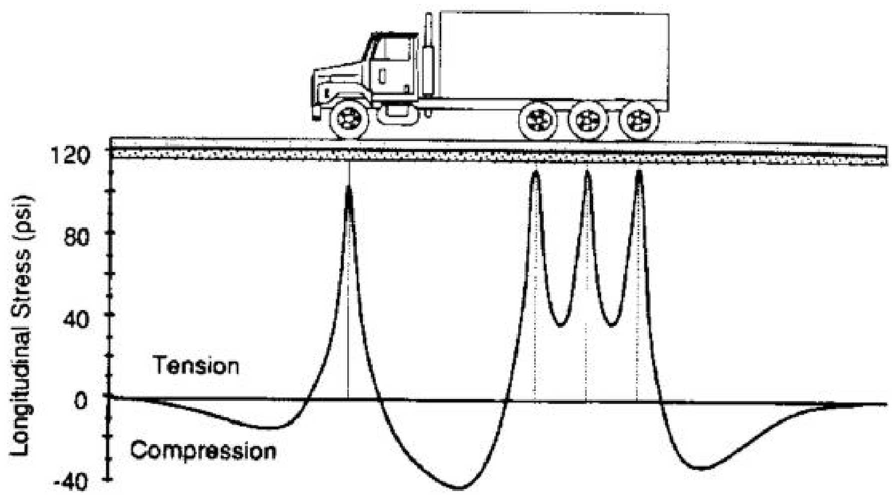
*LTL= Less-than-truckload
**TL= Truckload

limit for tridem groups was undertaken as the FBF is conservative for closely spaced axles. In contrast, it is liberal in the weight it allows for long multitrailer combinations. During the development of the truck configuration building blocks early in the study, a 97,000-pound six-axle semitrailer combination was selected for evaluation, because at that weight a 40-foot container loaded to the ISO

FigureV-5. Use of Spread-Tandem Versus Tridem Axles

There is increasing use of wide-spread (up to 10 feet) "spread-tandem" axle groups, particularly in flatbed heavy haul operations. These axles are allowed to be loaded at single axle limits–20,000 pounds on each of the two axles as opposed to 34,000 pounds on a closed tandem. They offer two key benefits relative to five-axle tractor semitrailers combinations: (1) flexibility in load distribution, and (2) full achievement of the 80,000-pound gross vehicle weight cap, which is limited by the ability to distribute up to 12,000 pounds on the steering axle of a combination. But they do so with significant pavement costs. Their expanding use could be counteracted with a higher tridem-axle load to the benefit of pavements.

The diagram below shows why tridem-axles are more pavement friendly than split-tandem axles. As loads are moved from farther to closer distances, the stresses they apply to the pavement structure begin to overlap; they stop acting as separate loads. While maximum deflection of the pavement surface increases as axle spacing is reduced, maximum tensile stress at the underside of the surface layer will decrease. Tensile stress is a primary cause of fatigue cracking and can decrease as axle spacing is reduced. However, the net effect of changes in axle spacing is very complex and dependent on the nature--flexible versus rigid--of the pavement structure.



(International Standards Organization) maximum limit could be moved without requiring a permit on Interstate highways. Implicit in this is a 51,000-pound limit for the tridem-axle group. (See Chapter III, North American Trade Scenario discussion.)

weight from both a pavement and a bridge perspective, found that the optimum limit was 44,000 pounds for a tridem axle with nine feet between the first and last axles in the group. If the axles were to be spread more than this, pavement fatigue would increase, while bridge stress would decrease. And conversely, if the nine feet were shortened, bridge stresses would increase, while pavement fatigue would decrease. As a result of the research, both the 44,000-pound and the 51,000-pound limits were evaluated. (See Figure V-6.)

The National Pavement Cost Model

The National Pavement Cost Model (NAPCOM) is used to estimate potential pavement impacts resulting from changes in the Nation's TS&W limits. NAPCOM is a complex simulation model initially developed in 1992 and subsequently improved for use in the 1997 *HCA Study*. The key output of NAPCOM for cost allocation is the relative responsibility for pavement damage attributable to different vehicle classes operating at different weights and highway systems. For TS&W analysis NAPCOM is used to estimate how overall pavement improvement needs would vary under alternative TS&W scenarios and to attribute changes in pavement rehabilitation costs to specific groups of vehicles. The model is sensitive to different weight policies, depending on truck configuration, including the number of axles.

Overview

To estimate the impact of the various scenarios on pavement requirements, NAPCOM was applied to generate: (1) lane-miles of failed pavement in the base case, and (2) lane-miles of failed pavement under the test scenario conditions. In each case, lane-miles of failed pavement were translated into pavement costs. NAPCOM implements a 20-year analysis to generate the number of failed lane miles by functional class of highway and highway type. The improvement needs relate to a 20-year stream of traffic (from 2000 to 2020).

Input Data

NAPCOM uses information about specific, representative highway sections supplied by the States through the FHWA's HPMS process. The HPMS includes approximately 100,000 records of pavement sections each of which includes detailed information on design characteristics, current condition of the pavement, and the traffic that uses that particular segment (current and 20-year projection).

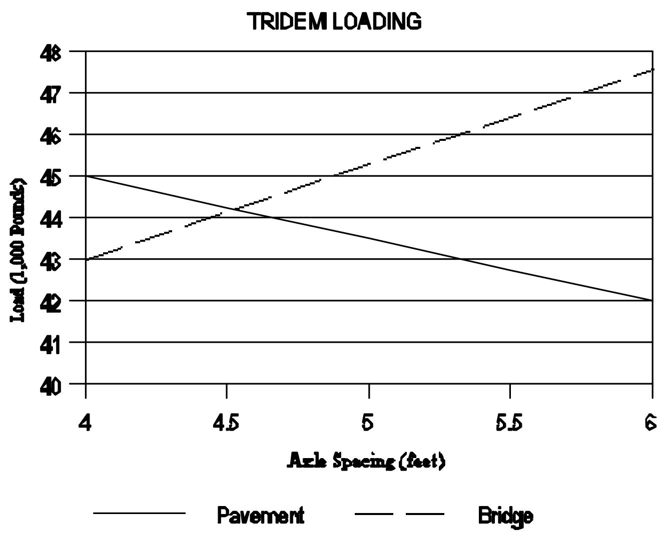
NAPCOM uses the following information from HPMS: number of lanes, type of pavement, pavement thickness, current pavement condition, average daily traffic, percentage of trucks in the traffic stream, predicted 20-year traffic levels, climatic zone, and some rudimentary information about the pavement base. The HPMS data is supplemented with additional State-characteristic information, to include: freeze-thaw cycles, freezing index, average rainfall and thickness of base.

NAPCOM uses the following fleet data developed for the *HCA Study*: (1) annual VMT by vehicle class, highway functional class, and State; (2) operating weight distribution for each vehicle class on groups of highway types in groups of States; and (3) axle weights for the midpoint of each weight group for each vehicle class.

Figure V-6. Tridem Axle Infrastructure Impacts

The complexity of the interactions of truck weights and dimensions on pavements and bridges is illustrated in the graph below. This graph shows that spreading the individual axles in the tridem-axle group increases pavement wear primarily through fatigue, but it decreases the maximum stresses in a simple bridge span by reducing the maximum stress at the midpoint of the span. It also shows that the optimal weight limit considering both pavement and bridge impacts for a tridem axle is 44,000 pounds when there is 4.5 feet between two adjacent axles. To spread the axles further would increase pavement wear beyond that of the present 34,000 pounds allowed on a tandem axle. To move the axles closer together would increase stresses in certain bridges beyond that allowed under the current bridge stress criteria.

Relative Pavement and Bridge Impacts
Tridem Axle



A different traffic loading was estimated for each TS&W policy scenario. This was done by starting with the VMT file created by the *HCA Study* and modifying it based on the new distribution of freight between truck and rail, from one truck configuration to another, and from one weight group to another for a given truck configuration (see Chapter IV). This produces a VMT file for each scenario stratified by truck configuration, weight group (5,000-pound increments), functional class of highway, and State.

Pavement Deterioration Models

NAPCOM relies on 11 pavement distress models to estimate when pavement restoration will be required. These models determine the expected pavement condition at the end of each year of analysis. They evaluate the following distresses on flexible pavements: (1) traffic-related Pavement Serviceability Rating (PSR) loss; (2) expansive-clay-related PSR loss; (3) fatigue cracking; (4) thermal cracking; (5) rutting; and (6) loss of skid resistance. Distresses considered for rigid pavements include: (1) traffic-related PSR loss; (2) faulting; (3) loss of skid resistance; (4) fatigue cracking; (5) spalling; and (6) soil-induced swelling and depression. Additionally, NAPCOM estimates the damage attributable to environmental factors.

To improve NAPCOM, the FHWA undertook new research using the mechanistic cause and effect relationships between wheel load and frequency-induced stress and pavement distress. Results were calibrated using recent empirical data to determine the impact of wheel loads and frequency on pavement deterioration. Weighted averages of the distresses were used to develop a single scale which determines the overall pavement condition and which is used to determine the need for rehabilitation.

NAPCOM distress models do not use AASHTO's Fourth Power Law for pavement load and deterioration. Rather, load relationships and exponential relationships for each of the types of distress have been estimated. For most of them, the exponent would be slightly less than four. The effect of load is not as great as the simple AASHTO road test relationship for loss of serviceability would indicate.

Cost Calculations

Of interest for this study, the model provides the number of failed lane miles by highway type (flexible or rigid) and functional class of highway. The estimate of total failed lane miles by functional class of highway is combined with pavement rehabilitation unit cost figures by functional class of highway to create an estimate of the impact on pavement rehabilitation costs, all expressed in 1994 dollars.

Assessment of Scenario Impacts

To properly measure the pavement impacts, each scenario result must be compared with those pavement costs that would be incurred without a change in truck weight policy, the base case (see Table V-4). The estimated cost to maintain the current pavement conditions for the year 2000 with no TS&W policy changes is $196 billion in pavement restoration costs over 20 years. A comparison of the relative pavement impacts of the scenarios reveals that the Triples Nationwide Scenario had the largest increase in pavement restoration costs. It had an impact of $58 million in costs over 20 years (0.03 percent of the base case).

The fact that these pavement impacts are very small should not be surprising as axle weight limits were not increased in any of the scenarios, except for the 44,000-pound and the 51,000-pound limits for the tridem-axle on the four-axle SUT, six-axle semitrailer, and eight-axle B-train configurations in the North American Trade Scenario.

Table V-4. Scenario Pavement Impacts

Analytical Case		VMT (million)		Impacts ($million)	
		All Highway Vehicles	**Heavy Trucks (3 or more axles)**	**20-Year Pavement Costs**	**Change from Base Case**
1994		2,359,984	109,979	194,285	- 2,254
2000 Base Case		2,693,845	128,288	196,539	0
Scenarios					
Uniformity		2,697,908	132,351	195,873	- 666
North American Trade	44,000-pound tridem axle	2,680,228	114,671	193,475	- 3,064
	51,000-pound tridem axle	2,680,189	114,632	194,092	- 2,447
LCVs Nationwide		2,664,119	98,562	196,141	- 398
H.R. 551		2,693,868	128,311	196,541	2

Further, this scenario, with the 44,000-pound tridem-axle weight limit, resulted in a net savings of $3.1 billion in pavement restoration costs (a 1.56 percent decrease) over 20 years. The North American Trade Scenario with the 51,000-pound tridem-axle weight limit would result in a savings over 20 years of $2.4 billion (a 1.25 percent decrease).

Uniformity Scenario

Although this scenario had a 3.2 percent increase in heavy truck VMT, pavement restoration costs were 0.3 percent lower than the base case pavement improvement costs. This results from the significant shift of VMT to lower weight groups for all configurations, but especially for combination vehicles.

At the most pavement-sensitive axle weights, this shift was as much as 5,000 pounds downward in GVW for semitrailer combinations and more for those truck configurations that typically operate above the 80,000-pound Federal maximum GVW limit. This decrease in weight resulted in reduced axle loads that resulted in even greater decreases in pavement wear. The positive effect of decreased axle loads more than offset the increased in VMT.

North American Trade Scenarios

These two scenarios, one based on a 51,000-pound tridem-axle weight limit and the other on a 44,000-pound weight limit, were estimated to result in the largest savings in pavement restoration costs. While heavy truck VMT in both scenarios was approximately 10 percent lower than the base case, pavement cost savings for the 44,000 pound tridem axle scenario were estimated to be greater than savings for the 51,000 pound tridem scenario (3.0 billion over 20 years versus $2.4 billion). The reductions in pavement costs result from reduced VMT and lower LEFs for the tridem-axle configurations per unit of payload.

VMT for five-axle semitrailer combinations was approximately 70 percent less than base case VMT for both scenarios while VMT for the eight-axle B-train increased from less that 700 million miles annually under the base case to almost 50 billion annual miles under the North American Trade Scenarios.

Also significant are the differences in LEFs for the scenario vehicles. Table V-4 shows that in terms of payload carried, the six-axle semitrailer and eight-axle B-train double have much lower LEFs than the five-axle semitrailer combination.

Longer Combination Vehicles Nationwide Scenario

Despite the fact that much heavier vehicles are assumed to operate under this scenario than under the base case, pavement restoration costs are
estimated to fall by $398 million over 20 years, a 0.2 percent decrease. The primary reason for the slight decrease in pavement costs is the fact that total truck VMT is
estimated to decrease by 23 percent compared to the base case. The configurations of greatest significance in this scenario in terms of changes in VMT are the five-axle semitrailer which loses freight to the TPD and the five-axle STAA double which loses freight to the triple. VMT by five-axle semitrailer combinations is predicted to decrease by 76.6 percent under this scenario while TPD VMT is predicted to increase from just 76 million in the base case to over 32 billion under this scenario. VMT for the STAA double-trailer combination drops by 82 percent, while triples VMT increases from 126 million to almost 6 billion.

Another significant factor in reduced pavement costs is the fact that TPDs cause less pavement wear per unit of cargo than the five-axle tractor-semitrailers they would replace. Triples and doubles cause about the same pavement damage to carry the same amount of cargo.

H.R. 551 Scenario

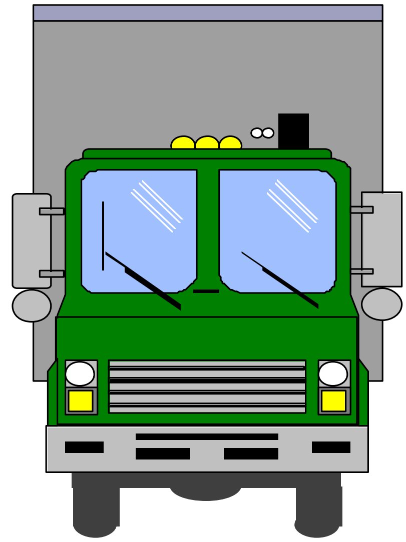
This scenario had no change in weight limits and virtually no impact on heavy truck VMT (an increase of 23 million—0.02 percent) and consequently, virtually no impact on pavement restoration costs.

Triples Nationwide Scenario

Pavement restoration costs under this scenario are estimated to be virtually unchanged (an increase of less than 0.1 percent). Total truck VMT is estimated to decrease by about 20 percent, but triples VMT in 2000 is estimated to increase from 126 million to almost 40 billion. Since triples cause more pavement wear per unit of cargo carried than the five-axle tractor-semitrailers they would replace, the large increase in pavement wear caused by increased triples traffic would offset reductions in pavement wear caused by decreases in traffic by other vehicle configurations, primarily the five-axle tractor-semitrailer.

CHAPTER VI

Bridge



Introduction

The Department, in its report to Congress on the *1997 Status of the Nation's Surface Transportation System*, found that 11.7 percent of the bridges on the Nation's arterial (including Interstate) and collector highway systems are structurally deficient and 15.2 percent are functionally obsolete (see Figure VI-1). The estimated annual cost to maintain current bridge structural and functional conditions is $5.6 billion (1995 dollars). This leads to the question: How much would various changes in truck size and weight (TS&W) limits affect current and future bridge investment requirements?

This study estimates changes in costs to correct structural bridge deficiencies that could result from TS&W policy changes. The study does not address functional obsolescence, since factors that affect functional obsolescence are largely independent of truck size and weight limits.

Basic Principles

Truck-Bridge Interaction

The impact of trucks on bridges varies primarily by the weight on each group of axles on a truck and the distances between axle groups. The number of axles in each group is less important than the distance between adjacent groups. Generally, except for some continuous bridges with long spans, the longer the spacing between two axle groups, the less the impact. Figure VI-2 illustrates the two principal types of bridges, simply supported bridges and continuously supported bridges.

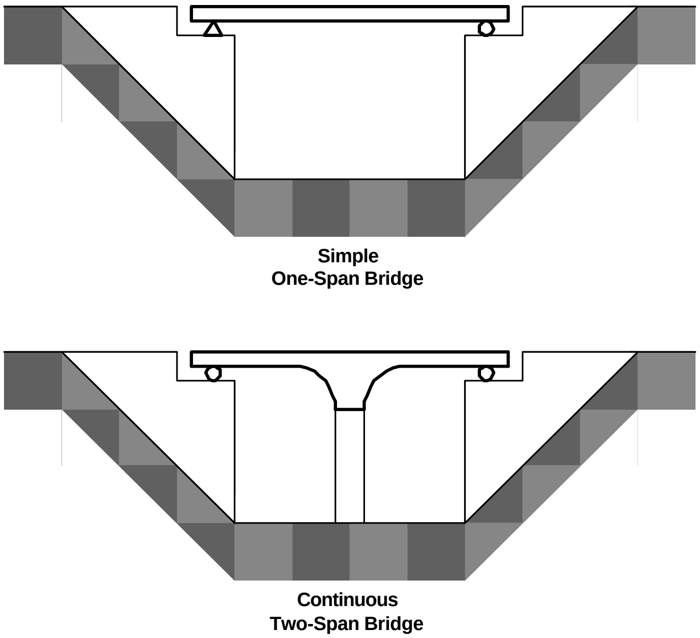
An increase in vehicle loads stretches bridge girders or beams. However, the maximum stress generally can be reduced by spreading axles and axle groups farther apart or, to a much lesser extent, by spreading the load across more axles (see Figure VI-3).

The relationship between axle loads, axle spacing, and bridge stress described above holds true for all simply supported span bridges and many continuously supported spans. However, depending on the length of continuous spans, longer axle spacings can increase stresses at the bridge inside piers. Continuous span bridges are designed to take advantage of the interactions that occur when axle groups are on the opposite side of the fixed

Figure VI-1. Structurally Deficient versus Functionally Obsolete Bridges

There are two types of deficient bridges, structurally deficient (SD) and functionally obsolete (FO). An SD bridge, as defined by the Federal Highway Administration, is one that (1) has been restricted to light vehicles only, (2) is closed, or (3) requires immediate rehabilitation to remain open. An FO bridge is one in which the deck geometry, load carrying capacity (comparison of the original design load to the State legal load), clearance, or approach roadway alignment no longer meets the usual criteria for the highway of which it is an integral part.

Figure VI-2. Simple and Continuous Span Bridges



beam connection on the central pier. This allows the use of smaller beams or girders to reduce bridge costs. However, if the two-axle loads are far enough apart and the two spans long enough, the beneficial effects will be negated.

The bridge impact analysis for this study considers both simple and continuous span bridges. The Federal Bridge Formula (FBF), which is designed to limit loads and groups of axles at different spacings to protect bridges from overloads, was based only on consideration of stresses on simple span bridges. Consequently, the FBF allows trucks to operate that could overstress certain continuous spans. Likewise, an alternative bridge formula developed by the Texas Transportation Institute (TTI) also considered only stresses on simple span bridges.

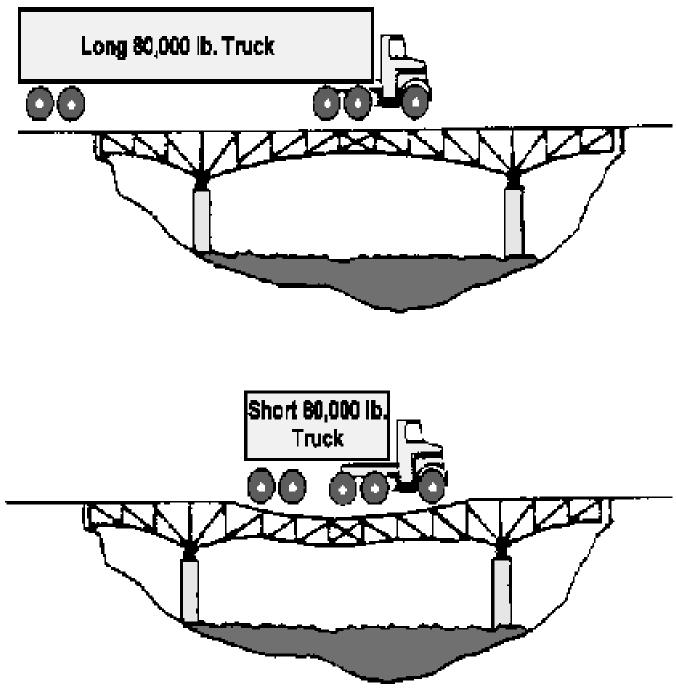
For short bridge spans, axle weights (live loads) and the weight of the span components (dead loads) are important. For longer spans,

Figure VI-3. Moments

One way to think of a moment is as two forces that tend to rotate a body, such as a bridge beam. This tendency is one source of stress in a bridge beam (the major one in a long bridge span) as the material properties and beam connection resist the rotational tendency. Further, this rotational tendency becomes stronger the farther the two forces are spread.

One of these forces results from an axle load and the other from the support at one end of the beam. One force acts in the opposite direction of the other giving rise to the rotational tendency of the two acting together. As these two forces are moved closer together, their rotational tendency is reduced. Consequently, when axle or axle groups are spread farther apart, for any given position of the truck on the bridge, the axle loads are closer to the supports which reduces the maximum moment induced by the vehicle load and the stresses in the beam.

Figure VI-4. Interaction of Bridge Span Length and Spacing of Truck Axle Groups



axle spacing becomes important in addition to the axle loads (see Figure VI-4). For spans longer than the overall length of the truck, the gross weight of the truck and its length are important along with the dead load of the span. For very long spans, the weight of the traffic is much less significant than the weight of the bridge span itself (that is, the dead load).

Bridge Impact Criteria

Previous TS&W studies have used bridge ratings as the basis for estimating whether bridges were structurally adequate to handle heavier truck loads expected under alternative truck size and weight scenarios (see Figure VI-6). Two ratings traditionally have been used by bridge engineers to rate the structural capacity of bridges, the “operating rating” which is set at 75 percent of the yield stress, and the “inventory rating”, which is set at 55 percent of the yield stress. There are several methods to rate bridges. In the past the Working Stress Design or Allowable stress rating methods were used. In recent years bridge engineers have developed new bridge rating techniques based on “load factor design” and “load and resistance factor design” principles. The rating technique used by a State in reporting its bridge ratings is not directly relevant to this analyses conducted for this study since analyses are based on comparison of moments produced by scenario vehicles to those produced by the rating vehicle, regardless of how the latter were determined.

This study, with some modifications, uses the “overstress criteria” underlying Bridge Formula B -- 30 percent overstress for H-15 bridge designs and 5 percent overstress for HS-20 bridge designs. The overstress terms are defined in Figure VI-6. Also, see Figure VI-5, “H-15 and HS-20 Bridge Loading. The study used the FBF overstress criteria because they reflect current truck weight regulation policy.

If a truck (given its weight, number of axles, and the spacing of these axles) conforms to the FBF, it is not considered overweight under current weight regulations, nor does it result in an expedited program to replace H-15 bridges.

Developing an alternative bridge formula was beyond the scope of this study. As noted above, TTI, in research supported by the Federal Highway Administration, developed an alternative bridge formula in the late 1980s that was based only on the gross weight and length of the vehicle. The American Association of State Highway and Transportation Officials considered this new bridge formula, but did not accept it over the current FBF. The TRB recommended a variation of the TTI bridge formula in its Special Report 225.

Analytical Approach

The Bridge Analysis and Structural Improvement Cost (BASIC) model was used to estimate bridge impacts. This model was specifically designed to evaluate alternative national TS&W policy options. Accordingly, it was designed to analyze quickly tens of thousands of bridges using readily available data from the National Bridge Inventory (NBI). BASIC is not a bridge rating program that requires detailed section properties and other data normally only available from the "as built" construction drawings. The program uses only data available in the NBI and a table of live load/dead load ratios for different types of bridges. It determines which bridges are overstressed by comparing the computed moment of the scenario vehicles to the computed moment of the rating vehicle. If any scenario vehicle produces a moment greater than the rating vehicle times the overstress criterion, the bridge is assumed to require replacement. Once it determines the bridges that require replacement, BASIC estimates the replacement cost based on reported unit bridge costs for each Sate. It also applies a queuing theory-based construction zone model to estimate delay and related dollar costs incurred by users while bridges are being replaced.
Bridge structural impact is a function of a particular bridge loading condition and not an accumulation of loads as is the case for pavements. Bridge deck deterioration may be related to axle load repetitions similar to pavements, but there was insufficient data to analyze potential nationwide impacts of the illustrative truck size and weight scenarios on bridge deck costs.

Changes to the vehicle fleet may also cause changes in levels of fatigue damage to the bridge superstructure and damage to bridge decks. Once a critical stress range is exceeded, the added fatigue damage due to the scenario vehicles relative to the current truck fleet is not significant, because fatigue damage is a function of both repetitions and axle loads, not gross weights. Most scenario vehicles do not have greater axle loads than vehicles of the current fleet. Also, although fatigue damage can be significant, most damage to bridge components is inexpensively corrected. A further consideration is the impact of truck size and weight scenarios on bridge deck costs. If total truck VMT decreases and axle loads do not increase as the result of TS&W limit changes, bridge deck deterioration may be reduced somewhat. No direct relationships currently exist between truck traffic, axle loads, and bridge deck deterioration, but research currently is underway to develop such relationships.

Figure VI-5. H-15 and HS-20 Bridge Loadings

Most bridges in the United States were designed to accommodate either an H-15 or HS-20 loading. An H-15 loading is represented by a two-axle single unit truck weighing 30,000 pounds (15 tons) with 6,000 pounds on its steering axle and 24,000 pounds on its drive axle. An HS-20 loading is represented by a three-axle semitrailer combination weighing 72,000 pounds with 8,000 pounds on its steering axle and 32,000 pounds on its drive axle and 32,000 pounds on the semitrailer axle. The "20" in HS-20 stands for 20 tons (4 tons on the steering axle and 16 tons on the drive axle). The "S" stands for semitrailer combination which adds in the additional 16 tons for the third axle to give a total of 36 tons or 72,000 pounds.

Overview

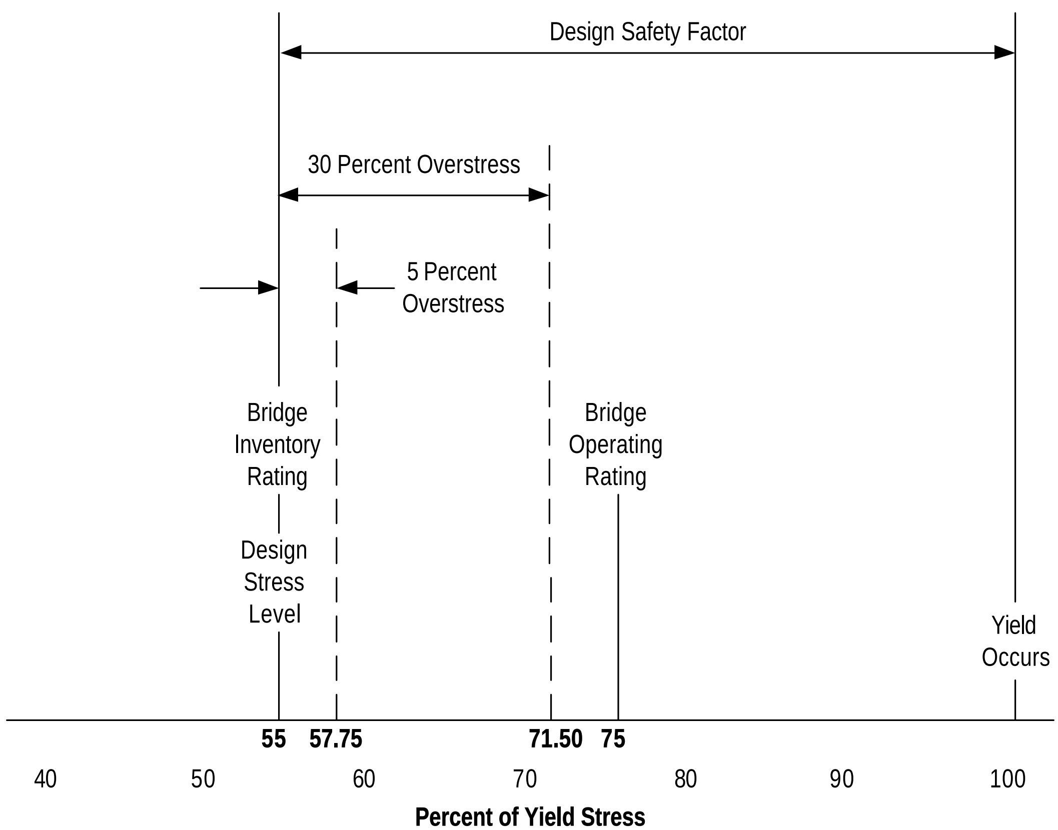
The bridge analysis for this study examines impacts of TS&W scenarios on all bridges in a sample of States from different regions of the country. For each bridge, BASIC requires data on the bridge type, bridge length, length of the main span, and the inventory rating. The inventory rating provides the safe-load carrying capacity of the bridge (see Figure VI-6). For each bridge, BASIC computes the bending moment for the rating vehicle, the base case vehicles, and the scenario vehicles. The bending moment calculations are based on both the live and dead loads for the bridge. "Dead load" refers to the weight of the bridge span components; the "live load" refers to the weight of the traffic on the span. Seven or eight truck configurations are analyzed for each scenario.

Based on the allowable overstress levels, bridges requiring replacement are identified. If the criterion for the bridge design type is exceeded, the bridge is assumed to require replacement. The cost of replacing each bridge is estimated and summed to estimate total bridge replacement costs. The user costs associated with replacing the deficient bridges are also calculated.

Like previous TRB studies, this study assumes that all deficient bridges would be replaced rather than being posted to limit maximum loads (thereby excluding some of the scenario vehicles) or strengthened. In practice it may be possible to strengthen some bridges, especially ones not expected to carry large volumes of the vehicles overstressing the bridge. There was no basis for estimating on a nationwide basis how many bridges might be strengthened rather than being replaced or what the cost to strengthen various types of bridges might be, so it was assumed that all bridges would have to be replaced. However, because in practice States might be able to strengthen some bridges rather than replacing them, cost estimates in this analysis may overestimate actual bridge costs associated with each illustrative scenario.

Figure VI-6. Relationship of Overstress Criteria to Design Stress and Bridge Ratings

The terms "overstress criteria," "design stress," " inventory rating," and "operating rating" are often used when discussing or evaluating impacts of TS&W options on bridges. These terms relate to the point at which a structural member (a load-carrying component) of a bridge undergoes permanent deformation, that is, the bridge member does not return to its original size or shape after the load is removed. The level of stress at which this permanent deformation occurs is called the "yield stress." Each of the related terms can be expressed as a percentage of this stress level. It is useful to do this to observe how each of the terms relate to each other as well as to the yield stress. Also, it is important to observe that, depending on the type of steel, a bridge member ruptures after considerable deformation relative to that which occurs at its initial point of yielding.



Relationship of Overstress Criteria to Design Stress and Bridge Ratings (Cont.)

It can be noted in the sketch that the standard stress level for the design of bridge members is 55 percent of the stress at which yield occurs. This safety factor provides a contingency for weaknesses in materials, poor quality of construction, noncompliance with vehicle weight laws, and future increases in bridge loads.

Bridges are rated by the States at either of two yield stress levels: the inventory rating, which is 55 percent of the yield stress (the same as the design stress) or the operating rating, which is 75 percent of the yield stress. These ratings are used to post bridges and for inventory purposes.

Past truck size and weight (TS&W) studies have used either of these two ratings to determine when a bridge should be replaced, given alternative TS&W policy options. A 1991 study of TS&W policy impacts on bridges used a 65-percent criterion to identify bridges needing replacement. It can be seen that bridge replacement needs would vary considerably depending on which rating was used.

The Federal Bridge Formula (FBF) is based on stress levels (overstress criteria) related to the design stress. When the FBF was formulated, a decision was made to allow loads to stress bridges designed for an H-15 loading at levels up to 30 percent over the "design stress." This type of design was used for bridges prior to the Interstate Highway Program, and these bridges are primarily located on lower functional class highways. Their early replacement was anticipated such that some shortening of bridge life could be tolerated. Bridges expected to have heavy truck traffic were designed with an HS-20 loading. The decision to allow loads no more than 5 percent over the design stress was intended to ensure that these bridges would function satisfactorily for their expected service life, 50 or more years, without the need for replacement.

This study used the FBF overstress criteria, rather than either the inventory or operating rating used in past studies, to indicate the need for bridge replacement, but with two exceptions. First, the criteria were applied to the rating stress level, and second the loads were permitted to exceed the inventory stress levels on H-17.5 (or higher H rating) bridges by only 15 percent versus the FBF's 30 percent. In terms of the yield stress, the 30 percent "overstress" is 71.5 percent, the 15 percent overstress is 63.5 percent, and the 5 percent overstress is 57.75 percent of the yield stress (see sketch). These criteria fall between the two bridge rating stress levels, and further they replicate the FBF criteria, which today allow a truck to exceed a bridge's inventory rating and not be considered overweight, that is, be found illegal or required to obtain an overweight permit. Whereas most bridges were designed using the HS-20, H-15 and H-20 design vehicles, recently several States have chosen to use the HS-25 design vehicle. Nonetheless, the bridge ratings in the NBI, as reported by the States, should generally not be the same as the original design ratings. The rating process should account for deterioration, strengthening, and the like. Also, a bridge may have been designed using an older Working Stress or Allowable Stress Design method, but now is rated by the Load Resistance Design rating method. Whereas bridge design and bridge rating is very dependent on which design method is used, it is not relevant to the concept of overstress as used in this study.

Figure VI-7. National Bridge Inventory

The National Bridge Inventory contains records of 581,862 bridges. The database is updated continuously and includes detailed information about all highway bridges in the country, on all functional systems. This information is used in the monitoring and managing of the Highway Bridge Replacement and Rehabilitation Program, as well as to provide the condition information presented in the biennial *Status of the Nation's Surface Transportation Report to Congress*.

Bridge Replacement

Model Inputs

To assess which bridges would be structurally inadequate to carry vehicle weights and dimensions assumed in each scenario, an 11-State sample of bridges was drawn from the National Bridge Inventory (NBI) (see Figure VI-7). The States, which were selected from various regions of the country, were Alabama, California, Colorado, Connecticut, Missouri, North Dakota, South Carolina, Texas, Virginia, Washington, and Wisconsin. Analytical results for the sample bridges, which include almost 30 percent of all bridges in the NBI, were expanded to reflect bridges in all States based on the deck area of the bridges in the sample States and the deck area of the bridges in the remaining States.

Questions were raised concerning whether bridges in States chosen to reflect each region of the country were truly representative of all bridges in those regions. No statistical analysis was conducted to verify that bridges were indeed representative, but because of the large overall sample size and the fact that no results are reported below the national level, the estimates of nationwide bridge costs in this analysis are not believed to be significantly affected by the choice of States in the sample.

Dead loads for the bridges were estimated based on detailed design information for 960 bridges of different types and span lengths. Given the type and span length of a bridge of interest, the dead load may be estimated from a table lookup feature in the model. While dead loads for specific bridges may vary from those estimated in this analysis, the methods used for the study's nationwide analysis are believed to be satisfactory.

This is the first nationwide TS&W study to consider both live and dead bridge loads. Previous studies have considered only live loads. However, with bridges of longer span length, the dead load becomes increasingly important, and in fact, the significance of the live load is reduced. In other words, the portion of total stress in a beam that results from the traffic load is less important than the portion of the stress resulting from the weight of the bridge span components.

Overstress Criteria

As noted above, this study assumed that bridges subjected to stresses that are not allowed under the FBF would have to be replaced. Thus bridges rated up to H-17.5 subjected to stresses that exceed 71.5 percent of the yield stress (1.3 times the design stress level of 55 percent of yield) are assumed to be structurally deficient to accommodate scenario vehicles. Bridges with a rating greater than H-17.5 are assumed to be deficient when stressed over 63 percent of yield. Bridges with an HS-20 rating that are subjected to stresses by scenario vehicles that exceed 57.5 percent of their yield stress (1.05 times the rating stress level of 55 percent of yield) are assumed to be structurally deficient to accommodate scenario vehicles.

Analytical Parameters

Available Routes

For the Longer Combination Vehicles (LCVs) Nationwide Scenario, Rocky Mountain Doubles (RMDs) and Turnpike Doubles (TPDs) were assumed to be restricted to a 42,500-mile system; only bridges on that system were tested to determine whether they are structurally adequate, based on the criteria described above, to carry those configurations. Other truck configurations in the scenario combinations were evaluated on all bridges in the sample States as they have the potential to use all the non-posted bridges in the NBI for access to terminals, places for loading and unloading, and places for food, fuel, rest, and repairs.

Specifications

Table VI-1 presents the weights, dimensions, and highway networks available to the truck configurations tested and the TS&W policy scenarios in which they are included. The GVWs are the weights for which the impacts were estimated. The maximum weight for no impact is given to show the difference in weight between the configurations as tested and the weight at which there would be no bridge impacts for each configuration.

Three-axle single unit trucks evaluated in the Uniformity Scenario could operate at the scenario weight without additional bridge impacts. Four-axle single unit trucks could operate at near the lower of the two North American Trade Scenario weights without additional bridge impacts, but the higher weight is considerably greater than the no impact weight. Five-axle semitrailers and STAA doubles could operate at the Uniformity Scenario weights with no bridge impacts. The six-axle semitrailer could operate at the lower of the two North American Trade Scenario weights without causing bridge impacts, but not at the higher weight. All of the LCVs would require bridge improvements, and with the exception of the seven-axle Rocky Mountain Double, the scenario weights are considerably above the no impact weight.

User Costs

In addition to the capital cost to replace bridges, the analytical approach estimates delay and excess vehicle operating costs accruing to users from traffic congestion during bridge replacement. The assumptions for accommodating traffic through the workzone are: (1) for twin bridges typically found on freeways, one bridge is taken out of service and all traffic uses the other; (2) for multilane bridges, one or two lanes are closed while traffic uses the remaining lanes with perhaps one being reversible to accommodate the predominant direction of the travel for the time of day; and (3) for a bridge with one lane in each direction, the procedure assumes either the new bridge is constructed before the old one is closed, a temporary bridge is provided while the bridge being replaced is built, or that there are adequate bypass

Table VI-1. Truck Configuration Parameters for Analysis of Bridge Impacts

Configuration	Scenarios	Gross Vehicle Weight (pounds)	Trailer Lengths (feet)	Outside Axle Spread (feet)	Highways Assumed Available	Maximum Weight for ANo Impact@ (pounds)
Three-Axle Truck	Uniformity	54,000	C	24.0	All	54,000
Four-Axle Truck	North American Trade	64,000	C	24.5	All	63,500
		71,000	C		All	63,500
Five-Axle Semitrailer	Uniformity	80,000	40	54.3	All	80,000
Six-Axle Semitrailer	North American Trade	90,000	40	54.8	All	90,300
		97,000	40	54.8	All	90,300
Five-Axle STAA double	Uniformity	80,000	28, 28	64.3	All	92,000
Seven-Axle Rocky Mt. Double	LCVs Nationwide	120,000	53, 28	94.3	42,500-mile System	115,300
Eight-Axle B-Train Double	North American Trade and LCVs Nationwide	124,000	33, 33	79.3	All	111,600
		131,000	33, 33	79.3	All	111,600
Nine-Axle Turnpike Double	LCVs Nationwide	148,000	40, 40	119.3	42,500-mile System	122,200
Seven-Axle C-Train Triple	LCVs Nationwide and Triples	132,000	28, 28, 28	97.2	65,000-mile System	116,100

opportunities and consequently no significant change in user costs.

Assessment of Scenario Impacts

The estimated costs, in 1994 dollars, for replacing bridges that would be stressed at levels above one of the three overstress thresholds discussed earlier and the user costs during bridge reconstruction are given in Table VI-2. Also shown are estimated costs to bring existing bridges up to standard to accommodate Base Case vehicles.

It is important to note that bridge costs are one time costs, not annual or recurring costs. For all scenarios, the user costs are at least as high as the capital costs, and for the scenarios with significant increases in GVWs, the delay costs are much higher.

The scenario analysis assumes that no bridges are posted or otherwise unavailable for the scenario vehicles. In practice State officials would have several options for bridges that might be structurally inadequate to accommodate vehicles that might be allowed under revised truck size and weight limits. One option would be to replace the bridge immediately if it was anticipated to carry substantial volumes of more damaging vehicles. A second option would be to postpone replacement if anticipated overstress was determined to be acceptable for a limited time. A third option would be to strengthen deficient bridges that would be expected to carry loads that could not safely be accommodated without improvements but which did not need immediate replacement. A fourth option would be to post bridges that were not economically important or were not required to carry large volumes of larger vehicles. Costs estimated in this analysis thus may be somewhat overstated and certainly not all costs would have to be incurred before heavier loads could be allowed to operate. Even if some bridges can be strengthened in the short run, many might have to be replaced sooner than otherwise would have been the case had there been no change in truck size and weight limits.

The Uniformity Scenario (see Table VI-2) would reduce current bridge investment requirements (by $20 billion). Savings result from the rollback of State weight limits that apply to the NO, which includes Interstate highways, that are higher than the Federal limits.

The bridge impacts of the North American Trade Scenarios are dominated by the weight (44,000 pounds and 51,000 pounds) allowed on the tridem-axle for the noted configurations. The bridge impacts are $51 billion and $65 billion for capital costs and $203 billion and $264 billion for user delay costs for the scenarios with the 44,000-pound and 51,000-pound tridem limit, respectively.

The bridge impact for the Longer Combination Vehicles Nationwide Scenario is $53 billion in capital costs and $266 billion in user delay costs. It is dominated by the nine-axle TPD at 148,000 pounds distributed across a length of 119.3 feet, and the eight-axle B-train double-trailer combination at 131,000 pounds distributed over 69.3 feet.

Theoretically, the H.R. 551 Scenario might increase bridge impacts as the lengths of some semitrailer combinations would be reduced as semitrailers longer than 53 feet would be phased out of service. Decreasing the length of a truck at a given weight increases the stress on bridges. This effect is very small for two reasons. First, the number of trucks affected is very small and second, the commodities carried in extra-long semitrailers are generally very light such that they have no impact on bridges. Therefore, this scenario has virtually no impact on bridges.

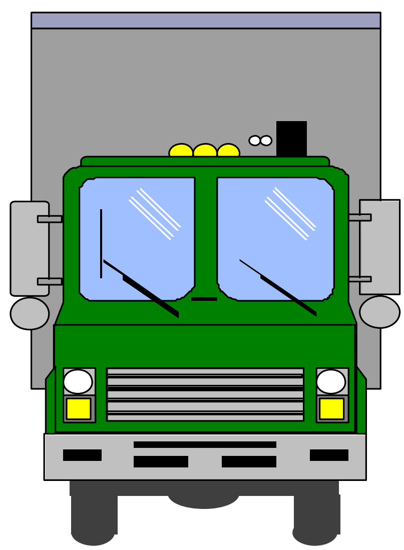
For the Triples Nationwide Scenario bridge costs ($16 billion in capital and $101 billion in user costs) result from the use of the seven-axle triple-trailer combination at a GVW of 132,000 pounds distributed over a length of 97.2 feet.

Table VI-2. Scenario Bridge Impacts

Analytical Case		**Costs ($Billion)**			**Change from Base Case ($Billion)**		
		Capital	**User**	**Total**	**Capital**	**User**	**Total**
1994 Base Case		154	175	329	0	0	0
2000 Base Case		154	175	329	0	0	0
SCENARIO							
Uniformity		134	133	267	-20	-42	-62
North American Trade	44,000-pound tridem axle	205	378	583	51	203	254
	51,000-pound tridem axle	219	439	658	65	264	329
LCVs Nationwide		207	441	648	53	266	319
H.R. 551		154	175	329	0	0	0
Triples Nationwide		170	276	446	16	101	117

CHAPTER VII

Roadway Geometry



Introduction

Some Longer Combination Vehicles (LCVs) are less maneuverable than vehicles currently in use. Intersection and interchange improvements would be required to safely operate these vehicles in many locations. Furthermore, scenarios in this study assume that some LCV configurations could only operate on a limited network of highways. They would have to be assembled and disassembled at staging areas adjacent to that network. The costs to adjust roadway geometric features and provide staging areas to properly accommodate the use of LCVs are included in this chapter.

Basic Principles

This section provides an overview of the relationship between vehicle turning characteristics and roadway geometry.

Truck Turning Characteristics

For this study, truck turning characteristics, "offtracking," were considered in determining the extent to which roadway geometrics would need to be upgraded to accommodate less maneuverable vehicles. When a vehicle makes a turn, its rear wheels do not follow the same path as its front wheels. The magnitude of this difference in path, known as offtracking, generally increases with the spacing between the axles of the vehicle and decreases for larger radius turns. Off-tracking of passenger cars is negligible because of their relatively short wheelbases; however, many combination trucks offtrack substantially.

Low-Speed Offtracking

When a combination vehicle makes a low-speed turn--for example a 90-degree turn at an intersection--the wheels of the rearmost trailer axle follow a path several feet inside the path of the tractor steering axle. This is called low-speed offtracking. Excessive low-speed offtracking may make it necessary for the driver to swing wide into adjacent lanes when making a turn to avoid climbing inside curbs or striking curbside fixed objects or other vehicles. When negotiating exit ramps, excessive offtracking can result in the truck tracking inward onto the shoulder or up over inside curbs. This performance attribute is affected primarily by the distance from the tractor kingpin to the center of the trailer rear axle or axle group (see Figure VII-1). In the case of multitrailer combinations, the effective wheelbase(s) of all the trailers in the combination, along with the tracking characteristics of the converter dollies, dictate this property. In general, longer wheelbases worsen low-speed offtracking. Figure VII-2 illustrates low-speed offtracking in a 90-degree turn for a tractor-semitrailer.

The standard double-trailer combination (two 28-foot trailers) and triple-trailer combination (three 28-foot trailers) exhibit better low speed offtracking performance than a standard tractor and 53-foot

Figure VII-1. Kingpin Setting

The kingpin, a part of the fifth wheel connection, is the pivot point between the tractor and semitrailer. The kingpin setting is the distance from the center of the fifth wheel connection to the center of the rear axle group., and affects the turning radius of the vehicle. The longer the kingpin setting, the larger the turning radius.

Figure VII-2. Low Speed Offtracking

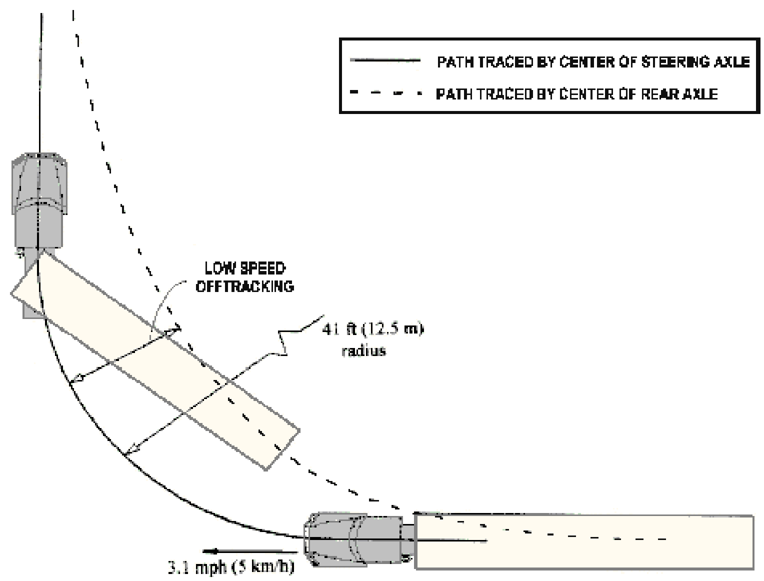
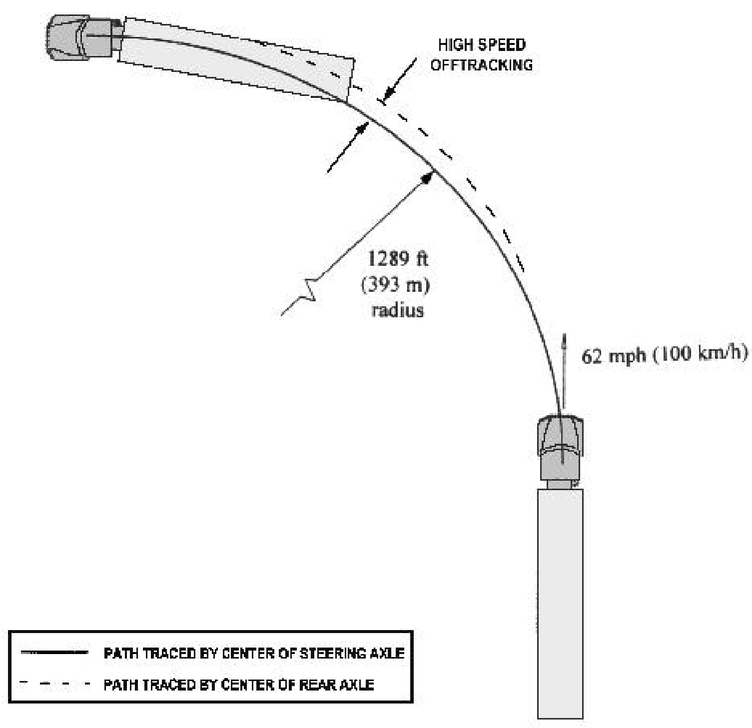


Figure VII-3. High-Speed Offtracking



semitrailer combination. This is because they have more articulation points in the vehicle combination, and use trailers with shorter wheelbases.

High-Speed Offtracking

High-speed offtracking is a speed-dependent phenomenon that results from the tendency of the rear of the truck to move outward due to the lateral acceleration of the vehicle as it follows a curve at higher speeds. As the speed of the truck increases from very slow, offtracking to the inside of the curve decreases until, at some particular speed, the rear trailer axles follow exactly the tractor steering axle. At still higher speeds, the rear trailer axles will track outside the track of the tractor steering axle. 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 also depends on the loads carried by the truck axles and the truck suspension characteristics. Figure VII-3 illustrates high-speed off-tracking for a standard tractor-semitrailer.

Roadway Geometry

and Truck Operations

Intersections

Most truck combinations turning at intersections encroach on either the roadway shoulder or adjacent lanes. For example, the turning path of a truck making a right turn is generally controlled by the curb return radius, whereas the turning path in left turns is not constrained by roadway curbs, but may be constrained by median curbs and other traffic lanes. Combination vehicles with long semitrailers are critical in the determination of improvements to intersections required to accommodate offtracking requirements.

It is generally agreed that proper roadway design and vehicle operation requires that no encroachment into the path of vehicles traveling in opposing directions of flow be allowed. A higher standard is often used for roadway design in urban areas, where no encroachment into any adjacent lane is allowed. This is particularly critical at signalized intersections where heavy traffic is a prevailing condition.

However, a substantial number of intersections on the existing highway and street network cannot accommodate even a five-axle tractor semitrailer combination with a 48-foot semitrailer. State and local officials have determined that costs to improve these intersections are not justified because of low traffic volumes, costs to relocate adjacent development, the existence of environmentally or historically sensitive sites adjacent to the highway, or other reasons.

Interchange Ramps

Access and exit ramps for controlled access highways, such as Interstates, are intended to accommodate certain types of vehicles at design speeds, as well as for high-speed and low-speed offtracking by combination vehicles. Tractor-48-foot semitrailer combinations cannot negotiate many existing interchange ramps without encroaching on the shoulder, but State and local officials may allow them to use those ramps anyway. Often, this practice results in premature deterioration of ramp shoulders and may represent a safety problem as well.

Horizontal Curvature

Truck combinations with longer trailers may offtrack more than is provided for in AASHTO design standards. For some roadways this may mean that the vehicles cannot stay within their travel lane on sharp curves. This can represent both a maintenance problem and a potentially severe safety problem if the roadway has no paved shoulder. If those vehicles were to be allowed on highways with such conditions, improvements would be required to assure that offtracking did not result in the vehicles leaving their lane.

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 these new trucks, and estimates the costs of these improvements. The focus of this research was to compare the new truck configurations with common, existing large trucks.

The baseline truck is the standard tractor-semitrailer combination with 48-foot trailer operating at 80,000 pounds and the STAA double combination with two 28-foot trailers operating at 80,000 pounds. The research analyzed 15 basic truck configurations. Within these basic configurations additional breakdowns were made according to body type, axle spacing, truck length, and trailer length, resulting in 89 specific cases being assessed. Figure VII-4 shows the basic configurations examined. All STAA twin-trailer combinations considered had two 28-foot trailers. The eigh-axle B-train double trailer combination with two trailers up to 33 feet in length was evaluated. The maximum size considered for the Rocky Mountain Double (RMD) combination included the first trailer at 53 feet and the second trailer at 28 feet. Turnpike Doubles (TPD) with two trailers up to 53 feet in length were

Figure VII-4. Basic Configurations Used in Roadway Geometry Analysis

- Three-axle Single Unit Truck (SUT)
- Four-axle SUT with Twin Steer Axles
- Four-axle SUT with Three Drive Axles
- Five-axle Tractor-semitrailer
- Six-axle Tractor-semitrailer
- Five-axle SUT with Two-axle Full Trailer
- Seven-axle SUT with Four-axle Full Trailer
- Five-axle STAA Double
- Six-axle STAA Double
- Seven-axle STAA Double
- Seven-axle Rocky Mountain Double
- Seven-axle B-train Double
- Eight-axle B-train Double
- Nine-axle Turnpike Double
- Seven-axle Triple

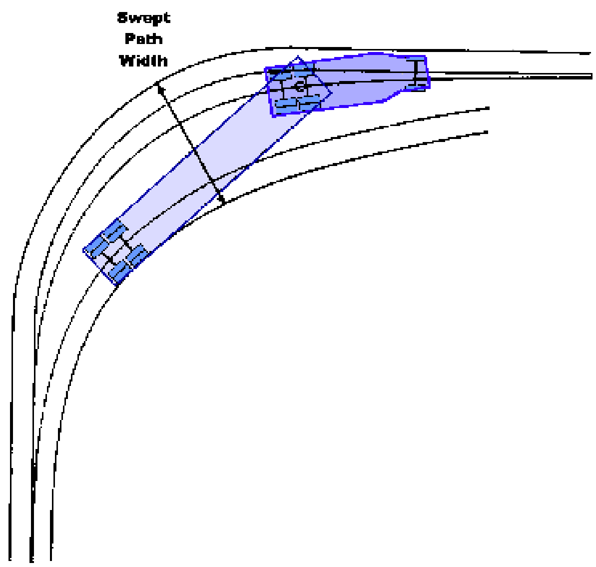
Figure VII-5. Staging Areas

Staging areas are used to break down long multitrailer combinations into single-trailer or shorter multitrailer vehicles for operation on highways where certain LCVs are not allowed to operate. The assumption that staging areas will be provided increases the overall roadway geometry costs for the Longer Combination Vehicles Nationwide Scenario, even though fewer interchanges would have to be improved. The study assumes that LCVs with offtracking greater than the baseline combinations would have to breakdown into single-trailer combinations when they leave a highway designated for their use. This breakdown occurs in either publicly or privately provided staging areas. It is also assumed that carriers would arrange for staging areas not publicly provided when these arrangements provide for more economical operations. Whether provided by the public or privately, the staging areas need to be in place and their costs need to be accounted for.

Presently, staging areas are used along the eastern turnpikes on which LCVs operate. In the West, LCVs have been operating for a considerable time without staging areas.

Figure VII-6. Swept Path

Swept path is the amount of roadway space the truck needs to make the turn without hitting something. The most appropriate descriptor of offtracking for many roadway geometric design applications is the "swept path width." This is shown in the sketch below as the difference in paths between the outside front tractor tire and the inside rear trailer tire(s) of the vehicle.



considered.

Offtracking characteristics of the study vehicles in relation to curves and intersections, were examined and costs were estimated to correct geometric deficiencies on roadways on which each configuration is assumed to operate. Improvement costs needed to eliminate excessive offtracking were estimated with and without staging areas being provided (see Figure VII-5).

Vehicle Offtracking

Performance

The offtracking characteristics of the larger scenario trucks are markedly different from the standard baseline trucks on the road. Research for this study examined low-speed and high-speed offtracking and swept path width of the LCVs. (See Figure VII-6.)

Table VII-1 presents the offtracking characteristics of the truck combinations evaluated in this study. The offtracking characteristics of single unit trucks are not presented as they have minimal offtracking and their swept path falls well within current lane width standards. Offtracking characteristics are given for an intersection of two-lane roadways with lane widths of 12 feet (current highway design standards call for lanes wider than 12 feet for two-lane roadways). The curb radius is 60 feet.

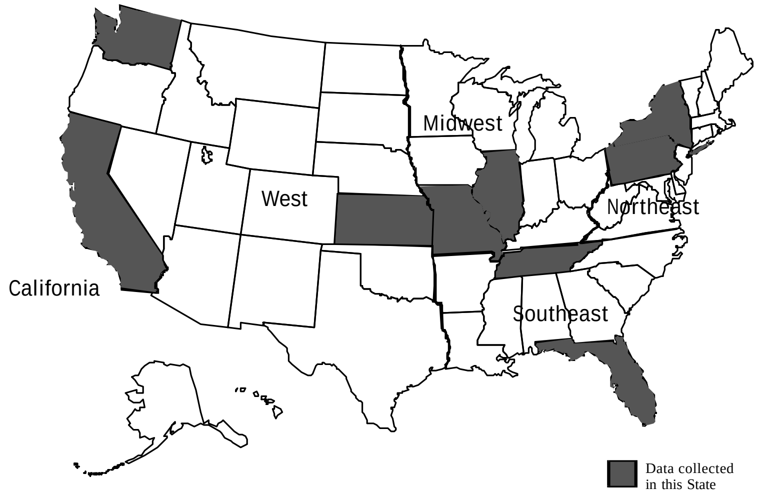
Table VII-1 Offtracking Characteristics for Trucks Turning Right at Typical Two-Lane Roadway Intersection

Truck Configuration	Trailer Length(s) (feet)	Kingpin Setting(s) (feet)	Offtracking		Swept Path		Encroachment to Inside of Track	
			feet	percent	feet	percent	feet	percent
Five-Axle Semitrailer	48.0 (Base Line Vehicle)	41.0	14.2	100	21.8	100	10.4	100
	53.0	46.0	16.5	116	24.2	111	12.8	123
	57.5	50.5	18.7	132	26.4	121	15.0	144
Six-Axle Semitrailer	53	44.0	15.6	110	23.2	106	11.8	113
Five-Axle Double	28, 28	21.9 21.9	8.4	59	16.1	74	4.7	45
Seven-Axle Rocky Mountain Double	53, 28	46.0 23.0	18.9	133	26.6	122	15.2	146
Eight-Axle B-Train Double	33,33	32.2 27.1	14.2	100	21.9	100	10.4	100
Nine-Axle Turnpike Double	53, 53	46.0 46.0	27.0	190	34.7	159	23.2	223
Seven-Axle Triple	28, 28, 28	23.0 23.0 23.0	12.7	89	20.4	94	9.0	87
(12-foot lanes, 60-foot curb return, 38-foot path radius)								

The table shows that those combinations with two and three short trailers offtrack less than the baseline vehicle, a 48-foot semitrailer combination with a 41-foot kingpin setting. The two semitrailer combinations with lengths of 53 feet and 57.5 feet show the sensitivity of offtracking to the kingpin setting. A 53-foot semitrailer with a 41-foot kingpin setting would offtrack the same as the 48-foot semitrailer combination, but the back of the trailer would swing out a little further due to the additional 5 feet from the center of its trailer axle group to the back of the trailer.

The effect of having multiple

Figure VII-7. Regions Used for Assessing Geometric Impacts



articulation points can be seen by comparing the offtracking of the 57.5-foot semitrailer with that of the RMD. Their offtracking characteristics are virtually the same, but the RMD, a combination with 53-foot trailer, and a 28-foot trailer has an additional 23.5 feet in cargo box length. The combination with the worst offtracking characteristics is the TPD with two 53-foot trailers.

Impacts

Geometric

The four roadway geometric elements critical to accommodating 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 a sample of roadways in nine States, selected from five regions: Northeast (New York and Pennsylvania), Southeast (Florida and Tennessee), Midwest (Illinois and Missouri), West (Kansas and Washington), and California (see Figure VII-7). Looking at five highway types in the sample States, researchers determined the mainline curve radii based on the 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, 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. Estimates were made for the number of locations or mileage that needed improvement and the amount and cost of widening for each truck that offtracks more than the baseline tractor with a 48-foot semitrailer.

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 baseline truck. There are turns and highway curves that cannot accommodate existing trucks. The costs are reported in the Base Case Scenario.

The scenario analyses assume that all of the needed geometric improvements have been made. More realistically, these improvements would have to be scheduled over a number of years, and therefore, the full use of the highways assumed available for them would take many years to occur.

Staging Areas

If the worst offtracking trucks, the TPDs and the RMDs, are allowed to go everywhere in the truck network, including urban areas, the costs to widen highways to accommodate them would be incalculable. Staging areas were assumed to exist at key rural interchanges and the fringes of major urban areas.

The research examined how often staging areas would be used, where they would be located, and what they would cost. On rural freeways, staging areas would be needed every 15.6 miles. Trucks with trip origins or destinations in an urban area would use urban fringe staging areas. Through trucks would use the interstate or other freeway systems to their destination.

As with geometric improvements, staging areas must be provided before full use of highways assumed available for long-double combinations can actually be realized. Providing public staging areas is likely to require many years.

Comments submitted to the docket on the issue of staging areas primarily concerned the number of areas assumed to be needed and their costs. Some thought more staging areas would be needed and that costs would be higher, while others commented that the number of staging areas assumed in this study is too high, especially since LCVs now operate in western States without staging areas.

A report to Congress by the Department in 1985 estimated a range of staging area needs. The low estimate was that staging areas would be needed every 150 miles in rural areas while in the high estimate, staging areas were assumed to be required every 25 miles. The total estimate of staging areas needed in the 1985 DOT study ranged from 463 to 1401. A 1990 study for the American Trucking Associations Foundation on the other hand estimated that only 32 publicly provided staging areas would be required nationwide with the remaining needs being met by the private sector.

Staging area needs estimated in this study were developed from a study by Pennsylvania State University and the Midwest Research Institute entitled, “Evaluation of Limitations in Roadway Geometry and Impacts on Traffic Operations for Proposed Changes in Truck Size and Weight Policy.” That study estimated that rural staging areas accommodating six LCVs would be required every 15.6 miles in rural areas and that urban interchanges accommodating 20 LCVs would be required on major routes entering and leaving each metropolitan area. Based on these assumptions a total of 2,455 rural staging areas and 830 urban staging areas are estimated to be required for LCV operations. This would be sufficient to accommodate 30 percent of LCVs expected to operate at any one time under the LCVs Nationwide Scenario, assuming that trailers would be left in the staging areas an average of 8 hours during assembly and disassembly operations. Needs certainly would not be uniform in all parts of the country. Some locations might need more or larger staging areas while others might need fewer staging areas.

Costs

Geometric Improvements

A model was developed to estimate geometric improvement costs for a given TS&W scenario based on the offtracking performance of the specified truck configurations, and the mileage and location of the roads on which the vehicles are expected to operate. The model is useful in determining geometric requirements for a large range of vehicle configurations for any specified highway network.

The costs to upgrade roadways to accommodate offtracking by scenario vehicles are given in Table VII-2. These include widening the lanes for sharp curves and moving curbs back. In the worst cases, widening includes adding a lane. These costs are summarized by mainline curves, at-grade intersections, and freeway interchanges. For the two long double-trailer configurations, costs with staging areas are given in parentheses along with the costs without staging areas.

The cost of each of the geometric deficiencies for a given scenario was determined and expanded based on the number of interchanges and intersections in each of the nine States that correspond to those in the sample. Next, the average spacing, or occurrence of these features in terms of highway miles by functional class was determined. These cost estimates were applied to the remaining States based on their highway miles in each functional class. This gives a national estimate of the costs to upgrade interchanges and intersections to accommodate vehicles with offtracking greater than a semitrailer combination with a 41-foot kingpin setting, which is typical for a 48-foot semi-trailer combination. The cost to upgrade sharp horizontal curves was based on data used in the Federal Highway Administration's HPMS Investment/Performance Models.

Staging Areas

The cost to provide public staging areas was also estimated. For rural areas, it was estimated that 2,455 staging areas, each sized to accommodate six trucks, would be required. The cost for constructing them was estimated to be $1.62 billion.

For urban areas (137 were considered), it was assumed that each highway route into the urban area that was considered available for long double combinations would have a staging area. This resulted in staging areas from two for many urban areas to as many as 14 for Indianapolis. The total for the country was 830 with six being the most typical number for urban areas. The cost to provide space for 20 trucks for each urban staging area was estimated as $3.57 million, which gives a total cost for urban staging areas of $2.96 billion.

Figure VII-8. Staging Area

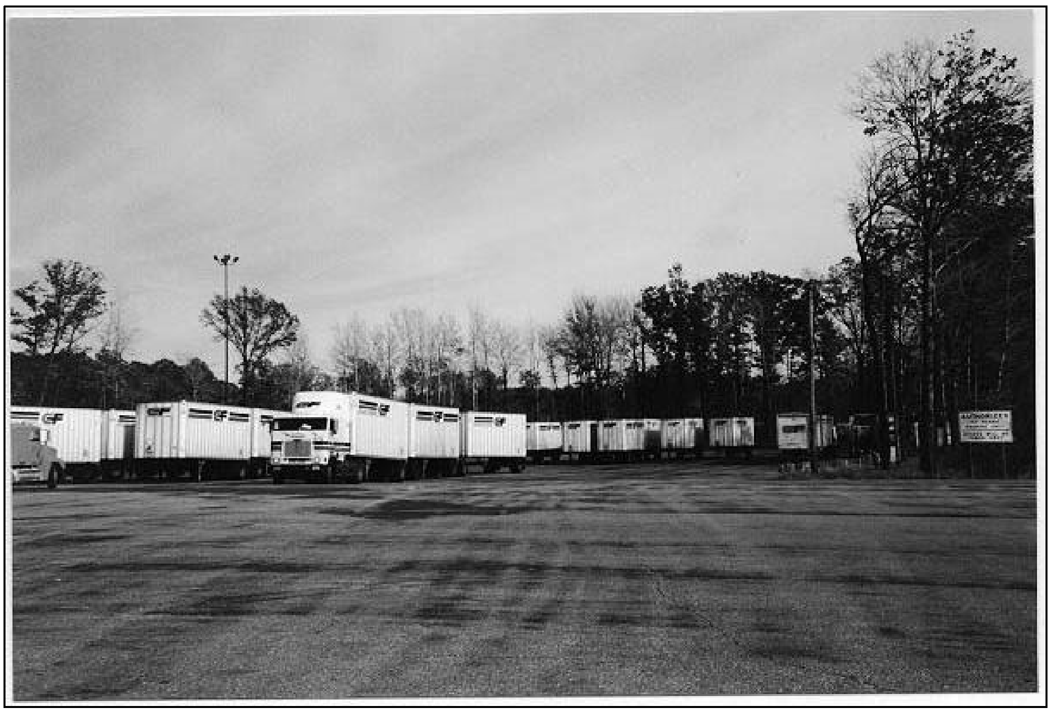


Table VII-2 Roadway Geometry Costs by Truck Configuration

Truck Configuration	Trailer Length (feet)	Improvement Costs ($ millions)			
		Mainline Curves	Intersections	Interchanges (with Staging Areas)	Total (with Staging Areas)
Five-Axle Semitrailer	48.0 (Base Line Vehicle)	86.4	37.1	630.7	754.2
	53.0	166.2	128.1	1,171.7	1,466.0
	57.5	172.4	183.4	1,331.6	1,687.4
Six-Axle Semitrailer	53	88.5	71.7	694.6	854.8
Five-Axle Double	28, 28	No additional costs are incurred; this vehicle offtracks less than the baseline vehicle.			
Seven-Axle Rocky Mt. Double	53, 28	136.0	174.0	1,255.6 (5,839.0)	1,565.6 (6,149.0)
Eight-Axle B-Train Double	33, 33	No additional costs are incurred; this vehicle offtracks the same as the baseline vehicle.			
Nine-Axle Turnpike Double	53, 53	281.3	701.0	2,959.7 (6,913.0)	3942.0 (7895.3)
Seven-Axle Triple	28, 28, 28	No additional costs are incurred; this vehicle offtracks less than the baseline vehicle.			

Assessment of Scenario Impacts

This section presents the costs to upgrade the highways that are assumed to be used by the study vehicles in each TS&W policy scenario. This upgrading improves the mainline curves and 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 (see Table VII-3).

The costs for each scenario are one time only costs (not annual costs), further, they would require a number of years to complete, given resource constraints and competing priorities in the States.

The study's overall results are based on the assumptions that the roadway geometry

Table VII-3 Scenario Roadway Geometry Impacts

Analytical Case	Worst Offtracking Vehicle in Scenario	Trailer Length (Feet)	Improvement Costs ($Million)				
			Main-line Curves	Inter-sections	Inter-changes	Total	Change in Total Costs from Base Case
1994 Base Case	Baseline Vehicles	48 or 53	86.4	37.1	630.7	754.2	0
2000 Base Case	Baseline Vehicles	48 or 53	86.4	37.1	630.7	754.2	0
SCENARIO							
Uniformity	Baseline Vehicles	48 or 53	86.4	37.1	630.7	754.2	0
North American Trade (51,000-Pound and 44,000-Pound Tridem-Axle Weight Limits)	Six-Axle Semitrailer	48 or 53	88.5	71.7	694.6	854.8	100.6
LCVs Nationwide[1] No Staging Areas	Nine-Axle Turnpike Double	53 and 53	281.3	701.0	2,959.7	3742.0	3,389.1
LCVs Nationwide[1] With Staging Areas	Nine-Axle Turnpike Double	53 and 53	281.3	701.0	6,913.0	7,895.3	7,141.0
H.R. 551	Baseline Vehicles	48 or 53	86.4	37.1	630.7	754.2	0
Triples Nationwide	Baseline Vehicles	48 or 53	86.4	37.1	630.7	754.2	0

[1] As the LCV's were analyzed based on the 42,500-mile network, the change in costs from the Base Case reflect the lower costs for the baseline vehicles for the lesser network.

improvements have been made and that the staging areas represented by the above costs are in place. In reality, funds need to be available and even then considerable time is required to make the improvements. Presumably, individual States would restrict the operation of long doubles until the necessary improvements have been made.

Uniformity Scenario

The costs shown in Table VII-2 are those for 53-foot semitrailer combinations with 41-foot kingpin settings. Most States require this setting to be 41 feet or less. Given this requirement, the roadway geometry costs for this scenario would be the same as the base case.

North American Trade Scenarios

The six-axle semitrailer combination dominates the eight-axle B-train double combination in both of these scenarios, as its offtracking is slightly worse (15.6 feet versus 14.2 feet) than those of the baseline vehicle, whereas the B-train double offtracks the same as the base line vehicle. The scenario's cost for eliminating this impact is $100.6 million over the Base Case improvement costs.

Longer Combination Vehicles Nationwide Scenario

The nine-axle TPD offtracks more than the other vehicles evaluated in this scenario. Therefore, the cost to eliminate its excessive offtracking is $3.33 billion and $7.28 billion with public staging areas added.

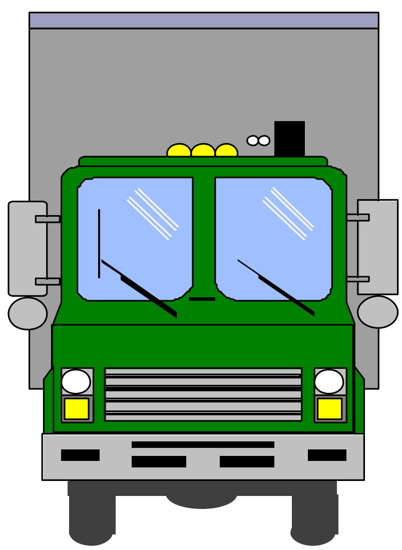
H.R. 551 Scenario

The impact shown in Table VII-2 is actually a savings of $170 million, as semitrailer lengths under this scenario would eventually be no longer than 53 feet. The impact estimate is based on the fact that 57.5-foot semitrailer combinations operate in ten, mostly Western States, and that no curves or intersections had been upgraded to accommodate them.

Triples Nationwide Scenario

There are no roadway geometry impacts and costs for this scenario (see Table VII-2) because the triple-trailer combination offtracks less than the typical semitrailer combination that operates on virtually all highways.

CHAPTER VIII



Safety

Introduction

Considerable debate has focused on the safety of larger and heavier trucks, and whether allowing truck sizes and weights to increase beyond what is commonly found today would degrade safety. Most studies that have attempted to answer this question have centered on two approaches—crash data analyses or comparative analyses of the safety-related engineering performance capabilities of various truck configurations. This study used both approaches. In addition, methods for relating changes in vehicle stability and control performance to changes in the expected number of truck crashes were considered.

Multiple factors that contribute to truck crashes include:

- Driver performance and behavior;
- Roadway design and condition;
- Weather and light conditions;
- Vehicle design, performance and condition;
- Motor carrier management commitment to safety and practices; and

Institutional issues such as motor carrier safety regulation and enforcement.

Within this broad context, isolating crash rates as only a function of truck size and weight (TS&W) variables is difficult. Because larger and heavier trucks are a relatively small subgroup of all trucks, differentiating their crash involvement patterns from that of other truck types becomes problematic. Available crash data bases are capable of ascertaining trends in overall truck safety and broad distinctions among vehicle types, but are less capable of clearly differentiating trends for smaller subsets of vehicles. There are, nevertheless, several key trends that are evident relative to truck safety in general and TS&W policy choices in particular. First, numerous analyses of crash data bases have noted that truck travel, as well as all vehicle travel, on lower standard roads (that is, undivided, higher speed limit roads with many intersections and entrances) significantly increases crash risks compared to travel on Interstate and other high quality roadways. The majority of fatal crashes involving trucks occur on highways with lower standards. Also, operating in higher traffic densities increases crash risk as a result of increased conflict opportunities with other vehicles. TS&W requirements affect operators' choices on which roads they will operate which types of trucks.

Second, TS&W policies influence vehicle stability and control because they directly affect key vehicle design attributes such as number of axles, track width, wheelbase, number of units in a combination, loaded weight, and overall length. Vehicle performance tests and engineering analyses have highlighted the significant differences that exist in the stability and control properties of different sizes, weights, and configurations of trucks. Some larger and heavier trucks are more prone to rolling over than other trucks; some are less capable of successfully avoiding an unforeseen obstacle when traveling at highway speeds. Some negotiate tight turns and exit ramps better than others; some can be stopped, maintaining stability, in shorter distances than others; and some climb hills and maneuver in traffic better than others. The influence of these differences increases when traffic conflict opportunities increase.

Larger and Heavier Truck Crash Patterns

Many past studies have attempted to identify the singular effect on crash propensity of size and weight differences among various truck configurations, with particular focus on double-trailer combinations or, more specifically, longer combination vehicles (LCVs). Their conclusions vary from slightly positive to slightly negative, to no difference. This disparity in findings is explained, in large part, by the different methodologies and data sets used to conduct the various studies.

Few of these past studies controlled for the confounding factors that can significantly influence overall crash rate results, principal among these being differences in operating environments. Thus, while some of these study results may appear to indicate no significant problems or concerns, the collective results cannot be used to infer what the crash experience of multitrailer combinations would be if the operational conditions under which they are now being used were to change. The results of these past studies merely reflect what has occurred under the existing restricted operating conditions.

Available data sets are capable of differentiating between the crash experiences of single-unit trucks (SUTs) and combination vehicles (principally tractor semitrailer) within the broader class of medium to heavy trucks. Further, truck crash data are available which distinguish between single-trailer and multitrailer combinations, however, this latter group includes all multitrailer combinations. Differentiation among the number or lengths of trailers in these combinations, or their operating weight, is typically not possible from reported data. This has the effect of including in the crash sample Surface Transportation Assistance Act (STAA) doubles (tractor and two 28-foot trailers weighing no more than 80,000 pounds), along with longer double-trailer and triple-trailer combinations weighing more than 80,000 pounds referred to as LCVs.

STAA doubles dominate multitrailer combination crash history since they are the most common vehicles in

Figure VIII-1. Efforts to Establish Longer Combination Vehicle Crash Rates

The Federal Highway Administration (FHWA) was not able to obtain sufficient data to estimate crash rates for longer combination vehicles (LCVs) because of the limited extent of LCV operations. One study did determine crash rates for LCVs but not by roadway and area type. However, this is not sufficient as these two parameters play a significant role in large truck crashes.

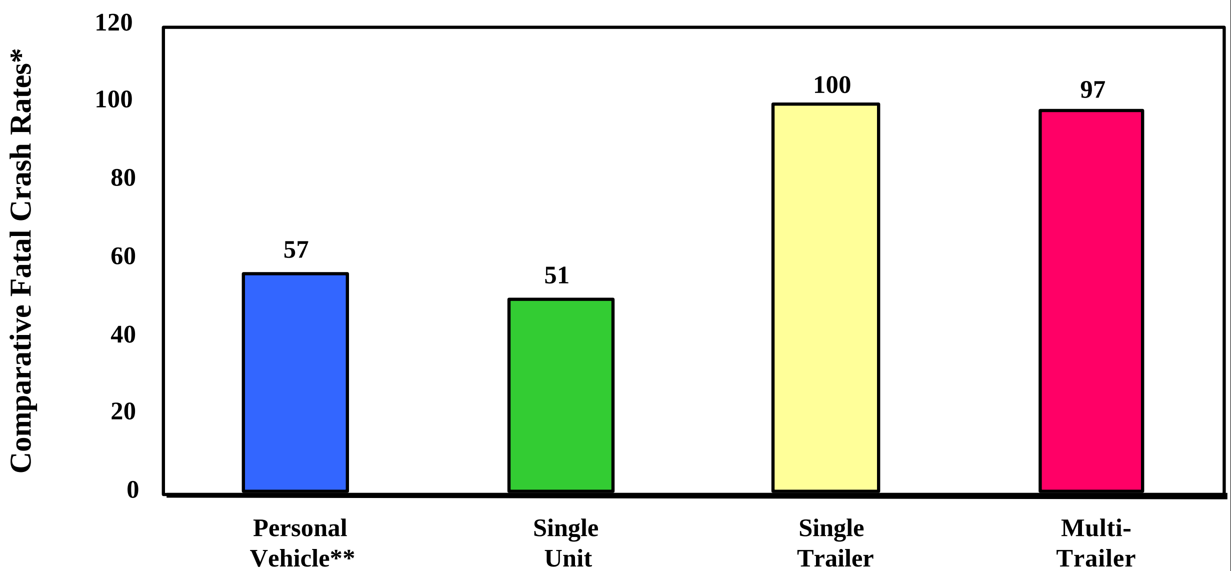
Using data from Utah, which collects the LCV crash data in the needed detail, the FHWA effort determined that: (1) over 20 years of data collection would be required in order to compute statistically reliable crash rates for long double- and triple-trailer combinations, and (2) these rates would be for Interstate highways only. If data were available from four other States in which LCVs now operate, this time could be reduced to 6 years to 8 years; but still the rate could only be applied to Interstate highways. Although not typically, LCVs do operate on non-Interstate highways to a small extent, which means that even more time would be needed to reliably estimate their crash experience on these highways.

use in this truck category. However, LCVs are configured similarly and have similar stability and control performance characteristics and, therefore, are likely to have similar crash propensities, although increasing the lengths of trailers improves some of these characteristics if weight is not increased.

Figure VIII-2 shows the 1991-1995 fatal crash involvement rates for passenger cars and for three subgroups of medium to heavy trucks: SUTs, single-trailer combinations, and multitrailer combinations. As can be seen, when aggregated data are used, multitrailer combinations exhibit a 3 percent lower overall fatal crash rate than single-trailer combinations, an apparent finding of concern for this study.
This picture changes, however, when the fatal crash rates for single-trailer and multitrailer combinations are disaggregated by roadway functional class, as shown in Figure VIII-3. Several patterns are evident. First, the involvement rate on rural Interstate highways, is 300 percent to 400 percent lower than it is on other rural roadway types and is generally the same for all vehicle types. Of particular note is that off the Interstates, the involvement rates for combination trucks are markedly higher than for cars and SUTs and when compared on the same rural roadway types (where these vehicles accumulate the majority of their travel and, therefore, exposure to crash risk), multitrailer combinations consistently exhibit higher rates than single-trailer combinations.

These crash rate differences by roadway functional class become important when one considers the operational use patterns of single-trailer and multitrailer combinations. Figure VIII-4 shows the travel distribution patterns of

Figure VIII-2. Fatal Crash Rates by Vehicle Class

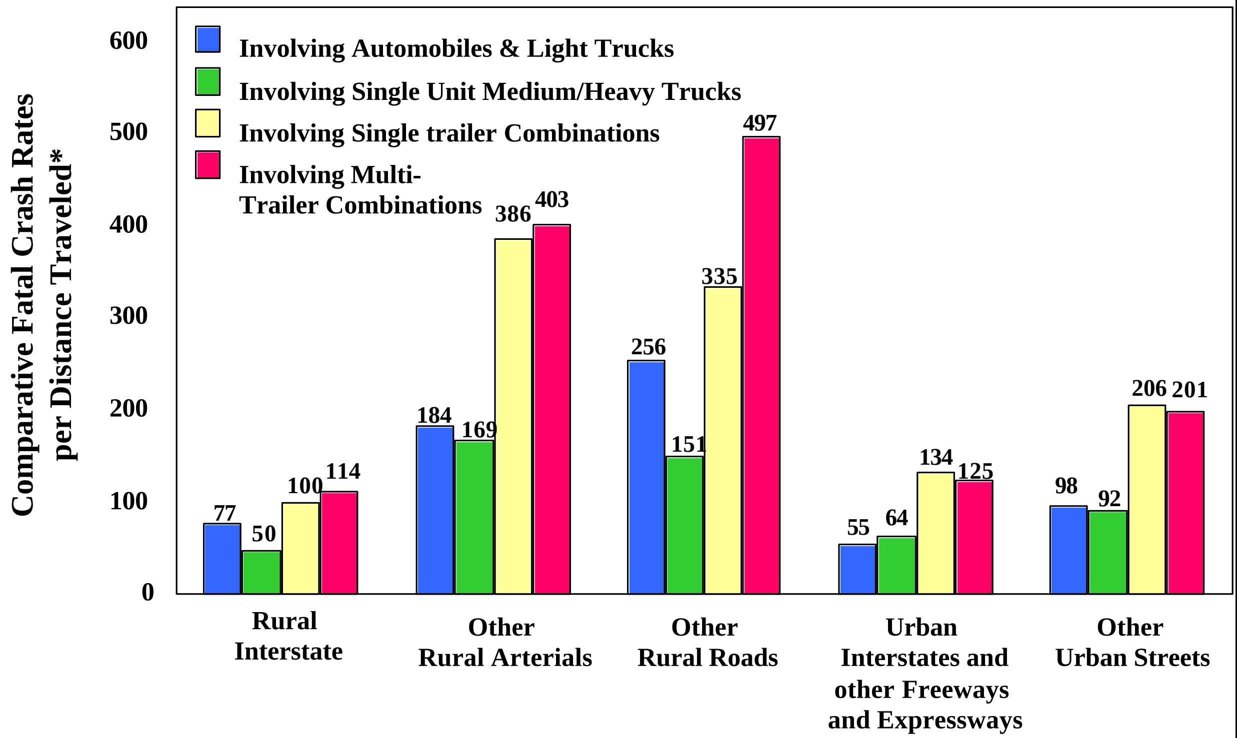


* Normalized relative to VMT for single trailer combinations which is set equal to 100.

** Includes automobiles, light trucks, and sport utility vehicles.

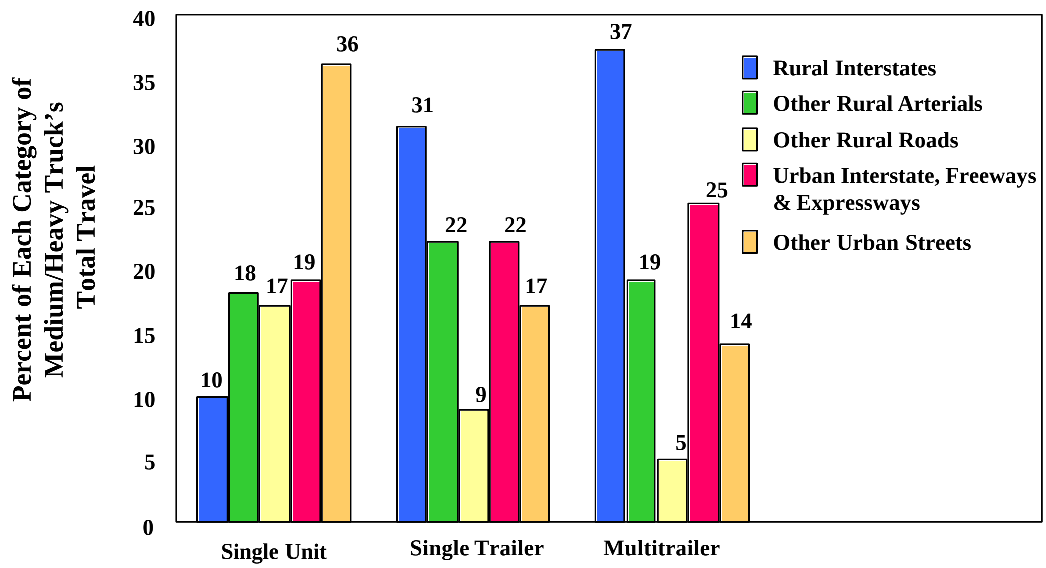
Source: FARS 1991-1995 (crash data), HCAS, 1997 (travel data)

Figure VIII-3. Fatal Crash Rates on Different Highway Classes



*** Normalized relative to single trailer combination units on rural interstates which is set equal to 100**
Source: FARS 1991-1995 (crash data), HCAS, 1997 (travel data)

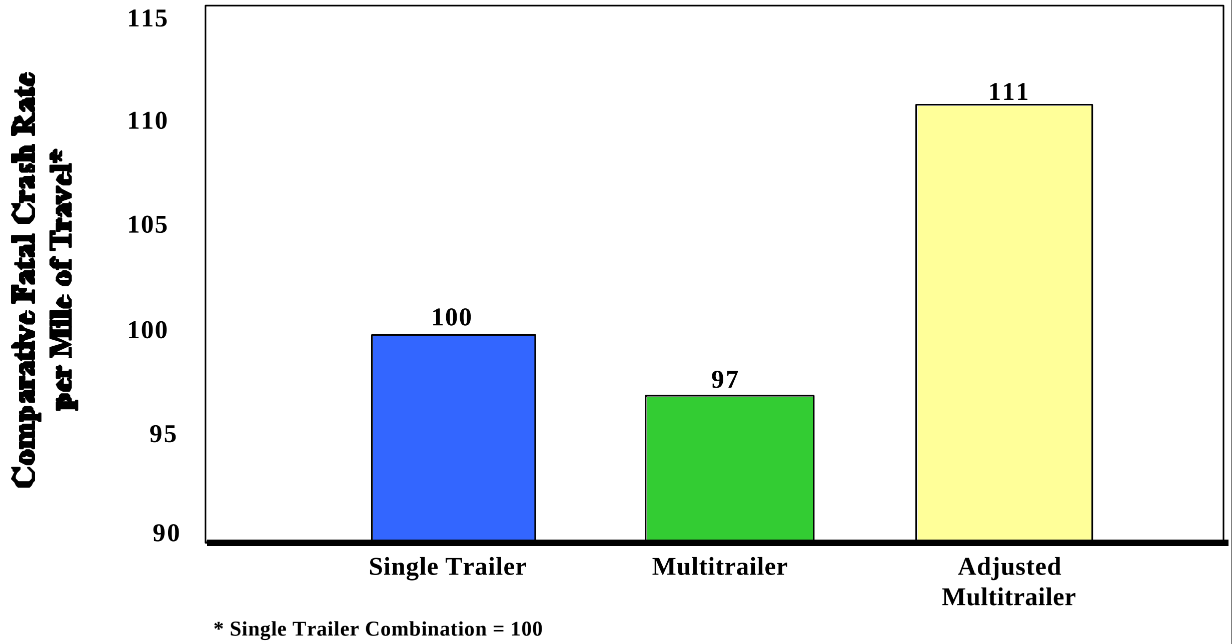
Figure VIII-4. Travel on Different Highway Classes by Single and Multitrailer Combinations.



*** Based on VMT distribution estimates for 1994.**

Source: Highway Cost Allocation Study, 1997

Figure VIII-5. Normalized Fatal Crash Rates

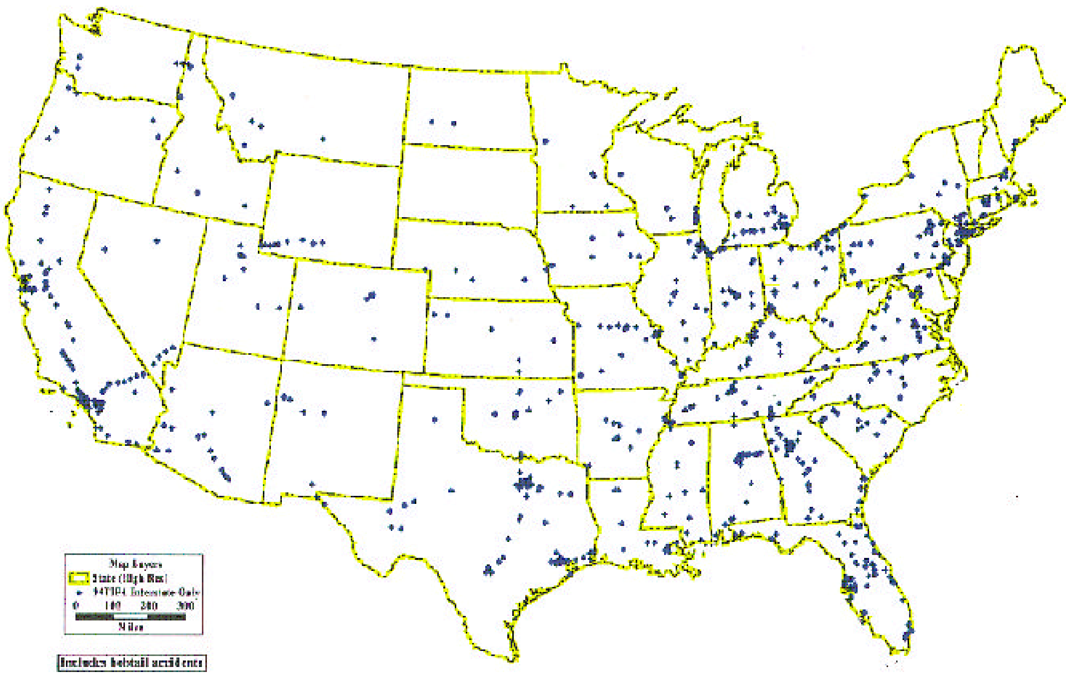


the three principal subgroups of medium to heavy trucks. As can be seen, multitrailer combinations accumulate 62 percent of their mileage on Interstate and comparable roads, compared to 53 percent for single-trailer combinations. Thus, single-trailer combination crash history is more heavily weighted and influenced by the risk exposure they experience on non-Interstate roads compared to that of multitrailer combinations.

These findings highlight a number of important issues. First, the use of aggregated rate data [that is, total number of crashes divided by total vehicle-miles-of-travel (VMT)] masks important operational differences between these two vehicle types. To adequately compare the two, it is necessary to gauge their performance in comparable operating environments. Second, any shift or increase in truck traffic, especially for multitrailer combinations, off Interstate highways would significantly increase safety risks.

One technique used to predict the future crash experience of multitrailer combinations, assuming differences in use patterns are removed from the analysis, is to apply the travel distribution pattern of single-trailer combinations to the crash rate histories of the multitrailer combinations and compute an adjusted crash rate. The result (see Figure VIII-5) indicates that, under conditions of generally unrestricted use similar to that of single-trailer combinations, multitrailer combinations—as they are currently designed and configured—could be expected to experience an 11 percent higher overall fatal crash rate than single-trailer combinations. This finding is significant in terms of the debate on "the safety of LCVs." It is important to note that this analysis technique assumes that single-trailer and multitrailer combinations: (1) have the same design features as they do today, and (2) will operate under the same

Figure VIII-6. Trucks Involved in Fatal Crashes on Interstate Highways – 1994



roadway environment at some
point in the future, which may or may not ever occur.

This type of analysis sheds light on the significant contribution that roadway type plays in crash causation but does not make clear the strong influence that another important aspect of operating environment – namely traffic density -- has on crash likelihood. As the data portrayed in Figures VIII-6 to Figure VIII-8 indicate, 72 percent of the fatal truck crashes, which occur in this country on both Interstate and non-Interstate roads, occur in essentially the eastern half of the country. These inherent differences exclusive of any other accident contributing factors, are important in several respects. First, past assessments of LCV crash histories, have tracked their experiences where they have been allowed to operate, which is predominantly on higher quality roads in the western region of the country.

Second, if LCV use expanded into the more heavily traveled, higher risk eastern portion of the country, it is not possible to project with certainty what the crash rates for larger and heavier trucks would be. But, this analysis indicates that crash rates would be higher than past history would suggest.

Vehicle Stability and Control

In addition to using crash data, the safety performance of larger and heavier trucks may be assessed based on their comparative stability and control performance properties. Trucks have a propensity to swerve out of their travel lane or roll over out-of-the-ordinary crash avoidance, when sharp turns or out-of-the-ordinary crash avoidance, lane-change

Figure VIII-7. Trucks Involved in Fatal Crashes on Non-Interstate Highway – 1994

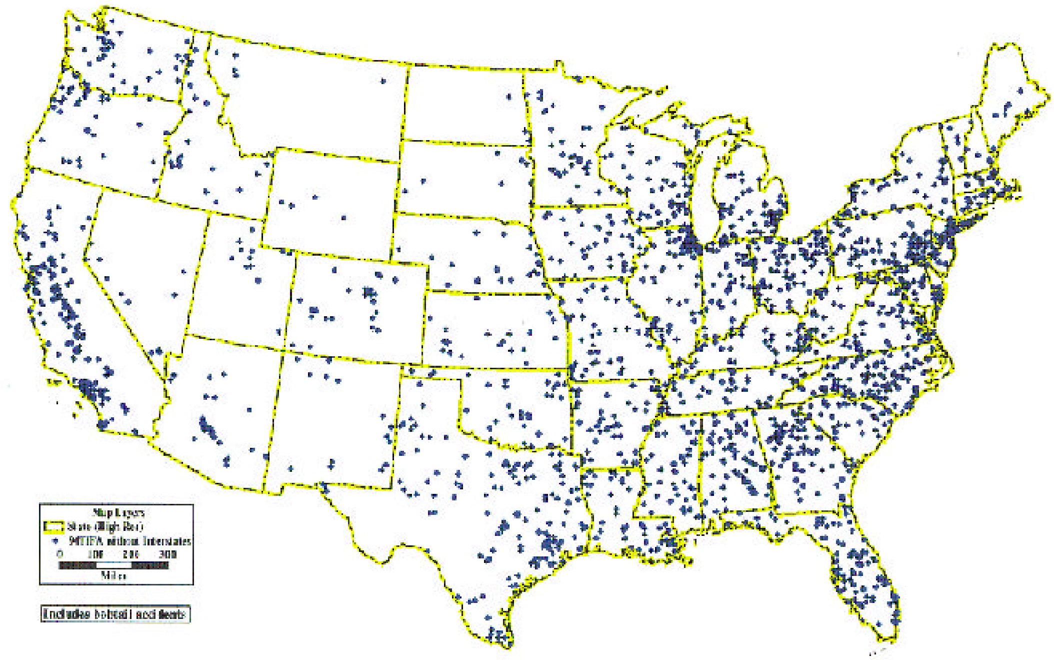
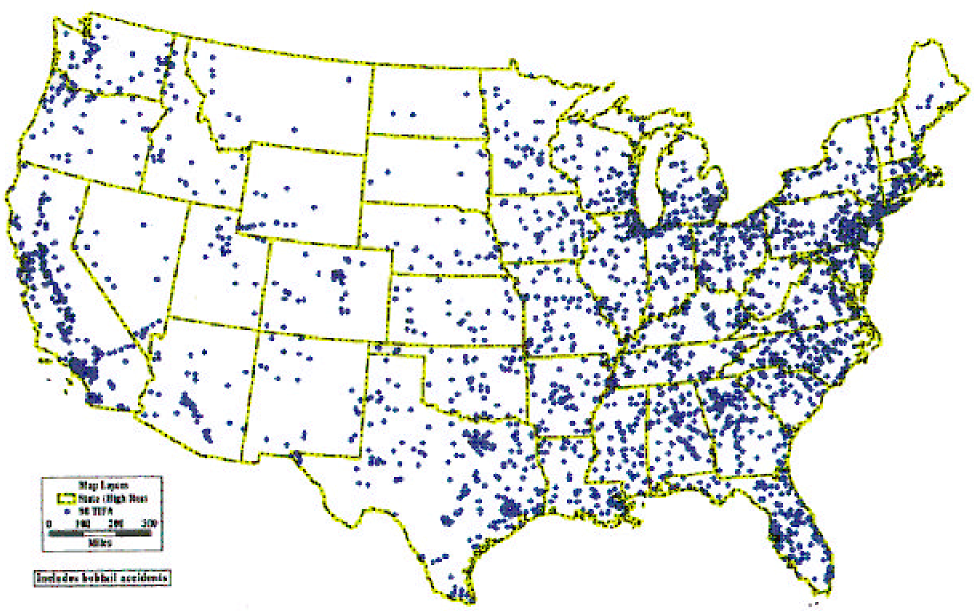


Figure VIII-8. Trucks Involved in Fatal Crashes on All Roadways – 1994



evasive maneuvers are attempted. Vehicle control issues include braking and off-tracking. Offtracking measures how well the back of a vehicle follows the front when going around a curve or making a turn.

Vehicle Stability

Rollovers account for 8 percent to 12 percent of all combination truck crashes, but are involved in approximately 60 percent of crashes fatal to heavy truck occupants. They greatly disrupt traffic when they occur in urban environments, particularly when hazardous materials are involved. There are two types of maneuvers, which if attempted at too high a speed, can cause trucks to roll over: steady-state turn induced rollover and evasive maneuver rollover.

Steady-State Turn Induced Rollover

This type of rollover typically occurs when a truck is traveling too fast and attempts a sweeping turn, usually at exit-ramps on Interstate highways or other freeways. The maneuver creates enough centrifugal force to exceed the vehicle's capability to counteract that force. All vehicles, but especially heavy trucks, are susceptible to this type of crash. The principal attributes which affect a vehicle's rollover tendencies are: the height of the center-of-gravity (c.g.) for the cargo, the track width of the vehicle, and suspension and tire properties.

The relevant measure of a vehicle's performance in this regard is its static roll stability (SRS). SRS is described in terms of 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. Higher SRS scores indicate better performance in this regard. Currently designed, "typical" tractor semitrailer combinations, when fully loaded to the current 80,000 pounds gross vehicle weight (GVW) limit, generally have SRS thresholds on the order of 0.30 g’s-0.33 g's. By comparison, a car does not roll over until its lateral acceleration reaches 0.8 g’s to 1.0 g's, and even then, it must usually be "tripped" by a curb or other surface discontinuity.

Larger, heavier vehicles do not necessarily have poorer performance in terms of SRS than do smaller, lighter ones. The important variable is how the payload is distributed along the length of the vehicle. Increasing the c.g. height of a vehicle by loading more payload onto a given vehicle increases its rollover propensity. Other critical factors are the travel speed of the vehicle around a curve, and the "tightness" of the curve as measured by the curve radius.

Evasive Maneuver-Induced Rollover

This type of rollover is primarily associated with multitrailer combinations, "doubles" and "triples," where it is the result of a “crack-the-whip” phenomenon. Single-trailer combinations do not normally experience this phenomenon, but if loaded high enough, they and other trucks can roll over as well.

Evasive-maneuver rollovers occur when vehicles are traveling at speeds generally above 50 miles-per-hour (mph), with faster speeds exacerbating the tendency and lower speeds completely eliminating it. The maneuver that triggers this response is an abrupt left then right or right then left, single-lane change maneuver as might be needed to avoid an unexpected obstacle in the truck’s path (see Figure VIII-9).

In this evasive maneuver, the lateral acceleration experienced at the tractor is amplified at each succeeding trailer in the combination, such that the rearmost trailer in the combination can experience lateral acceleration levels two to three times that of the

Figure VIII-9. Standard Evasive Maneuver

The Society of Automotive Engineers has developed a standardized test for evaluating vehicle dynamic stability performance (J2179). The test includes a rapid steering input sufficient to move the truck to one side or the other 4.8 feet within a longitudinal (in the direction of travel) distance of 200 feet while traveling at 55 miles per hour. This test is used to determine the rearward amplification and load transfer ratio for a truck configuration.

tractor. Thus, seemingly benign maneuvers successfully executed by the tractor can result in the rearmost trailer skidding sideways into adjacent lanes, or worse, rolling over.

The principal vehicle attributes which affect this tendency are: (1) the number of articulation or coupling points in the combination—doubles usually have three, whereas triples have five—with more articulation points increasing the tendency; (2) the wheelbase lengths of the trailers in the combination, with shorter trailers increasing the tendency; and (3) the SRS's of the individual trailers in the combination, with lower individual SRS's increasing the likelihood of a rollover. There are two measures which describe this performance attribute. The first is a dimensionless ratio, termed the rearward amplification (RA) factor, which 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 for this performance measure indicate acceptable performance. Semitrailer combinations have an RA equal to 1.0, that is, there is essentially no rearward amplification. Currently designed STAA doubles (two 28-foot trailers) have RAs on the order of 1.7.

Reducing the number of articulation points in the combination from three to two improves its performance by 80 percent. Doubling the length of the trailers improves their performance 100 percent. On the other hand, eliminating articulation points and lengthening trailers degrades low-speed offtracking performance. Figure VIII-10 describes actions that can be taken to improve vehicle stability.

The second measure is also a dimensionless ratio termed load transfer ratio (LTR). It is a measure of the dynamic roll stability of a truck.

When a truck executes a lane change or other dynamic maneuver, sideward forces load one wheel on an axle more than the other. The effect of this shifting of the axle load to one side of the truck can be significant at speeds above 50 mph. Under these conditions, the LTR represents the proportion of the total axle load that is carried on one side of the truck relative to the other. A perfectly balanced vehicle has 50 percent of the load on an axle on one wheel and 50 percent on the other. At LTR's much above 0.7, most trucks or trailers are highly susceptible to rolling over, while at a value of 1.0, rollover is almost certain to

Figure VIII-10. Controlling Vehicle Instability

In the case of single-unit trucks, the tendency to transfer load from one side to the other is strongly influenced by the truck's tire and suspension properties, its physical dimensions (primarily track width and center of gravity height), frame torsional stiffness (resistance to twisting), and number of axles.

In the case of multitrailer combinations, roll coupling is a vehicle design feature which counters dynamic roll instability. It uses a coupling feature designed to take advantage of the fact that two adjacent units in a multitrailer 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, which converts a semitrailer to a full trailer, 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 they are rolling in opposite directions during an evasive lane change maneuver.

The same practical effect can be accomplished through the use of such advanced technology as electronically controlled braking systems, which employ load and speed sensitive differential braking to maintain the direction of the individual units in combination vehicles making evasive maneuvers. This greatly reduces the crack-the-whip phenomenon and dynamic roll instability inherent in multitrailer vehicles especially. These systems are currently in the demonstration research stage, but they can be expected to be operational in the near future.

occur given a steering input equal to the standard test (see Figure VIII-9). Lower values of this performance metric indicate comparatively better performance.

Vehicle Control

Braking performance is a general concern that applies to all trucks, and it is not particularly influenced by changes in truck sizes or weights. This assumes, however, that the required number of axles and brakes are added as the vehicle's weight increases and all of the vehicle's brakes are well maintained and functional. However, having more axles and brakes add to brake maintenance problems.

Counterbalancing brake

maintenance concerns is the fact that anti-lock braking systems (ABS) are being fitted to all new truck tractors and trailers. ABS will enhance vehicle stability and control during hard braking for all trucks, but it will be especially beneficial to multitrailer combinations as they have more brakes, due to more axles, to be properly applied under the control of these braking systems.

Finally, the additional measures to indicate a vehicle's ability to negotiate turns and otherwise "fit" within the dimensions of the existing highway system principally include low-speed offtracking and overall vehicle length. Excessive offtracking can disrupt traffic flow and/or damage the infrastructure. Longer length vehicles require more time to pass or to be passed by other vehicles on a two-lane road. Also, increasing vehicle weight without increasing engine power results in lower acceleration. Lower acceleration increases the potential for traffic conflicts on grades and when merging at freeway interchanges.

All these concerns can be incrementally exacerbated as trucks increase in size or weight and, therefore, also need to be addressed when considering the ability of a given segment of roadway to safely accommodate these vehicles. These properties are discussed in Chapter IX, Traffic Operations.

Comparison of Vehicle Stability and Control Performance

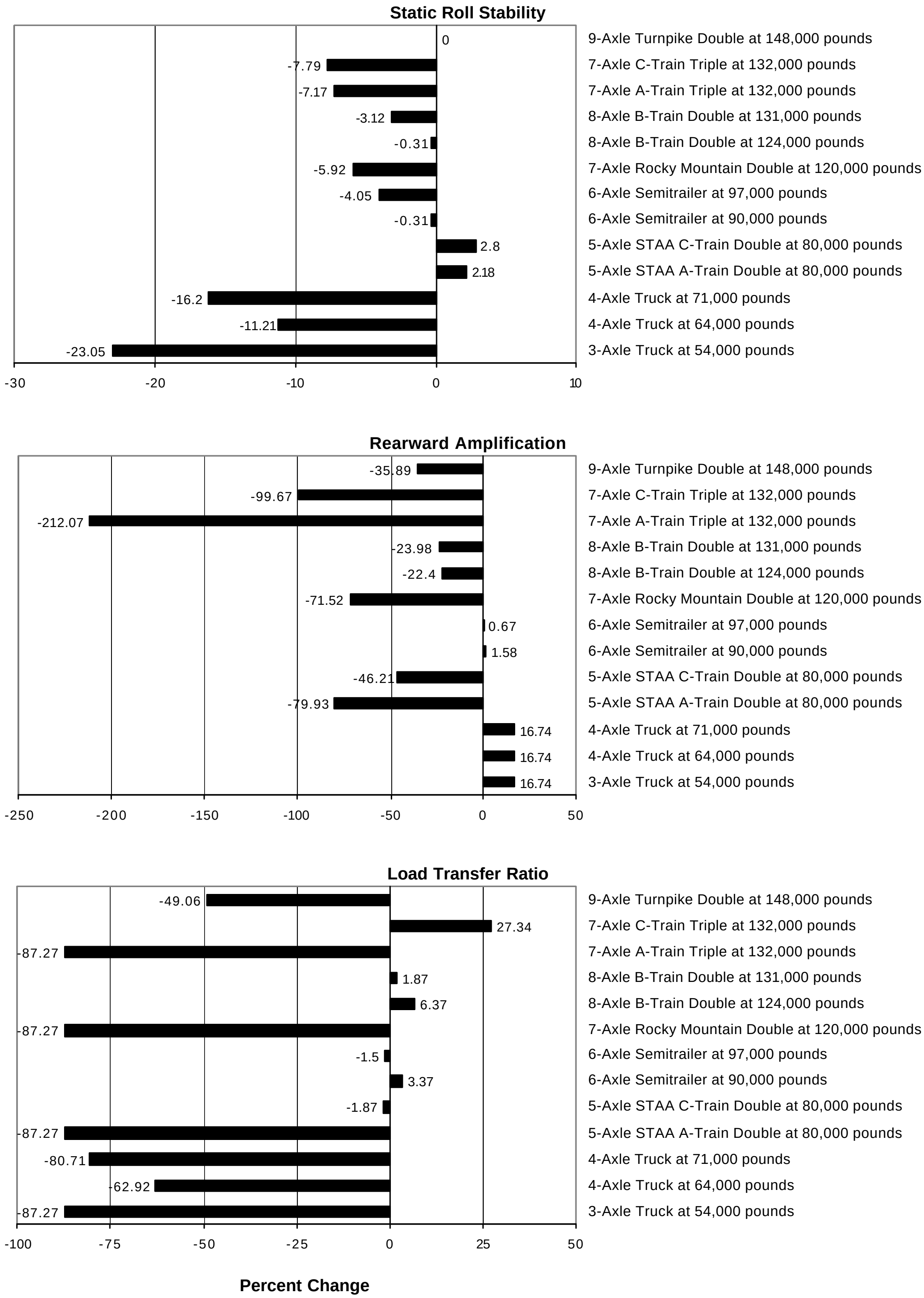
As part of this study, the performance of 14 truck configurations was analyzed, using the three vehicle stability performance measures described above. Table VIII-1 provides the vehicle weights and trailer (or cargo body) lengths, the number of axles for each truck or unit (if the vehicle is a combination), the number of articulation points in the combination, and type of hitching used in multitrailer combinations. These are the parameters that determine vehicle stability and control performance. For these analyses, worst-case loading conditions (maximum payload weight and c.g. height) and uniform loading within the available cargo body space were assumed.

Figure VIII-11 indicates how the performance of 13 study vehicles compares to that of the standard five-axle semitrailer combination loaded to 80,000 pounds. In practically all cases the performance of the larger multitrailer combinations, as well as SUTs, do not equal---in some instances by wide margins—the performance of the standard tractor semitrailer that is now in widespread use. The indicated weight for each configuration in Figure VIII-1is the sum of weights allowed on each axle group. These are the same loaded weights used to estimate scenario impacts.

It is important to note that the relative results reported in Figure VIII-11 would vary if a different base comparison vehicle were chosen. In the case of multitrailer combinations, another comparison that is often made is between the performance of different larger multitrailer combinations and a standard STAA double. When this is done, some of the multitrailer combinations (notably B-train and some C-train double combinations) perform comparatively better than STAA doubles.

Further, the results in Figure VIII-11 pertain only to presently designed and

Figure VIII-11. Comparison of Stability and Control Measures for Scenario Vehicles Relative to Five-Axle Tractor Semitrailer



configured heavier vehicles. Past studies have shown that significant performance improvements are possible through the use of different vehicle designs—such as wider vehicles and lower floor heights; new equipment such as enhanced electronic braking, tire, and suspension systems; and B-train and C-dolly trailer connections.

Table VIII-1 confirms that presently-designed multitrailer combinations experience proportionally more fatal rollover crashes than do single-trailer combinations. This statistical observation supports the use of engineering performance evaluations of these vehicle types as a means of assessing their relative crash likelihood. Although these are simulation model results, they predict vehicle stability performance with greater accuracy than crash data.

Assessment of Scenario Impacts

This section draws on information from the previous sections of this chapter to qualitatively compare the effects of the policy scenarios on highway safety. The scenarios can be qualitatively judged in terms of the relative shifts

Table VIII-1 Vehicle Descriptions and Specifications

Configuration	Loaded Weight (pounds)	Number of Axles on Power Unit, Trailer(s)	Box or Trailer Length(s) (feet)	Number of Articulation Points	Type of Trailer-to-Trailer Hitching
Five-Axle Semitrailer (Baseline Vehicle)	80,000	3,2	53	1	None
Three-Axle Single-Unit Truck	54,000	3	20	0	None
Four-Axle Single-Unit Truck	64,000	4	25	0	None
	71,000	4	25	0	None
Six-Axle Semitrailer	90,000	3,3	53	1	None
	97,000	3,3	53	1	None
Five-Axle A-Train STAA Double	80,000	2,1,2	2@28	3	A-Dolly
Five-Axle C-Train STAA Double	80,000	2,1,2	2@28	3	C-Dolly
Seven-Axle Rocky Mt. Double	120,000	3,2,2	1@53,1@28	3	A-Dolly
Eight-Axle B-Train Double	124,000	3,3,2	2@28	2	B-Train
	131,000	3,3,2	2@33	2	B-Train
Seven-Axle A-Train Triple	132,000	2,1,2,2	3@28	5	A-Dolly

Table VIII-2 Exposure Change Associated With Each Scenario

Truck Configuration	Number of Axles	Base Case Vehicle-Miles-of-Travel (VMT)	Tractor (Truck) VMT Change (percent difference from Base Case)					
			Uniformity	H.R. 551	N. Am. Trade		LCVs Nat'wide	Triples Nat'wide
					51,000 Tridem Axle	44,000 Tridem Axle		
Single Unit	3	9,707	2.5	0	-16.2	-12.1	0	0
	4	2,893	11.4	0	23.7	24.3	0	0
Semitrailer	3 and 4	14,049	0	0	0	0	0	0
	5	83,895	8.7	0.02	-70.2	-73.5	-76.6	-72
	6 and 7	6,595	-44.5	0.03	3.0	2.4	0	0
Truck Trailer	4 - 6	3,638	2.7	0	0	0	0	0
STAA Double	5 and 6	5,994	-0.1	0	0	0	-82.1	-82.1
B-Train Double	8	683	-73.9	0	6,725	7,075	204	0
Rocky Mt. Double	7	632	-54.1	0	0	0	-20.1	0

that are projected to occur from one configuration type to another and the associated tractor (truck) travel miles that would result.

As noted earlier in this section, truck crashes are not caused by any one single factor, but rather are the result of multiple factors—vehicle performance being just one. As noted earlier in this chapter increased operations of multitrailer combinations on lower standard roads would increase crash risk.

All other things being equal, increases or decreases in the exposure to crash risk proportionally increases or decreases the likelihood of a crash. Thus, changes in the number of truck trips made to haul the same amount of freight, could alter the likelihood of crashes. However, it is not possible, given data limitations, to know if this is a linear relationship.

Table VIII-2 shows estimates of the percent changes in truck VMT that single-unit and combination trucks would experience in the year 2000, under each of the above scenarios. VMT is the most frequently used measure of exposure to the risk of a crash.

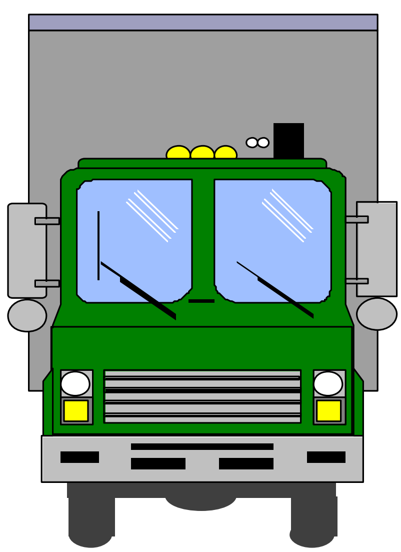
Table VIII-3 qualitatively characterizes and compares the various vehicle configurations combinations in more widespread use in this country. Given lack of information on the density of the cargo being carried by trucks, one cannot reliably determine the c.g. height of loaded trucks (c.g. height is the most important determinant of vehicle stability). If this information were available, one could predict vehicle and truck fleet performance with greater certainty. However, lacking this information, the worst loading condition is assumed for comparison purposes.

Table VIII-3 Comparison of Truck Use and Stability by Configuration

Truck Configuration	Current Use	Vehicle Stability and Control Characteristics (under worst loading conditions)
Single-Unit Truck	Used extensively in all urban areas for short hauls.	At speeds above 50 mph these vehicles are very unstable when making evasive maneuvers. Of all vehicles analyzed they are the least stable.
Semitrailer	Used extensively for long and short hauls in all urban and rural areas.	Generally adding axles to these configurations (and others) improves their performance.
STAA Double	Most common multitrailer combination. Used mostly on rural freeways between less-than-truckload (LTL) freight terminals.	Due to its extra length in cargo space this vehicle is the most stable in static rollover, but it is very dynamically unstable due to its short trailers.
B-Train Double	Some use in the northern plains States and the Northwest. Mostly used in flat trailer operations and for liquid bulk hauls.	Although at the weight evaluated, this vehicle performs less well than the five-axle semitrailer, it performs much better than the Surface Transportation Assistance Act (STAA) double.
Rocky Mountain Double	Used on turnpikes in Florida, the Northeast, and Midwest and in the Northern Plains and Northwest in all types of motor carrier operations.	This vehicle performs somewhat better in rearward amplification than the STAA double but less in static rollover. It performs better than single-unit trucks.
Turnpike Double	Used on turnpikes in Florida, the Northeast, and Midwest and in the Northern Plains and Northwest in mostly truckload operations.	This vehicle is stable in both rollover and rearward amplification, but it has severe low-speed offtracking.
Triple	Used on the Indiana and Ohio Turnpikes and many western States between LTL freight terminals.	With single drawbar converter dolly (A-train), this vehicle is considerably worse than the STAA double, but with double drawbar dolly (C-train), it performs about as well in rollover, but much better in rearward amplification.

CHAPTER IX

Traffic Operations



Introduction

Longer and heavier trucks tend to disrupt traffic flow on roadways more than conventional vehicles. However, more trucks of any size or weight would also disrupt traffic. Disruption occurs in the through traffic lanes, at roadway intersections, and on freeway interchanges. Common measures of disruption include hours of delay and congestion costs.

This chapter presents estimates of changes in delay and associated congestion costs resulting from the truck size and weight (TS&W) policies tested in the five illustrative scenarios: Uniformity, North American Trade, Longer Combination Vehicles (LCVs) Nationwide, H.R. 551, and Triples Nationwide. Qualitative assessments of other, related, impacts are also discussed.

Basic Principles

Traffic Congestion

Traffic congestion depends on the capacity of and the amount of traffic on a given highway. It is assessed in terms of passenger car equivalents (PCE). Further, highway capacity depends on the level of service that is intended for the highway. A level-of-service indicates traffic conditions in terms of speed, freedom to maneuver, traffic interruptions, comfort and convenience, and safety. 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.

Trucks are larger and, more importantly, accelerate more slowly than passenger cars, and thus have a greater effect on traffic flow than passenger cars. On level terrain and in uncongested conditions conventional trucks may be equivalent to about two passenger cars in terms of their impact on traffic flow. In hilly or mountainous terrain and in congested traffic their effect on traffic flow often is much greater and they may be equivalent to 15 or more passenger cars. The actual number of PCEs depends on the operating speed and grade of the highway section, the vehicle's length, and its weight- to-horsepower ratio which is a measure of how the vehicle can accelerate. Tables IX-1 and IX-2 show PCEs for trucks operating in rural and urban areas under different conditions. The effects of differences in truck length and weight-to-horsepower ratio is shown in those tables. The tables are not intended to show extreme situations either in terms of roadway or vehicle characteristics; under different characteristics the PCEs could be higher than shown in those tables.

The PCEs for all the traffic on a given roadway increase with increased sizes and weights of trucks and decrease with fewer trucks in the traffic stream. The net effect of these opposing changes for each scenario analyzed is presented in this chapter.

Table IX-1 shows PCEs for trucks on rural highways. It demonstrates that the highest PCEs occurs on highways with the steepest grades and highest speeds. Table IX-2 shows PCEs for trucks on urban highways. It again shows the effect of highway speed on PCEs. After grade and highway speed in importance is the weight-to-horsepower ratio of the trucks.

Other Traffic Effects

In addition to congestion, this Study has assessed, but not quantified in detail, the impact of longer and heavier trucks on the operation of traffic in the areas of vehicle offtracking, passing, acceleration (including merging, speed maintenance,

Table IX-1. Vehicle Passenger Car Equivalents on Rural Highways

Roadway Type	Grade Percent	Grade Length (miles)	Vehicle Weight-to-Horsepower Ratio (pounds/horsepower)	Truck Length (feet) 40	80	120
Four-Lane 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
Two-Lane Highway	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

and hill climbing), lane changing, sight distance requirements, and clearance times. As with congestion, the speed (a function of weight, engine power, and roadway grade) and length of a vehicle are the major factors of concern, although vehicle speed is more important than length in assessing congestion effects.

Offtracking

There are several measures of a vehicle's ability to negotiate turns or otherwise "fit" within the dimensions of the existing highway system, but the principal measure is low-speed offtracking. Two other measures are high-speed offtracking and dynamic high-speed offtracking. High-speed offtracking , is steady-state swing out of the rear of a 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. On roadways with standard lane widths, the two high-speed offtracking effects are not large enough to be of concern. Excessive low-speed offtracking can disrupt

Table IX-2. Vehicle Passenger Car Equivalents on Urban Highways

Roadway Type	Traffic Flow Condition	Grade	Vehicle Weight-to-Horsepower Ratio (pounds/horsepower)	Truck Length		
				40	80	120
Interstate	Congested	0	150	2.0	2.5	2.5
			200	2.5	3.0	3.0
			250	3.0	3.0	3.0
	Uncongested	0	150	2.5	2.5	3.0
			200	3.0	3.5	3.5
			250	3.0	3.5	4.0
Freeway and Expressway	Congested	0	150	1.5	2.5	2.5
			200	2.0	2.5	2.5
			250	2.0	3.0	3.0
	Uncongested	0	150	2.0	2.0	2.0
			200	2.5	2.5	2.5
			250	3.0	3.0	3.0
Other Principal Arterial	Congested	0	150	2.0	2.0	2.5
			200	2.0	2.0	3.0
			250	3.0	3.0	4.0
	Uncongested	0	150	3.0	3.0	3.5
			200	3.5	3.5	3.5
			250	3.5	4.0	4.0

traffic operations and result in shoulder or inside curb damage at intersections and at interchange ramp terminals designed like intersections that are used heavily by trucks. There is little, if any, link between low-speed offtracking and the likelihood of serious crashes (fatal or injury-producing). This is due to the vehicle's very low speed when turning sharply. The reader is referred to Chapter VII, Roadway Geometry, for a detailed discussion of offtracking.

Standard STAA doubles (two 28-foot trailers) and triple-trailer combinations (three

Table IX-3. Effects of Speed Differentials on Crash Involvement

Speed Differential (mph)	Crash Involvement	Involvement Ratio (related to 0 speed differential)
0	247	1.00
5	481	1.95
10	913	3.70
15	2,193	8.88
20	3,825	15.49

28-foot trailers) exhibit better low-speed offtracking performance than a standard tractor and 48-foot or 53-foot semitrailer combination, as they have more articulation points in the vehicle combination and use trailers with shorter wheelbases.

Passing or Being Passed on Two-Lane Roads

Cars passing LCVs on two-lane roads could need up to an 8 percent longer passing sight distance compared to passing existing tractor-semitrailer combinations. For their part, longer trucks would also require longer passing sight distances to safely pass cars on two-lane roads. Also heavier trucks require more engine power to pass another vehicle if it is necessary to accelerate to pass the overtaken vehicle.

Operators of longer or heavier vehicles have to be more diligent to avoid potential passing conflicts. Standards for marking passing and no-passing zones on two-lane roads, developed in the 1930's, are based on cars passing cars. The operation of trucks in these zones was not considered when these standards were developed nor has it been considered since then. However, this is mitigated by the fact that truck drivers have a better view of the road as they sit higher than car drivers.

Vehicle Acceleration

Acceleration performance determines a truck's basic ability to blend well with other vehicles in traffic, which is of particular concern in cases where frequent truck-car conflicts can be anticipated. This issue needs to be addressed when considering the ability of a given segment of roadway to safely accommodate longer and heavier trucks. Poor acceleration is a concern as it can result in large speed differentials between vehicles in traffic, and crash risks increase significantly with increasing speed differential.

Table IX-3 indicates that crash involvement may be from 15 times to 16 times more likely at a speed differential of 20 miles-per-hour (mph).

As a vehicle's weight increases, its ability to accelerate quickly for merging with freeway traffic and to maintain speed (especially when climbing hills) is degraded, unless larger engines or different gearing arrangements are used. These concerns may also be addressed by screening routes to ensure they are suitable for use by any vehicle at its proposed weight and dimensions. Aerodynamic truck designs, by reducing drag, help trucks to accelerate and maintain speed as well.

On routes with steep grades

Table IX-4. Distribution of Grades on Arterial Highways

Grade (percent)	0.00 - 0.49	0.50 - 2.49	2.50 - 4.49	4.50 - 6.49	6.50 or more
Miles of Highways (thousands)	64.7	47.4	15.2	4.6	1.2
Percent of Total	48.6	35.6	11.4	3.4	0.9

that are frequently traveled by trucks, special truck climbing lanes have been built. Otherwise, trucks should be able to maintain reasonable grade climbing performance. In the past, hill climbing performance has been addressed by requiring larger trucks to be equipped with higher horsepower engines. However, this type of specification can be counterproductive, since larger engines consume more fuel and emit more air pollutants. While in some cases, larger engines may be necessary to maintain grade climbing performance, experience has shown that a more easily enforced approach is to specify minimum acceptable speeds on grades and minimum acceptable times to accelerate from a stop to 50 mph or to accelerate from 30 mph to 50 mph.

Grades

The Highway Performance Monitoring System (HPMS) provided the highway grade data for the 48 contiguous States and the District of Columbia. The highway types examined were rural freeway, rural multilane, rural two-lane, urban freeway, and urban arterial. Table IX-4 summarizes this information by mileage. It shows that almost half of the highway system has a grade of no more than 0.5 percent and that more than 80 percent has a grade of no more than 2.5 percent.

In addition, highway design policies place limits on the steepness of grades. Federal policy for the Interstate System specifies maximum grades as a function of design speed. For example, highways with design speeds of 70 mph may not have grades exceeding 3 percent. Gradients may be up to 2 percent steeper than those

Figure IX-1. Highway Performance Monitoring System

The Highway Performance Monitoring System database is the primary source of information for the Federal government about the Nation’s highway infrastructure. This is the most comprehensive nationwide data system in use for any aspect of the Nation’s infrastructure. Data collection is the responsibility of the States, and it is updated each year. The States forward the data to the Federal Highway Administration, which maintains and uses these data for a variety of strategic planning and highway investment evaluation uses. The Office of Highway Policy Information is responsible for receiving, reviewing, and tabulating these data.

limits in rugged terrain. Generally, the steepest grades to be encountered by heavy trucks are to be found in the mountainous areas of the western United States, and to a lesser extent, on some of the older highways in the northeastern States.

Table IX-1 shows the marked effect that percent and length of grade have on truck climbing ability if the truck does not have a low ratio of GVW to horsepower.

Industry Experience with Heavier Trucks

Fleet owners who operate large trucks (mostly in the West), were asked about their experience with combination vehicles. They said they purchase trucks with large enough engines that allow drivers to maintain reasonable and efficient speeds. Tractor manufacturers corroborated this, indicating that trucking companies and individual drivers want and buy trucks with large engines. Engine manufacturers build 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.

Over the past 20 to 30 years, engine power has grown at a more rapid rate than weight. Trucks today maintain speed and accelerate better than they ever have.

Traction

If single-drive-axle tractors are used in multitrailer combinations, the tractor may not be able to generate enough tractive effort to pull the combination up a hill under slippery road conditions, especially if it is heavily loaded. In these cases, either tandem- axle tractors or tractors equipped with automatic traction control would be appropriate. Specially built tractors are used in Colorado to push multitrailer combinations when they have traction problems.

Lane Changing

Compared to conventional tractor-semitrailer combinations, longer vehicles require larger gaps in traffic flows in order to change lanes or merge with traffic. Skilled drivers can compensate for this vehicle property by minimizing the number of lane changes they make and using extra caution when merging. The effect of this performance characteristic is proportional to vehicle length and the traffic densities in which a given vehicle operates.

Intersection Requirements

Heavier vehicles entering traffic on two-lane roads from unsignalized intersections could take more time to accelerate up to the speed limit. If sight distances at the intersection are obstructed, approaching vehicles might have to decelerate abruptly, which could cause a crash or disrupt traffic flow. Longer trucks crossing unsignalized intersections from a stopped position on a minor road could increase by up to 10 percent the distance required for the driver of a car in the cross traffic to see the truck and bring the car to a stop without impacting the truck.

How truck size (dimensions), design features, loading (weight distribution), and operation affect traffic congestion, offtracking, passing, acceleration, lane

Table IX-5. Traffic Operations Impacts of Truck Size and Weight Limits

Vehicle Features		Traffic Congestion	Vehicle Offtracking		Traffic Operations			
			Low Speed	High Speed	Passing	Acceleration (merging and hill climbing)	Lane Changing	Intersection Require-ments
Size	Length	- e	- E	+ e	- E	—	- E	- E
	Width	—	- e	+ e	- e	—	- e	—
	Height	—	—	- e	—	—	—	—
Design	Number of units	—	+ E	- E	—	—	- e	—
	Type of hitching	—	+ e	+ E	—	—	+ E	—
	Number of Axles	—	+ e	+ e	—	—	+ e	—
Loading	Gross vehicle weight	- e	—	- E	- E	- E	- e	- E
	Center of gravity height	—	—	- e	—	—	- e	—
Operation	Speed	+ E	+ E	- E	- E	—	+ e	+ E
	Steering input	—	- E	- E	—	—	- E	—

+/- As parameter increases, the effect is positive or negative.
E = Relatively large effect. e = relatively small effect. -- = no effect.

changing, and intersection requirements are shown in Table IX-5 This table shows that the important parameters are vehicle length and weight with speed closely related to weight. Increases in allowable lengths may only be compensated for by limiting operations to multilane facilities except for short distances. Weight may be compensated for by requiring that vehicles be able to maintain sufficient speed in order to not disrupt traffic excessively on any route used.

A feature of each scenario that eliminates certain traffic impacts is that axle loads are not increased. This means that there is no increased demand on any one set of brakes for stopping or descending long steep grades due to trucks being heavier as, necessarily, they must have more axles to be allowed to carry more weight.

Analytical Approach

Highway user delay and congestion costs were assessed using three traffic simulation models—one for Interstate highways, one for rural two-lane highways, and one for urban arterials. As these models are sensitive to vehicle length, gross weight, and engine power, the analysis for this Study is sensitive to these factors. To obtain PCEs by truck length and gross weight-to-horsepower ratio, the models were run for two sets of representative roadway geometric conditions for each of the three highway types.

The truck vehicle-miles-of-travel (VMT) by truck configuration and weight that is estimated to result from new TS&W policy scenarios is substituted in the traffic delay model for the base case truck VMT, and the change in highway operating speed by functional class is calculated to obtain the change in delay for all highway users. This change in delay in vehicle hours is then multiplied by a time value of $13.16 per hour to obtain the change in congestion costs. This value was taken from the Highway Economic Requirement System ($10.92 in 1990 dollars) and adjusted for increased fuel consumption and inflation for 1994.

Assessment of Scenario Impacts

The impacts of the policy scenarios on traffic -- highway user delay, congestion costs, low-speed offtracking, passing, acceleration (merging and hill climbing), lane changing, intersection requirements -- are discussed below.

It can be seen that the Triples Nationwide scenario, which would increase the weight limit significantly, could reduce delay and congestion costs by up to 7.6 percent in 2000. This assumes that requirements are in place to ensure the heavier trucks have engines with power sufficient to perform as existing trucks perform. Truck engines with enough power to accelerate a truck up to traffic speed and to maintain speed on grades at the same performance level as 80,000-pound vehicles are available on the market today for combinations weighing up to 130,000 pounds. Regarding time to pass or clear intersections, the longest truck combinations would require from 10 percent to 15 percent more time for these traffic maneuvers than a five-axle semitrailer combination.

As reference numbers for the delay and congestion cost for each scenario, the estimated delay on U.S. highways in 1994 is 18.7 billion hours and the costs for this aggregate delay were estimated to have been $246.5 billion. This estimate is based on data in *Highway Information Quarterly*, June 1998, Office of Highway Policy Information, FHWA and VMT estimates from the DOT's *1997 Federal Highway Cost Allocation Study*. With no change in TS&W policy, in the year 2000 the aggregate delay and associated costs are estimated to increase by 19 percent to 22.3 billion hours and $292.9 billion respectively.

Vehicle offtracking is assessed in terms of the costs to improve geometric features to the extent necessary to remove any traffic operations problem that results from excessive offtracking. These costs are included in Chapter VII, Roadway Geometry, and discussed here in qualitative terms. The remaining traffic operations impacts-- passing, acceleration, lane changing, and intersection requirements -- are also discussed in qualitative terms.

Table IX-6. Uniformity Scenario Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	22,400
Congestion Costs ($million)	246,500	292,900	294,800
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Improvement for roadways on which long doubles now operate but would not in the future.
Passing		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case
Lane Changing		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Negligible change over 2000 base case

Uniformity Scenario

As a result of the shift of freight from heavier and longer vehicles to five-axle semitrailer combinations at 80,000 pounds, this scenario would increase traffic congestion and associated costs in the year 2000 by 0.4 percent (see Table IX-6).

North American Trade Scenarios

These scenarios are estimated to improve traffic operations in a small way across all impacts (see Table IX-7). However, for some of the impacts, this is based on the assumption the requirements are in place to ensure that increased engine power for those configurations with increased gross vehicle weights. Traffic delay and congestion costs would be slightly more (0.2 percent) in 2000 than they would be otherwise.

Longer Combination Vehicles Nationwide Scenario

The large increase in LCV use resulting from this scenario would have several adverse effects if their operations were not restricted (see Table IX-8).

The scenario assumes these traffic operations problems would be addressed by restricting the use of these LCVs to multilane divided

Table IX-7. North American Trade Scenarios Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	22,000
Congestion Costs ($million)	246,500	292,900	289,500
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	No impact. Featured vehicle off-tracks the same or less than baseline vehicle
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length. (This is counterbalanced by large decrease in heavy truck VMT.)
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length. (This is counterbalanced by large decrease in heavy truck VMT.)

highways with entry and exit only at interchanges where needed improvements have been made. Otherwise, traffic operations and safety could be expected to be degraded on two-lane highways and during periods of peak traffic congestion. As these LCVs are heavier, as well as longer, provision for adequate engine power would need to be required to ensure smooth traffic flow through freeway interchanges and up steep grades. However, it is estimated that this scenario would reduce user delay and congestion costs by 3 percent below that which can otherwise be expected in 2000.

H.R. 551 Scenario

This scenario, by eliminating semitrailers longer than 53 feet, will somewhat improve traffic flow through intersections where these longer trailers now operate. Beyond this, as shown in Table IX-9, its impacts are negligible.

Table IX-8. Longer Combinations Nationwide Scenario Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	21,600
Congestion Costs ($million)	246,500	292,900	284,300
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Significant degradation (27.0 feet for turnpike double versus 16.5 feet for semitrailer)
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length. (This is counterbalanced by large decrease in heavy truck VMT.)
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions (LCVs should not operate through intersections with significant traffic volumes or insufficient sight distances for other traffic.)

Triples Nationwide Scenario

As with the LCVs Nationwide Scenario, this scenario would result in a large increase in the use of triple-trailer combinations. However, offtracking is not a problem for triple-trailer combinations, although length and additional weight remain significant concerns in regard to traffic operations. Also, this scenario can be expected to reduce highway user delay and congestion cost by 8 percent from that which can be expected in 2000 (see Table IX-10).

Table IX-9. Triples Nationwide Scenario Traffic Impacts

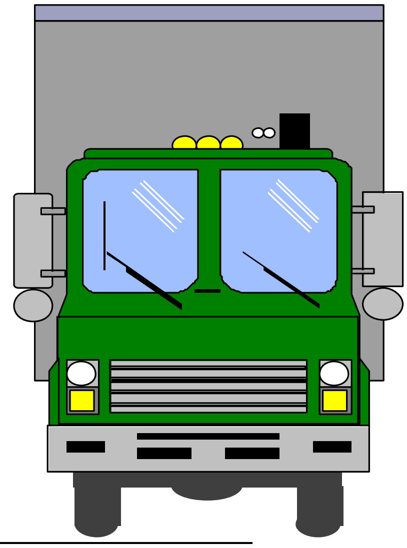
Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	20,600
Congestion Costs ($million)	246,500	292,900	270,500
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Some improvement as a triple trailer combination offtracks less (12.7 versus 16.5 feet) than semitrailer combinations.
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length which is counterbalanced by decrease in heavy truck VMT.
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Additional length requires sufficient sight distances for other traffic.

Table IX-10. Triples Nationwide Scenario Traffic Impacts

Impact	1994	2000 (base case)	2000 (scenario)
Traffic Delay (million vehicle-hours)	18,700	22,300	20,600
Congestion Costs ($million)	246,500	292,900	270,500
Low-Speed Offtracking		Some degradation from 1994 resulting from VMT increase for long double combinations	Some improvement as a triple trailer combination offtracks less (12.7 versus 16.5 feet) than semitrailer combinations.
Passing		Some degradation from 1994 resulting from VMT increase	Requires operating restrictions.
Acceleration (merging and hill climbing)		Some degradation from 1994 resulting from VMT increase	Requires sufficient engine power.
Lane Changing		Some degradation from 1994 resulting from VMT increase	Some degradation due to additional length which is counterbalanced by decrease in heavy truck VMT.
Intersection Requirements		Some degradation from 1994 resulting from VMT increase	Additional length requires sufficient sight distances for other traffic.

CHAPTER X

Energy and Environment



Introduction

The study scenarios are evaluated in terms of 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-miles-of-travel—VMT). Other significant variables include vehicle weight, speed, and truck operational parameters.

Fuel consumption, air pollution, and noise emissions occur everywhere trucks operate. The impacts of air pollution and noise emissions vary geographically; both vary according to the population exposed to those impacts, and air pollution can vary according to other regional factors including the presence of other sources of air pollution and atmospheric conditions that may affect the dispersal of pollution. Energy consumption has a nationwide impact.

Noise pollution is very localized. It is 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 Federal Highway Cost Allocation (HCA) Study*. Resource constraints prohibited development of such estimates for each illustrative scenario. In general, scenarios that would reduce truck VMT would reduce air pollution costs, but changes would not be proportional with changes in VMT, particularly at specific locations. However, changes in truck emissions would be largely proportional to changes in VMT.

Basic Principles

Energy Consumption

Table X-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.

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

Table X-1. Miles Per Gallon for Study Truck Configurations

Configurations	GVW (pounds)					
	40,000	60,000	80,000	100,000	120,000	140,000
Three-axle Single-Unit Truck	5.11	4.42				
Four-axle Single-Unit Truck	4.80	4.15				
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	4.76		
Seven-Axle Rocky Mt. 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

Source: Highway Revenue Forecasting Model

Table X-2. Air Pollutant Emission Rates

Configuration	Air Pollutant Emission (grams/VMT)			
	Nitrogen Oxides	Particulate Matter(10)	Volatile Organic Compounds (VOC)	Sulphur Oxides
Three-axle Single Unit	9.55	0.399	1.94	0.111
Other Heavy Trucks	12.65	0.788	1.03	0.520

Source: Derived from EPA's Mobile 5A and Part5 models 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.

Air Quality

As indicated earlier, air pollutant emissions by large trucks correlate with VMT. Analytical models of these emissions do not generally differentiate between truck configurations or different weight groups. Consequently, only the available rates for three-axle single unit trucks and heavy trucks, (trucks with four axles or more) on urban routes are reported in Table X-2.

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.

Analytical Approach

Energy Consumption

Truck travel and fuel use information developed for the *1997 Federal HCA Study* provided the basis for the analysis of annual energy consumption associated with the introduction or elimination of particular vehicle configurations and weights.

Base Case VMT for the Year 2000 by truck type and operating weight, was obtained from the diversion analysis (see Chapter IV). For each scenario, an alternative Year 2000 VMT distribution was also developed. This was multiplied by gallons-per-vehicle-mile-of-travel estimates to estimate total truck fuel consumption for each scenario.

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.

Table X-3. Noise Passenger Car Equivalents for Trucks

Vehicle Type	Speed (mph)				
	20	30	40	50	60
Passenge	1.00	1.00	1.00	1.00	1.00
Truck	84.85	43.82	27.42	19.06	14.16

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

As previously mentioned, scenario VMT was obtained through the diversion analysis. 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 X-3. The cost per noise equivalent was estimated for each vehicle class based on a synthesis of research findings from other studies.

The Department 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. The models were also used for the *1997 Federal HCA Study*. Figure X-1 describes DOT's noise prediction model. Highway Performance Monitoring System (HPMS) data on VMT by highway class and density of development were used to estimate the number of residential units affected. Noise cost estimates were based on predicted changes in residential property value caused by changes in noise levels.

Noise-related costs are only estimated for freeway travel. There are several reasons why the analysis was limited to freeway travel including:

Figure X-1. Federal Highway Administration Highway Traffic Noise Prediction Model

The Federal Highway Administration Traffic Noise Model calculates traffic noise levels using updated acoustical algorithms, as well as newly-measured emission levels for five standard vehicle types: automobiles, medium trucks, heavy trucks, buses, and motorcycles. The model considers the sources of truck noise (engine, exhaust stack, and tires) among other factors. It estimates overall weighted sound levels for locations with and without noise barriers. It analyzes: (1) both constant-flow and interrupted-flow traffic, (2) attenuation due to rows of buildings and dense vegetation, (3) effects of parallel noise barriers, (4) results of multiple diffractions, and (5) noise contours.

(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.

Assessment of Scenario Impacts

The area-wide impacts of energy consumption, exhaust emissions, and noise all vary with VMT. Changes in VMT for key truck configurations are shown in descriptions of impacts for each scenario.

For air pollution, meteorological conditions and, to a lesser extent geography, have a large effect on impacts. These conditions determine how concentrated the air pollutant emissions become and the chemical reactions that take place in the atmosphere to produce critical levels of air pollution. Since air pollution costs for the various TS&W scenarios could not be estimated within the scope of this study, the impact table for each scenario shows that these costs are not available (NA). However, as an indicator of changes in emissions, each impact table shows an estimate of the change in truck VMT estimated for the scenario.

Uniformity Scenario

For this scenario, it is assumed that much of the freight in those truck configurations that typically operate above the Federal weight limits will divert to those configurations that operate most economically at or below the Federal limits. As seen in Table X-4, this scenario results in an estimated 3.2 percent increase in heavy commercial truck VMT.

Table X-5 shows that this increase in VMT resulted in a 2.1 percent increase in fuel use and 0.9 percent increase in noise costs. While air pollution costs have not been determined, truck VMT in urban areas increased 3.2 percent, which indicates that there would be an increase in air pollution costs in areas prone to such impacts.

North American Trade Scenarios

For this scenario, with either the 51,000-pound or 44,000-pound tridem-axle weight limit, it is estimated that there would be significant diversion of freight to trucks that have more axles and are allowed more weight. This would be diversion from the three-axle single-unit truck to the four-axle truck. For the five-axle semitrailer, over 70 percent of its freight would divert to the eight-axle B-train double with a small amount to the six-axle semitrailer under either the 51,000-pound or 44,000-pound tridem-axle weight limit. Overall, this results in a 12 percent decrease in heavy commercial truck VMT under both tridem-axle weight limits (see Table X-6 and Table X-7). This decrease would result in over a 6 percent decrease in fuel use (see Table X-8 and Table X-9). Air pollution costs have not been determined yet, but truck VMT in urban areas would decrease by more than 5 billion miles in both cases, which indicates that there would be a decrease in air pollution costs in those areas prone to these impacts. Unexpectedly, noise costs increase even though urban freeway VMT decreases by 3 billion. This may be explained by the fact that the VMT decrease is small and that the number of tires in use on the roads increases approximately 15 percent. There would also be an increase in engine noise from greater loads. Consequently, these secondary changes may overwhelm the effect of the small decrease in VMT.

Longer Combination Vehicles Nationwide Scenario

This scenario has the greatest estimated reduction in heavy commercial truck VMT, 23.2 percent, which is shown in Table X-10. The nine-axle turnpike double with its high cubic capacity and GVW allowance is expected to be very attractive to freight shippers. Also, the triple-trailer combination attracts virtually all the freight from the Surface Transportation Assistance Act (STAA) double-trailer combinations (twin-trailer vehicles operating at weights less than 80,000 pounds GVW), which are predominately used by less-than-truckload (LTL) carriers. The reduced heavy commercial truck VMT resulted in a 13.8 percent reduction in fuel consumption but a very modest increase of 0.5 percent or $21 million in noise costs (see Table X-11). The estimated reduction of 5 billion miles in heavy commercial truck travel on urban roadways indicates that air pollution costs would be reduced in those areas prone to having significant air pollution.

H.R. 551 Scenario

As shown in Table X-12, this scenario has virtually no impact on heavy commercial truck VMT. Consequently, there is virtually no impact on energy consumption, air pollution, or noise as seen in Table X-13.

Triples Nationwide Scenario

In this scenario, the triple-trailer combination attracts not only most of the LTL freight from the STAA double-trailer combination vehicles (with STAA double-trailer combination VMT reduced 82.1 percent), but it also attracts both light and heavy density truckload freight (a 72.1 percent reduction in VMT for the five-axle semitrailer combination) because it is the configuration with the most cubic capacity and the highest weight allowance. The scenario resulted in a 20.2 percent reduction in heavy commercial truck VMT as shown in Table X-14.

This reduced heavy commercial truck VMT and resulted in a 12.8 percent reduction in fuel consumption, but only a very modest reduction in noise costs, 0.2 percent or $7 million, resulted (see Table X-15). The estimated reduction of 8 billion miles in heavy commercial truck travel on urban roadways indicates that air pollution costs would be reduced in those areas prone to significant air pollution.

Table X-4. Vehicle Miles of Travel by Configuration Under Uniformity Scenario

Truck Configuration	Number of Axles	VMT (millions)		Change from Base Case	
		Base Case	Scenario	Absolute	Percent
Single Unit	3	9,707	9,949	242	2.5
	4	2,893	3,224	331	11.4
Semitrailer	5	83,895	91,205	7,310	8.7
	6 and 7	6,595	3,660	-2,935	-44.5
STAA Double-Trailer	5 and 6	5,994	5,986	-8	-0.1
B-Train Double-Trailer	8	683	178	-505	-73.9
Rocky Mountain Double-	7	632	290	-342	-54.1
Turnpike Double-Trailer	9	76	20	-56	-73.7
Triple-Trailer	7	126	54	-72	-57.1
Total for Heavy	—	128,288	132,351	4,063	3.2
All Highway Vehicles	—	2,693,845	2,697,908	4,063	0.2

Table X-5. Energy and Environmental Impacts of Uniformity Scenario

Impact	2000 Base Case	Change from 2000 Base Case	
		Absolute	Percentage
VMT for Heavy Trucks (millions)	2,693,845	4,063	3.2
Energy Consumption (million gallons)	29,947	635	2.1
Urban VMT for Heavy Trucks (millions)	51,625	1,700	—
Air Pollution Costs	NA	NA	NA
Urban Freeway VMT for Heavy Trucks (millions)	27,503	797	—

Table X-6. Vehicle Miles of Travel by Configuration Under North American Trade Scenario, 51,000 Pound Tridem Axle Weight Limit

Truck Configuration	Number of Axles	VMT (millions)		Change from Base Case	
		Base Case	Scenario	Absolute	Percent
Single Unit	3	9,707	8,131	-1,576	-16.2
	4	2,893	3,578	685	23.7
Semitrailer	5	83,895	24,996	-58,818	-70.2
	6 and 7	6,595	6,792	197	3.0
B-Train Double-Trailer	8	683	46,619	45,936	6,726
Total for Heavy Trucks	—	128,288	114,632	-13,656	-10.6
All Highway Vehicles	—	2,693,845	2,680,189	-13,656	-0.5

Table X-7. Energy and Environmental Impacts of North American Trade Scenario, 51,000 Pound Tridem Axle Limit

Impact	Change from Base Case	
	Absolute	Percentage
VMT for Heavy Trucks (millions)	-13,656	-10.6
Energy Consumption (million gallons)	-1,870	-6.2
Urban VMT for Heavy Trucks (millions)	-5,163	—
Air Pollution Costs	TBD	TBD
Urban Freeway VMT for Heavy Trucks (millions)	-2,849	—
Noise Cost ($millions)	255	5.9

Table X-8. Vehicle Miles of Travel by Configuration for North American Trade Scenario, 44,000 Pound Tridem Axle Weight Limit

Truck Configuration	Number of Axles	VMT (millions)		Change from Base Case	
		Base Case	Scenario	Absolute	Percent
Single Unit	3	9,707	8,529	-1,178	-12.1
	4	2,893	3,595	702	24.3
Semitrailer	5	83,895	22,274	-61,621	-73.5
	6 and 7	6,595	6,755	160	2.4
B-Train Double-Trailer	8	683	49,003	48,320	7,075
Total for Heavy Trucks	—	128,288	114,671	-13,617	-10.6
All Highway Vehicles	—	2,693,845	2,680,228	-13,617	-0.5

Table X-9. Energy and Environmental Impacts of North American Trade Scenario With 44,000 Pound Tridem Axle Weight Limit

Impact	Change from Base Case	
	Absolute	Percentage
VMT for Heavy Trucks (millions)	-13,617	-10.6
Energy Consumption (million gallons)	-1,889	-6.3
Urban VMT for Heavy Trucks (millions)	-5,074	—
Air Pollution Costs	TBD	TBD
Urban Freeway VMT for Heavy Trucks (millions)	-2,895	—
Noise Cost ($millions)	281	6.5

Table X-10. Vehicle Miles of Travel by Configuration for Longer Combinations Nationwide Scenario

Truck Configuration	Number of Axles	VMT (millions)		Change from Base Case	
		Base Case	Scenario	Absolute	Percent
Semitrailer	5	83,895	19,611	-64,284	-76.6
STAA Double-Trailer	5 and 6	5,994	1,075	-4,919	-82.1
B-Train Double-Trailer	8	683	2,079	1,396	204.4
Rocky Mt. Double-Trailer	7	632	505	-127	-20.1
Turnpike Double-Trailer	9	76	32,418	32,342	42,555
Triple-Trailer	7	126	5,992	5,866	4,656
Total for Heavy Trucks	—	128,288	98,562	-29,726	-23.2
All Highway Vehicles	—	2,693,845	2,664,119	-29,726	-1.1

Table X-11. Energy and Environmental Impacts of Longer Combinations Nationwide Scenario

Impact	Change from Base Case	
	Absolute	Percentage
VMT for Heavy Trucks (millions)	-29,726	-23.2
Energy Consumption (million gallons)	-4,129	-13.8
Urban VMT for Heavy Trucks (millions)	-9,168	—
Air Pollution Costs	TBD	TBD
Urban Freeway VMT for Heavy Trucks (millions)	-5,267	—
Noise Cost ($millions)	21	0.5

Table X-12. Vehicle Miles of Travel by Configuration Under H.R. 551 Scenario

Truck Configuration	Number of Axles	VMT (millions)		Change from Base Case	
		Base Case	Scenario	Absolute	Percent
Semitrailer	5	83,895	83,916	20	0.03
	6 and 7	6,595	6,597	2	0.03
Total for Heavy Trucks	—	128,288	128,311	23	0.02
All Highway Vehicles	—	2,693,845	2,693,868	23	0.0009

Table X-13. Energy and Environmental Impacts of H.R. 551 Scenario

Impact	Change from Base Case	
	Absolute	Percentage
VMT for Heavy Trucks (millions)	23	0.02
Energy Consumption (million gallons)	3.6	0.01
Urban VMT for Heavy Trucks (millions)	6	—
Air Pollution Costs	TBD	TBD
Urban Freeway VMT for Heavy Trucks (millions)	3	—
Noise Cost ($millions)	0.3	0.007

Table X-14. Vehicle Miles of Travel by Configuration for Triples Nationwide Scenario

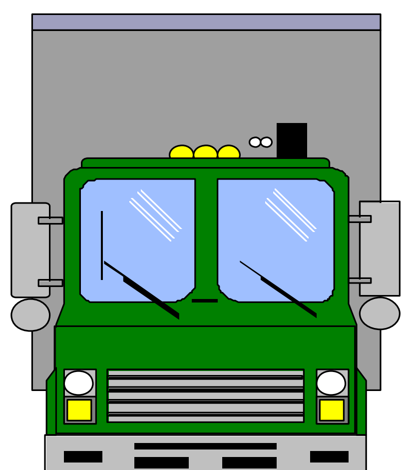
Truck Configuration	Number of Axles	VMT (millions)		Change from Base Case	
		Base Case	Scenario	Absolute	Percent
Semitrailer	5	83,895	23,405	-60,490	-72.1
STAA Double-Trailer	5 and 6	5,994	1,075	-4,919	-82.1
Triple -Trailer	7	126	39,647	39,521	31,366
Total for Heavy Trucks	--	128,288	102,400	-25,888	-20.2
All Highway Vehicles	--	2,693,845	2,667,955	-25,888	-1.0

Table X-15. Energy and Environmental Impacts of Triples Nationwide Scenario

Impact	Change from Base Case	
	Absolute	Percentage
VMT for Heavy Trucks (millions)	-25,888	-20.2
Energy Consumption (million gallons)	-3,819	-12.8
Urban VMT for Heavy Trucks (millions)	-8,010	—
Air Pollution Costs	TBD	TBD
Urban Freeway VMT for Heavy Trucks (millions)	-5,301	—
Noise Cost ($millions)	-7	-0.2

CHAPTER XI

Rail



Introduction

Motor carriers, railroads, barges, and pipelines are the principal transportation modes for the movement of intercity freight, with motor carriers and rail possessing the greatest market share in both revenues and tonnage. While railroads handle more bulk traffic than trucks, *e.g.*, coal and chemicals, they nonetheless compete with trucks for certain commodities and, of course, for intermodal traffic.

The passage of the Staggers Rail Act in 1980 provided the railroads the opportunity to restructure their systems and operations and to price their services competitively with other modes of transportation. Since Staggers, the loss in market share to trucks that railroads experienced reversed and began to increase, led by the growth in intermodal traffic.

Increases in truck sizes and weights would change the economics of truck-rail competition for freight by providing new opportunities for truck productivity improvements. Allowing heavier payloads would lower truck transportation and other logistics costs facing a shipper. To the extent that the trucking industry would be able to offer shippers lower total logistics costs, shippers would shift freight that currently moves by rail to the larger, heavier trucks. Because rail is a decreasing cost industry, railroads would be required to spread the relatively unchanged fixed costs of operating their system over a smaller traffic base, *i.e.*, railroads would face higher costs on their remaining traffic. Figure XI-1 describes characteristics of decreasing cost industries.

Four of the six scenarios analyzed in this study evaluate the effects of larger and heavier trucks. To the extent shippers remaining on the railroad face higher costs as a consequence of lost traffic, the net national cost saving attributable to productivity improvements associated with larger trucks will be reduced.

This chapter examines the extent to which changes in truck size and weight (TS&W) could have financial effects on the railroad industry. The chapter also examines how the impact of a change in truck size and weight regulations varies by

Figure XI-1. What is a 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.

Figure XI-2. The Class I Railroad Industry

In 1994, there were 12 Class I rail systems as defined by the Surface Transportation Board. The impact of changes in truck size and weight (TS&W) regulations are analyzed for these railroads. The Class I railroads are the Atchison Topeka and Santa Fe Railway, Burlington Northern Railroad, Chicago and Northwestern Railroad, Conrail, CSX, Grand Trunk Western, Illinois Central Railroad, Kansas City Southern Railway, Norfolk Southern Railroad, Soo Line, Southern Pacific Railroad, and Union Pacific Railroad.

selected railroads. Individual railroads will be affected differently depending on whether the freight they carry can be efficiently diverted to larger trucks.

Basic Principles

Overview of Class I Rail Industry

As 1994 is the base data year for the Comprehensive Truck Size and Weight Study, a review of conditions in the Class I railroad industry for that year provides a useful basis for comparison with the effects of the truck size and weight scenarios on the industry in the study Year 2000. Figure XI-2 identifies the 12 Class 1 railroads in operation in 1994. Considerable restructuring of the railroad industry has occurred since 1994. Figure XI-3 discusses that restructuring and why the current study was unable to consider potential implications of that restructuring.

Overall, in 1994, the rail industry did well. Railroad business significantly outpaced growth projections while providing high levels of service to customers. The railroads continued to increase market share, with records being set in 1994 for total volume and intermodal freight, in particular. Class I railroads handled

Figure XI-3. Restructuring of the Railroad Industry

Since 1994, there have been four significant Class I railroad mergers. In 1995, the Burlington Northern Railroad and the Atchison Topeka and Santa Fe Railway merged their systems. In 1995, the Union Pacific Railroad and the Chicago and Northwestern Railroad were merged, which was followed by the 1996 Union Pacific/Southern Pacific consolidation. Finally, in 1998, Norfolk Southern Railroad and CSX Railroad acquired and are now in the process of integrating Conrail assets into their respective systems. The study does not take these recent mergers into account. It is difficult to speculate today what the study outcome would be as a result of these consolidations since, for example, traffic flows on the merged systems have not been established for waybill analysis. However, because these mergers are not considered, portraying the distinctions between railroads resulting from their different traffic bases and operating characteristics can be demonstrated as originally planned.

39.2 percent of the Nation's total freight revenue ton-miles over a privately owned network that totals nearly 110,000 route miles. However, because the railroads handle a larger portion of bulk commodities than truck, this traffic represented only 7.9 percent of intercity freight revenue.

As in previous years, bulk commodities continued to be the mainstay of the U.S. railroad freight transportation market share in 1994. To expand into new markets, most of the Class I carriers had looked at logistics support and services and just-in-time operations as high margin opportunities for growth. All North American railroads had entered into intermodal agreements with major trucking and steamship lines by 1994.

The top seven U.S. railroads accounted for over 90 percent of 1994 Class I railroad business. None of the U.S. railroads spanned the continent—three operated in the Eastern U.S. and four in the West. All seven railroads had lines into Chicago. Nearly one-fourth of all carloads carried in North America are joint line movements—their journeys begin on one railroad and end on another.

Intermodal rail performed extremely well, as in past years, but coal was again the industry*s top commodity. The following statistical profile shows that the rail industry was well integrated with most U.S. major commodity business groups in 1994:

- Coal accounted for 39.1 percent of total rail tonnage, 24.5 percent of rail carloadings, and 21.7 percent of rail revenues. In 1994, rail revenues for carrying coal were $7 billion, or 8.3 percent higher than the previous year.

- Intermodal rail traffic grew by nearly 15 percent or by more than one million containers and/or trailers.

- Chemicals and allied products were 14.1 percent of total rail revenues and increased by 5.7 percent to $4.6 billion.

- Motor vehicles and equipment accounted for 9.8 percent of total rail revenues, up 7.7 percent to $3.2 billion.

- Food and associated products were 7.5 percent of total rail revenues, up 3.9 percent to $2.4 billion.

- Farm products accounted for 7.4 percent of total rail revenues, down 5.0 percent to $2.4 billion.

The Class I railroad traffic in 1994 totaled a record 1.201 trillion revenue ton-miles, 8.2 percent higher than the previous year. The growth in revenue ton-miles was attributable to both higher tons originated and longer hauls. Car miles grew significantly as well, to 28.5 billion, a 6 percent growth rate, with the empty return ratio showing marked improvement. The rail industry's share of total intercity revenue ton-miles reached 39.2 percent in 1994, a 3 percent increase over the previous year. The industry realized significant gains in productivity as revenue ton-miles per employee improved 9.3 percent over 1993 and revenue ton-miles per locomotive improved 6.2 percent even with significant locomotive fleet expansion.

Financial Performance and Implications

In 1994, financial

performance was at its best for any single year in over two decades; net revenues from operations, operating revenues less operating expenses, reached $5.3 billion and net income, a measure of profitability, totaled $3.4 billion. The industry operating ratio, total operating expenses divided by total operating revenue, was 81.5 percent an improvement from 85.1 percent the year before. The ratio shows how well a carrier is managing costs.

The industry*s return on investment (ROI) was a relatively impressive 9.4 percent, up from 7.1 percent the year before and the highest in recent industry history. Rail freight rates continued their long decline both in nominal and real dollar terms. The revenue yield, as measured in cents per revenue ton-mile, fell to 2.49 cents, which is 19.3 percent lower in nominal dollars, and 41.8 percent lower in real dollars than comparable 1984 figures. These improvements experienced by the railroad industry were largely the result of the significant economic regulatory reforms embodied in the Staggers Act.

Methodology

The process for estimating the post-diversion impact on the rail industry that could result from the decreased number of rail shipments and rate reductions for those remaining rail shippers is described in this section. The objective of this analysis is to compute a revised industry balance sheet, for the analysis year 2000 for the illustrative TS&W scenarios. In this way, the scenario impact on revenue, freight service expense (FSE), contribution, and ROI resulting from changes in traffic can be assessed.

The rail impact analysis employs two models, the Department of Transportation's Intermodal Transportation and Inventory Cost (ITIC) Model and an Integrated Financial Model described in Figure XI-4. Both are discussed below. These models required that the data for the analysis be extrapolated to the study Year 2000. This was accomplished by applying rail traffic growth rates developed by DRI/McGraw Hill to the following data sources: (1) Class I railroad financial and operating statistics as compiled by the Association of American Railroads (AAR) in the *Analysis of Class I Railroads—1994*; and (2) the 1994 Surface Transportation Board's (STB's) Carload Waybill Sample. The data used from the *Analysis of Class I Railroads* is compiled from R-1 reports submitted by the railroads to the STB. Figure XI-5 discusses adjustments made by the STB to rail revenues reported in the Waybill that improve the analytical results.

The revenue and traffic diversions used to assess rail impacts are derived from the ITIC Model. The model uses the STB Carload Waybill Sample as the basis for rail freight flows and undertakes to estimate shipper transportation and inventory costs for moving freight by rail and truck under different truck size and weight scenarios.
In this analysis, the ITIC model allows the railroads to

Figure XI-4. Integrated Financial Model

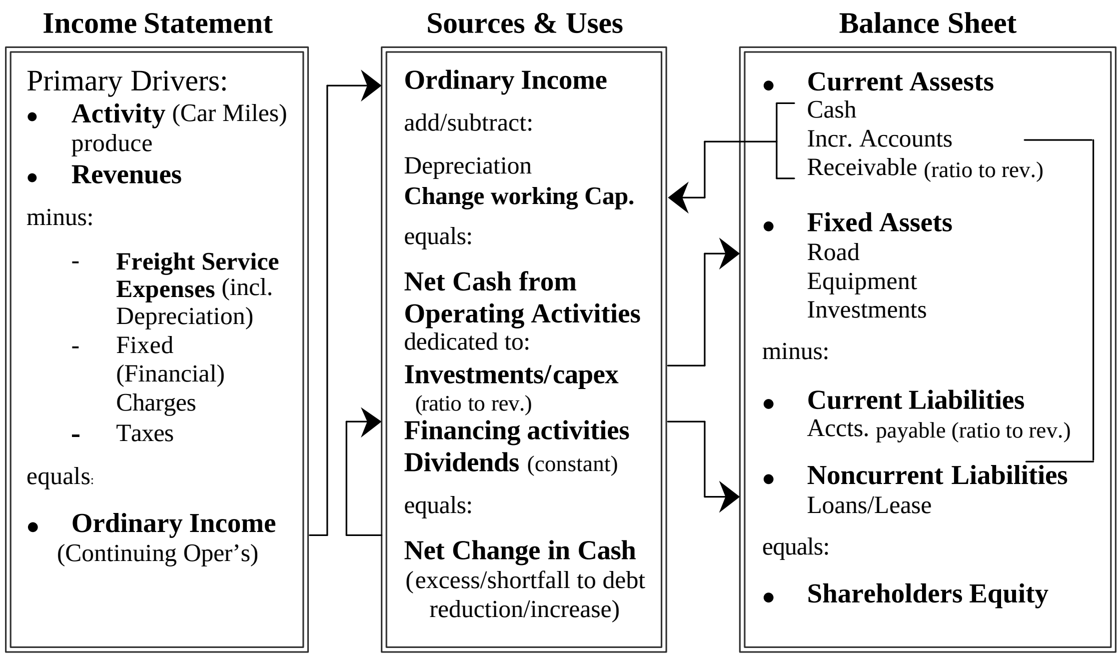


Figure XI-5. Rail Revenues

Percent change calculations in rail revenues were performed by the Surface Transportation Board (STB) with the highly confidential rail revenues in their sole possession. The use of these revenues provides an extra degree of accuracy in assessing rail impacts. The revenues that are available on the confidential version of the Waybill do not reflect actual contract revenues. Railroads, however, report these revenues to the STB. In most aggregate analyses, using the revenues provided on the Waybill would not be a problem, but because the ITIC Model uses individual shipments as input, we asked the STB to calculate percentage changes with the highly confidential data.

respond to increased truck competition by lowering their own rates down to variable cost, if necessary, to prevent diversion of rail freight to trucks. If motor carriers can offer shippers lower transportation and inventory costs than rail variable cost plus inventory costs, then the model assumes that the railroad will lose the traffic and it will divert to truck. 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 car miles decrease due to losses in traffic, the unit (car 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 to hold traffic, railroads lose revenue but all costs remain.

The post-diversion effects listed above are measured by the following key ITIC Model outputs: (1) the remaining rail revenues after accounting for losses in revenues from both diversion and from discounting to hold traffic; and (2) the remaining post-diversion car miles used to assess the effect of diversion on rail FSE.

The ITIC Model provides values for revenue and car miles for both the base case and each scenario. Percent changes from the base case to the scenario were calculated from these values. These percent changes were then applied to financial and operating statistics in the AAR, *Analysis of Class I Railroads—1994* (grown to the Year 2000) to determine the revenues and car miles used as inputs into an Integrated Financial Model.

The Integrated Financial Model was used to estimate the impact that changes in TS&W regulations would have on the rail industry's financial condition. As inputs, this model uses ITIC Model outputs described above and the change in FSE with respect to changing car miles (cost elasticity) derived by Gerard McCullough in his 1993 dissertation, *A Synthetic Translog Cost Function for Estimating Output-Specific Railroad Marginal Costs*. FSE from the *Analysis of Class I Railroads —1994* represents variable cost, the variable and fixed cost portions of depreciation charges, and interest expense railroads incur.

According to McCullough, for the industry, the cost elasticity is 0.6101. As railroads lose traffic, measured in car miles, and the associated revenues, reductions in cost do not decrease in a one-to-one relationship with car miles as noted by the elasticity value, 0.6101. Rather, railroads shed costs much more slowly because of the high fixed and common cost component of total costs that characterize the industry. To illustrate, if there were a 10 percent decline in rail car miles, the application of the 0.6101 elasticity coefficient indicates that freight cost would decline only 6.1 percent. As a consequence, the cost to handle the remaining traffic in terms of cost per car mile would increase in the post-diversion case as would be expected in a decreasing cost industry. This increased cost for remaining rail traffic represents an offset to shipper cost savings experienced by truck and former rail shippers as a result of truck size and weight changes, yielding the net national change in shipper costs.

Figure XI-4 presents a "wiring diagram" that demonstrates how the Integrated Financial Model works. The model links the Income Statement, Sources and Uses of Funds, and Balance Sheet information, as well as ROI for the rail industry, to evaluate each of the truck size and weight scenarios under consideration. The model imports the independent variables noted above

—percent changes in revenues and car miles —from the ITIC Model into the Income Statement to calculate the effects on the industry balance sheet. By using measured changes in the Income Statement variables—revenues, expenses (including FSE), income, and cash generated and expended—the model produces a revised industry Balance Sheet as output. The output includes a new FSE resulting from a change in car miles in the post-diversion study Year 2000. The Integrated Financial Model is also used to calculate the post-diversion ROI, and the increase in rail rates that would be required to return the rail industry to pre-diversion financial conditions.

The Integrated Financial Model analysis was applied to the rail industry as a whole and four "focus" railroads. The analysis of focus railroads is described in Figure XI-6. Similar to the application of the cost elasticity for the industry, the analysis applies individual elasticity coefficients for each focus railroad.

The elasticities applied in the analysis for the industry and the study railroads are noted in Table XI-1. These elasticities demonstrate that individual rail carriers show different sensitivities to changes in cost resulting from changes in car miles. For example, Conrail has an elasticity of 0.5795 and the Union Pacific has an elasticity of 0.7893. For a 10 percent loss in car miles, Conrail would only lose 5.795 percent of cost while Union Pacific would lose 7.893 percent of cost. For the two railroads there is about a 30 percent difference in impacts.

Study Caveats

The rail impact analyses results are generally plausible but some imprecision 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.

DRI/McGraw Hill developed growth rate estimates for traffic volumes, both rail and truck, for the Year 2000, the study year. For rail, two growth rates were estimated, one for intermodal traffic and one for all other traffic. To expand 1994 car miles, revenue, and FSE to the Year 2000, a traffic-weighted average of these rail growth rates was applied to the

Table XI-1. Industry and Railroad Cost Elasticities

Railroad	Elasticity
Industry	0.6101
Santa Fe	0.7543
Union Pacific	0.7893
Conrail	0.5795

Figure XI-6. Focus Railroads

This study focuses on the rail industry as a whole and on four "focus railroads" —two in the West, the Atchison Topeka and Santa Fe Railway (Santa Fe) and the Union Pacific Railroad—and two in the East, Conrail and Norfolk Southern Railroad. Looking at different railroads operating in different regions of the country demonstrates that the industry is not monolithic. Individual railroads handle significantly different traffic mixes and operate over different types of terrain and geographic areas. As a result, individual railroads' response to increases in truck sizes and weights, measured in percent of lost revenue, increased freight service expense, and lost car miles, will vary. For example, some railroads handle a larger portion of truck competitive traffic than others, while some carriers handle chiefly non-truck competitive bulk commodities, such as coal. Western carriers operate over extreme mountainous terrain, significantly different than in the East. Another important factor is the distance over which the carriers operate. For example, the four railroads operating in the West in 1994 moved traffic over much longer distances than railroads operating in the East. Selection of two railroads from the West and two from the East illustrates the disparity in effects that changes in TS&W can have across different railroads.

Analysis of Class I Railroads – 1994 base year data.

One criticism of this approach is that it fails to account for continued improvements in rail productivity over the 1994 to 2000 period. Rail technology and operations are considered static in the study, although capital investment and certain other factors are adjusted to account for the 2000 traffic volume. Given the extensive productivity gains made by railroads since passage of the Staggers Act in 1980, the issue is whether, and to what extent, this assumption unduly affects the rail impact results.

A consensus among observers of the rail industry is 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 as a consequence of changes in truck sizes and weights. In any case, while stepped up investment will be made to accommodate 2000 traffic, efficiency or productivity gain is expected to significantly lag the industry's performance in recent years. Therefore, it can be concluded that the effect on the rail impact results of the assumed static productivity are minor.

The rail analyses makes use of a rail FSE elasticity coefficient to account for the railroad's declining cost structure. As previously noted, the elasticity applied to the Class I Railroads as a group is 0.6101. It was developed in an econometric

Table XI-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, Friedlaender, Chiang, & Velturo (1993)	1.57	0.6380

* Gerard J. McCullough, *A Synthetic Translog Cost Function for Estimating Output Specific Railroad Marginal Costs,* p. 4, October, 1993.
** 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.

analysis of the industry based on *Analysis of Class I Railroads* data from 1978 through 1991. The issue is whether the coefficient can be applied credibly to data for the Year 2000, *i.e.*, to what extent has the coefficient changed in the intervening years? While the precise change in the elasticity coefficient is unknown, and would require an entirely new econometric analysis to determine, we believe the change in the study's impact measurements would be insignificant. Table XI-2 shows the results of six studies stretching from 1974 - 1993 where different researchers calculated returns to density for the industry and 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 years. McCullough observes that early work by Freidlaender & Spady (1981) was subsequently revised downward, which corresponds more closely with results noted in Table XI-2. Therefore, for the purpose of this study, and calculation of rail financial impacts, use of the 1991 cost elasticity coefficient is unlikely to have a substantially misleading effect on the outcome.

Assessment of Scenario Impacts

Base Case

Table XI-3 illustrates the total freight revenues, total FSE, contribution, and ROI for the industry and the four focus railroads for the base case. The base case applies the 1994 revenue per car mile to estimated Year 2000 car miles. For the industry, freight revenues would be

Table XI-3. Revenues, Freight Service Expense, Contribution, and ROI for Base Case Scenario

Railroad	Revenue	Freight Service Expense	Contribution	ROI %
Industry	$35,390,022,000	$29,832,728,000	$5,557,294,000	9.8
Santa Fe	3,090,909,000	2,659,124,000	431,785,000	7.7
Union Pacific	5,957,431,000	4,833,812,000	1,123,619,000	11.9
Conrail	4,198,333,000	3,566,132,000	632,200,000	8.7
Norfolk Southern	4,517,226,000	3,382,563,000	1,134,663,000	11.4

$35.4 billion. FSE incurred for moving the traffic would be $29.8 billion.

Contribution 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. For the industry, it would be $5.6 billion. Because contribution is closely linked to ROI, changes in contribution are an important measure of the impact of the scenarios on the rail industry.

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 generate sufficient financial resources to replace capital assets over the long run. Using results from the ITIC Model, ROI was calculated using the Integrated Financial Model for each scenario.

Uniformity Scenario

The Uniformity Scenario tests the impact of eliminating State grandfather authority and establishing current Federal TS&W limits on the National Network for large trucks. The potential diversion from truck-to-rail and therefore the impact on railroads was not tested due to limitations of the ITIC model (see Chapter IV).

North American Trade Scenarios

Two North American Trade Scenarios are analyzed: the first tests a 44,000 pound tridem-axle and the second tests a 51,000 pound tridem-axle. These axle weights are tested on one currently allowed configuration—the six-axle tractor semitrailer—and one new configuration—the twin 33-foot eight-axle double-trailer combination.

44,000 Pound Tridem Axle

This scenario specifies maximum GVWs of 90,000 pounds for the six-axle tractor semitrailer and 124,000 pounds for twin 33-foot eight-axle double trailer combinations.

Table XI-4 shows lost revenues, FSE, and contribution resulting from the application of this scenario. For the industry, the 44,000 pound Tridem scenario would result in total lost revenues of $3.2 billion, including $2.4 billion in lost revenue due to diversion from rail to truck. An additional $837 million would be lost as railroads reduced rail rates down to variable costs in response to lower truck rates in an effort to hold on to the remaining rail traffic.

For the industry, the $3.2 billion in lost revenues is matched by a $857 million reduction in FSE, illustrating the fact that railroads do not shed costs proportionately as revenues are lost. Rail contribution would be depleted by nearly $2.4 billion.

Table XI-5 shows losses in car miles, FSE, revenues, contribution, and resulting ROI in percentage terms. For the industry, there was a 4.7 percent loss in car miles with an associated 2.9 percent decline in FSE. Railroad revenues would decline by 9 percent, falling three times faster than FSE. As a result, contribution would fall a full 42.8 percent. ROI for the industry would fall from 9.8 percent in the base case to 6.3 percent.

Under this scenario, the eastern railroads —Conrail and Norfolk Southern— would have the greatest losses. This can be attributed to their relatively shorter hauls and higher rates compared to the Western focus railroads. Conrail would lose 9.1 percent of its car miles, 16.1 percent of its revenues, and a full 76.8 percent of its contribution. As a result, post-diversion ROI would decline by more than 60 percent to 3.2 percent from 8.7 percent in the base case. Norfolk Southern would lose 9.2 percent of its car miles, 6.5 percent of its FSE, and 12.6 percent of its revenues, resulting in a 30.5 percent

Table XI-4. Lost Revenues, Freight Service Expense, and Contribution for North American Trade Scenario With 44,000 Pound Tridem Axle

Railroad	Revenues Lost from Diversion	Revenues Lost from Rail Discounting	Total Lost Revenues	Total Lost Freight Service Expense	Total Lost Rail Contribution
Industry	$2,401,272,951	$836,914,049	$3,238,187,000	$857,265,000	$2,380,923,000
Santa Fe	140,219,754	38,744,246	178,964,000	44,729,000	134,235,000
Union Pacific	348,984,545	148,461,455	497,446,000	166,730,000	330,715,000
Conrail	503,011,987	171,240,013	674,252,000	188,472,000	485,780,000
Norfolk Southern	451,548,257	115,815,743	567,364,000	221,264,000	346,100,000

Table XI-5. Car Miles, Freight Service Expense, Revenues from Operations, Contribution, and ROI for North American Trade Scenario With 44,000 Pound Tridem Axle

Railroad	Car miles Percent Change	FSE Percent Change	Revenues Percent Change	Contribution Percent Change	Post Diversion ROI
Industry	-4.7	-2.9	-9.0	-42.8	6.3
Santa Fe	-2.2	-1.7	-5.8	-31.1	5.6
Union Pacific	-4.4	-3.4	-8.4	-29.4	9.1
Conrail	-9.1	-5.3	-16.1	-76.8	3.2
Norfolk Southern	-9.2	-6.5	-12.6	-30.5	8.4

loss in contribution. Norfolk Southern would lose one fourth of the value of its ROI which fell from 11.4 percent to 8.4 percent.

For the western carriers, much of the rail traffic that would be susceptible to diversion moves over long distances at relatively lower per mile tariffs making it highly truck competitive. But the two focus railroads experience different impacts as a result of this scenario. Even though Santa Fe would face a smaller reduction in car miles, FSE, and revenues than the Union Pacific, the effect on its contribution would be greater. Santa Fe would experience a 31.1 percent loss in contribution compared to Union Pacific's loss of 29.4 percent. This is largely the result of Santa Fe's higher cost structure relative to its revenue. The ROIs for this scenario are shown in Table XI-5.

Because the rail industry is a decreasing cost industry with relatively high fixed cost, the cost per car mile for handling post-diversion traffic rises as traffic is lost. Where FSE is the measure of that cost, the base case FSE per car mile for the industry is $1.167. Post-diversion FSE per car mile increases to $1.19. For Conrail FSE per car mile increases from $1.25 to $1.303. Norfolk Southern's would increase from $1.024 to $1.054.

The effects on Union Pacific and Santa Fe are somewhat less. Union Pacific's FSE per car mile would increase from $1.005 to $1.015 while Santa Fe's would go from $1.058 to $1.064.

51,000 Pound Tridem Axle

This scenario specifies the maximum legal GVWs at 97,000 pounds for six-axle tractor semitrailers and at 131,000 pounds for twin 33-foot eight-axle double trailer combinations.

Table XI-6 shows that under this scenario the industry is estimated to experience losses in revenues of $3.8 billion and a reduction in FSE of $1.05 billion. Rail contribution is estimated to drop by $2.8 billion. Table XI-7 illustrates that car miles are estimated to drop by 5.8 percent under this scenario with a resulting 3.5 percent decline in FSE for the industry. The industry could lose 11 percent of its revenues, which is more than three times the reductions in costs following the losses in traffic. As a result, industry contribution would fall nearly 50 percent. ROI would fall from 9.8 percent in the base case to 5.8 percent. The effects on the study railroads are summarized in Tables XI-6 and XI-7.

Under this scenario, FSE per car mile for the industry increases from $1.167 to $1.195. Conrail's FSE is estimated to increase from $1.25 to $1.311 while Norfolk Southern's goes from $1.024 to $1.061. Union Pacific's FSE per car mile would increase from $1.005 to $1.017. Santa Fe's would increase from $1.058 to $1.065.

Longer Combination Vehicles Nationwide Scenario

This scenario allows both larger and heavier trucks over an extensive road network. (See Chapter III). Table XI-8 illustrates the total dollars lost in revenues, FSE, and contribution for the industry and the focus railroads resulting from the Longer Combination Vehicles (LCVs) Nationwide Scenario. For the industry, revenues losses total nearly $6.7 billion, including revenues lost from discounting of $1.1 billion. Reductions in FSE total $3.6 billion. Rail contribution is depleted by $3.1 billion.

Table XI-6. Lost Revenues, Freight Service Expense, and Contribution for North American Trade Scenario With 51,000 Pound Tridem Axle

Railroad	Revenues Lost from Diversion	Revenues Lost from Rail Discounting	Total Lost Revenues	Total Lost Freight Service Expense	Total Lost Rail Contribution
Industry	$2,909,059,441	$898,906,559	$3,807,966,000	$1,046,554,000	$2,761,412,000
Santa Fe	167,837,728	41,727,272	209,565,000	52,551,000	157,012,000
Union Pacific	412,849,877	162,042,123	574,892,000	203,739,000	371,153,000
Conrail	579,790,182	191,863,818	771,654,000	213,064,000	558,590,000
Norfolk Southern	529,870,511	119,706,489	649,577,000	264,174,000	385,403,000

Table XI-7. Changes in Operational and Financial Indicators Under the North American Trade Scenario With 51,000 Pound Axles

Railroad	Car miles Percent Change	FSE Percent Change	Revenues Percent Change	Contribution Percent Change	Post Diversion ROI
Industry	-5.8	-3.5	-11.0	-49.7	5.8
Santa Fe	-2.6	-2.0	-6.8	-36.4	5.3
Union Pacific	-5.3	-4.2	-9.7	-33.0	8.8
Conrail	-10.3	-6.0	-18.4	-88.4	3.2
Norfolk Southern	-11.0	-7.8	-14.4	-34.0	8.1

Table XI-9 illustrates the relationships between the losses in car miles, freight service expense, revenues, contribution, and resulting ROI in percentage terms that would occur under the LCVs Nationwide Scenario. Industry results show that following a 19.6 percent decline in car miles, FSE would fall by 12 percent. At the same time, railroad revenues would decline by 18.9 percent, falling more than cost. As a result, industry contribution would fall 55.8 percent. ROI for the industry would fall from 9.8 percent to 5.3 percent.

Under this scenario, the eastern railroads —Conrail and Norfolk Southern—with their shorter hauls and higher rates would be affected more than the western carriers—Santa Fe and Union Pacific—in terms of reductions in traffic.

Because Conrail experiences attractive revenue divisions from its connecting carriers on joint line movements and exhibited higher cost structures, it is more severely affected by the LCVs Nationwide scenario than other carriers. Conrail would lose a high proportion of its intermodal traffic and a significant portion of its boxcar traffic. Table XI-8 shows that Conrail would lose $1.5 billion in revenues with an offsetting decrease of only $1.04 billion of FSE, for a contribution loss of $463 million. As a result, Conrail's ROI would fall from 8.7 percent in the base case to 3.7 percent post-diversion. Norfolk Southern, however, would lose 32.9 percent of its car miles, 23 percent of its FSE, 23.3 percent of its revenues, and 21.9 percent of its contribution. As a

Table XI-8. Lost Revenue, Freight Service Expense and Contribution for LCVs Nationwide Scenario

Railroad	Revenues Lost from Diversion	Revenues Lost from Rail Discounting	Total Lost Revenues	Total Lost Freight Service Expense	Total Lost Rail Contribution
Industry	$5,581,006,318	$1,097,090,682	$6,678,097,000	$3,574,666,000	$3,103,431,000
Santa Fe	357,309,105	132,290,895	489,600,000	190,749,000	298,851,000
Union Pacific	771,615,472	214,467,528	986,083,000	544,829,000	423,254,000
Conrail	1,319,955,701	180,528,299	1,500,484,000	1,037,007,000	463,477,000
Norfolk Southern	935,969,692	102,089,308	1,038,059,000	789,166,000	248,893,000

Table XI-9. Changes in Operational and Financial Indicators Under LCVs Nationwide Scenario

Railroad	Car miles Percent Change	FSE Percent Change	Revenues Percent Change	Contribution Percent Change	Post Diversion ROI
Industry	-19.6	-12.0	-18.9	-55.8	5.3
Santa Fe	-9.5	-7.2	-15.8	-69.2	3.1
Union Pacific	-14.3	-11.3	-16.3	-37.7	8.4
Conrail	-50.2	-29.1	-35.7	-73.3	3.7
Norfolk Southern	-32.9	-23.0	-23.3	-21.9	9.5

consequence, its post-diversion ROI would fall to 9.5 percent from 11.4 percent in the base case.

For the western carriers Santa Fe could be expected to experience greater impacts in both absolute and relative terms because a high proportion of its revenues are generated from intermodal traffic, which has a relatively higher cost structure. While the Santa Fe would lose 9.5 percent of its car miles, it would suffer a 69.2 percent decline in contribution, resulting in a post-diversion ROI of 3.1 percent versus 7.7 percent in base case. In contrast, Union Pacific would lose 37.7 percent of its contribution due to the fact that its cost structure has been lower relative to its revenues.

Under this scenario, the industry and the focus railroads face the greatest increases in FSE per car mile. For the industry, FSE per car mile goes from $1.167 to $1.279. Conrail's increases from $1.25 to $1.78 and Norfolk Southern's increases to $1.171 from its base of $1.024. Union Pacific faces increases from $1.005 to $1.041. Santa Fe's goes from $1.058 to $1.086.

H.R. 551 Scenario

The H.R. 551 Scenario would decrease the cubic capacity for the existing five- and six-axle tractor semitrailers. The potential diversion from truck-to-rail, and therefore the impact to railroads, was not tested due to limitations of the ITIC Model (see Chapter IV).

Triples Nationwide Scenario

This scenario tests the impacts of allowing triple-trailer combinations with a GVWs 132,000 pounds on an extensive road network.

Table XI-10 illustrates the total dollars lost in revenues, FSE, and contribution for the industry and the focus railroad resulting from this scenario.

As a result, the industry would face losses in revenues of $2.9 billion, including $645 million from discounting to hold onto traffic. FSE would decline by $735 million. Rail contribution is depleted by $2.1 billion.

Table XI-11 indicates the percentage change in car miles, FSE, revenues, contribution, and resulting ROI under the triple-trailer combination nationwide scenario for the industry and the focus railroads.

Overall, for the individual focus railroads, the impact with respect to changes in contribution was relatively the same with the exception of Conrail. The eastern carriers, however, did experience more traffic losses to trucks than those in the West. Conrail and Norfolk Southern both experienced over a 7 percent loss in car miles. However, even with this similarity, the impact on Conrail was far greater with respect to lost contribution, as it loses 73.4 percent compared to Norfolk Southern's loss of 29.1 percent. Conrail's ROI fell from 8.7 percent in the base case to 3.5 percent post-diversion.

In contrast, Union Pacific would experience a 4.24 percent loss in car miles, followed by a 3.3 percent reduction in FSE and a 7.39 percent loss in revenues. Its loss in contribution was 24.8 percent. As a result, its ROI fell from 11.9 to 9.6 percent. Santa Fe, with its high cost structure relative to its revenues, lost 2.3 percent of it car miles, 1.7 percent of its FSE, and 5.6 percent of its revenues, resulting in 29.2 percent reduction in contribution for a post-diversion ROI of 5.7 percent compared to 7.7 percent in the base case.

Table XI-10. Lost Revenues, Freight Service Expense, and Contribution for Triples Nationwide Scenario

Railroad	Revenues Lost from Diversion	Revenues Lost from Rail Discounting	Total Lost Revenues	Total Lost Freight Service Expense	Total Lost Rail Contribution
Industry	$2,218,231,487	$644,821,513	$2,863,053,000	$735,318,000	$2,127,735,000
Santa Fe	139,566,283	32,597,718	172,164,000	45,531,000	126,633,000
Union Pacific	336,281,771	103,972,229	440,254,000	161,770,000	278,484,000
Conrail	482,968,363	126,629,637	609,598,000	146,313,000	463,285,000
Norfolk Southern	420,662,284	83,911,716	504,574,000	174,518,000	330,056,000

Table XI-11. Changes in Rail Operational and Financial Indicators for the Triples Nationwide Scenario

Railroad	Car miles Percent Change	FSE Percent Change	Revenues Percent Change	Contribution Percent Change	Post Diversion ROI
Industry	-4.04	-2.5	-8.09	-38.2	6.7
Santa Fe	-2.27	-1.7	-5.57	-29.2	5.7
Union Pacific	-4.24	-3.3	-7.39	-24.8	9.6
Conrail	-7.08	-4.1	-14.52	-73.4	3.5
Norfolk Southern	-7.26	-5.2	-11.17	-29.1	8.5

This scenario has least impact on changes in FSE per car mile. For the industry, FSE per car miles increases from $1.167 to $1.187. Conrail's would increase to $1.291 from $1.024 and Norfolk Southern's would increase from $1.024 to $1.048. Union Pacific and Santa Fe are virtually unaffected but do face increases. For Union Pacific FSE per car mile increases to $1.015 from $1.005. Santa Fe's increases from $1.058 to $1.064.

Interpretation of

Results

Railroad Response

Rate Increases Necessary to Replace Contribution

The analysis above uses the ITIC Model combined with the Integrated Financial Model to estimate the impact of a change in truck sizes and weights on the rail industry. But how the rail industry will respond to the loss of rail traffic, revenues, and contribution is not known. For example, will individual rail carriers be able to increase prices on remaining rail traffic to replace lost revenues or will the erosion in financial strength take place unabated?

The section presents the results of additional analysis undertaken to estimate how much rail rates would have to increase in order to recapture contribution and restore railroad ROI to pre-diversion levels. While this is an interesting intellectual exercise, the unique characteristics of the rail industry need to be taken into consideration in determining the probability that such a strategy could actually take place. Some maintain that contribution replacement could take place if railroads are able to increase rail rates on captive shippers, those shippers with no transportation alternative. However, consideration of this option is not a very realistic solution. First, the number of captive shippers is small relative to the total number of rail shippers. Second, it is likely that railroads are already charging all shippers, including captive shippers, the maximum rates possible—rates are constrained by both competition and maximum rate regulation.
But, even if rail rates were to increase, the rate increase would be followed by a further reduction in rail traffic, as more rail shippers would be induced by the higher rail rates to ship their goods by truck. Because this study is a static analysis, it is unable to evaluate the real world, long term, dynamic response of the rail shippers to a rail rate increase designed to recapture the projected lost rail revenues.

For the LCV Scenario, Table XI-12 illustrates the rail rate increases for all traffic that would be required to replace lost contribution and restore ROI for the industry and each of the focus railroads to pre-diversion levels. These rate increases are estimated by assuming that all remaining traffic would bear the consequential increases evenly (not likely to be the case). For the other scenarios, rate increases necessary to replace lost contribution and restore ROI would be somewhat less. If it were

Table XI-12. Estimated Rail Rate Increase on All Traffic to Replace Lost Contribution and Restore ROI

Industry	11%
Conrail	17%
Santa Fe	11%
Union Pacific	8%
Norfolk Southern	6%

possible to examine and apply these rate increases to captive traffic only, then the increases noted in Table XI-12 would be significantly higher.

Erosion of Financial Strength

As previously discussed, the financial condition of the rail industry and each of the focus railroads deteriorated under each of the scenarios. For the industry, the loss in contribution in the LCV Scenario was nearly 55 percent. Under the two Tridem-Axle scenarios—44,000 and 51,000 pound—losses in contribution were 43 percent and 50 percent, respectively. Under the Triples Scenario, the loss was 38 percent.

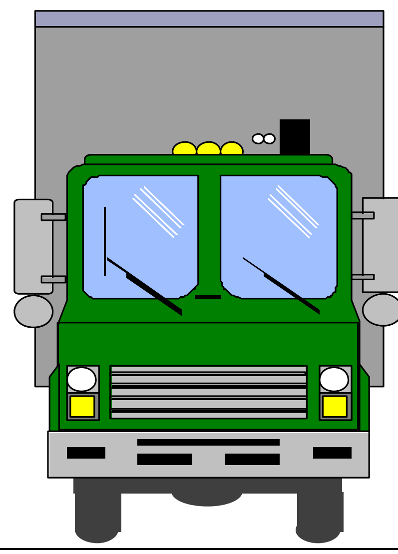
Corresponding with these losses were reductions in ROI, which would affect the industry and each of the focus railroads' ability to access capital.

Clearly no industry can endure the loss of half its contribution as predicted in the LCV Scenario. If these losses were to occur, the effects would be predictable: total elimination of any shareholder distributions and cancellation of capital spending, at a minimum. Since 1990 the industry has put in place over $30 billion of capital investment to replace plant and equipment. At the rate of loss implicit in the above calculations, this would be depleted in less than a decade.

While it is unlikely that railroads would be able to increase rates and restore contribution and ROI to pre-diversion levels, one can only assume that the carriers would have difficulty gaining access to financial capital to maintain and replace assets. On the one hand, such difficulties would force the carriers to shrink their systems to return ROI to acceptable levels and once again gain access to financial markets. If shrinkage of the system is not possible, then the carriers would be forced to defer maintenance and would be unable to replace assets needed to meet their customers' needs. As a consequence, there would be service deterioration.

CHAPTER XII

Shipper Costs



Introduction

Shippers strive to minimize transportation and inventory costs. In the event of a change in truck size and weight (TS&W) regulations the array of available transportation options changes, potentially changing the transportation and inventory costs presented to shippers.

Basic Principles

A change in TS&W regulations may alter a shipper's logistics costs. "Logistics" is defined as that set of activities involving the movement and placement of goods to meet supply and demand. These costs include transportation, inventory, product packaging, plant location, and loading dock labor. Of all of these factors, a shipper's total logistics expense is most directly impacted by transportation and inventory costs.

Transportation Cost

Transportation cost is the cost of moving a shipment from its origin to its destination. This chapter focuses on the change in costs for rail and truck shippers. In 1994, rail shippers paid $31 billion in transportation expenses (Railroad Facts, 1997) and shippers using heavy commercial trucks paid $216 billion [see Chapter IV, Intermodal Transportation and Inventory Cost (ITIC) Model]. Truck transportation costs exclude those for light commercial trucks, such as two-axle single unit trucks (SUT), that account for over 50 percent of total truck vehicle-miles-traveled (VMT), because these vehicles are not affected by the study scenarios. Figure XII-1 summarizes relationships between transportation costs and changes in truck size and weight limits.

Inventory Costs

Changes in truck size and weight limits also affect inventory costs as described in Figure XII-2. Inventory costs include warehousing, depreciation, taxes, obsolescence, insurance, ordering and interest expenses. Total national inventory carrying cost was estimated to be $272 billion in 1994 (Cass Logistics). This is calculated as a percent of the 1994 value of inventory as reported by the Census Bureau. However, this estimate includes more than the inventory costs represented in the ITIC Model. The ITIC Model only includes the ordering, interest, holding (or warehousing), and insurance costs. Costs such as depreciation, taxes, and obsolescence are not directly affected by changes in TS&W and are not included in the

Figure XII-1. Transportation Costs and Changes in Truck Sizes and Weights

Changes in truck size and weight (TS&W) regulations impact truck shipper transportation cost. If TS&W regulations become more restrictive, then the payload-per-truck decreases and the transportation cost per-ton-mile increases. On the other hand, if TS&W regulations become more permissive then the payload-per-truck will increase and the transportation cost per-ton-mile decreases. Changes in TS&W regulations impact rail shipper transportation cost because some will divert their freight to the new truck configuration(s) or obtain reduced rates from the railroads as the railroads compete with lower truck rates.

Figure XII-2. Inventory Costs and Changes in Truck Sizes and Weights

Inventory costs respond to changes in payloads caused by changes in truck size and weight limits. In a simple example, if a shipper changes from using a single 53-foot trailer to twin 53-foot trailers (as occurs in the Longer Combination Vehicles Nationwide Scenario), then the payload per delivery would double as would the inventory cost. On the other hand, if a shipper changes from using rail boxcars to a new truck configuration then the payload per delivery would decrease as would the inventory cost.

model.

Relationship Between Transportation and Inventory Costs

Relationships between transportation and inventory costs vary for different commodities. For example, a pound of coal is cheap; it is ordered in large quantities, order processing is relatively inexpensive, and it is usually stored in open mounds. These inexpensive transportation and inventory costs result in shippers preferring railroads for large bulk shipments of coal.

Alternatively, the attributes of computer chips lead a shipper to prefer using either truck or air for small shipments because a pound of computer chips is expensive, the annual volume is relatively small, order processing is expensive due to strict specifications, storage is costly since it must be secure, and the shelf life is short due to the speed of innovation.

Many commodities are somewhere between the two extremes of coal and computer chips. For example, paper products are characterized by broad variations in prices, annual volumes, and storage requirements. With such a range of commodity attributes, it is understandable why paper products travel in a variety of modes and truck configurations.

The important commodity attributes are price, annual volume, order cost, and inventory carrying cost. In general, as price or carrying cost increases, the optimal size of the shipment decreases. On the other hand, when annual volume or order cost increases, the optimal size of the shipment increases.

Analytical Approach

Transportation and inventory impacts are derived from the ITIC Model (see Chapter IV). For a given change in TS&W limits, the model predicts whether changes in transportation and inventory costs will cause a given shipment to be transported by an alternative mode or truck configuration. If the total cost is lower for a proposed truck configuration, relative to the current configuration, the shipment will divert. If a shipment diverts, the shipper's transportation and inventory costs change. The transportation and inventory costs savings do not include payment for any of the impact costs estimated in Chapter V-Chapter XI. In practice, if infrastructure costs associated with truck size and weight changed significantly, transportation agencies might change user fee rates to reflect those changes.

Shipper costs for truck transportation are computed by multiplying the VMT predicted by the ITIC Model by the transportation cost-per-mile for each configuration and weight group.

Rail shipper transportation cost is computed using the revenues reported in the Surface Transportation Board's (STB) Carload Waybill. As discussed in Chapter XI, these revenues were adjusted by the STB to reflect rail contract moves as appropriate. As indicated in Chapter IV, the ITIC Model allows a railroad to discount its price down to variable cost before the freight is shifted from rail to truck. Therefore, in addition to the savings to rail shippers that move to new truck configurations, there are rate reductions for some rail shippers.

As noted above, changes in inventory costs (both positive and negative) would be expected to mitigate changes in transportation cost. Inventory costs vary markedly among industries and across firms within each industry. While key inventory costs are included in the shipment-by-shipment analysis in the ITIC Model, aggregate changes in inventory costs associated with the various illustrative scenarios could not be estimated. An important element on the future TS&W research agenda is improvement of inventory cost data and relationships between inventory costs and transportation decisions.

Assessment of Scenario Impacts

Uniformity Scenario

The Uniformity Scenario would cause payloads carried by some existing truck configurations to decrease since the weight limits in States that have grandfathered weights currently exceeding the Federal limits would be decreased. As Table XII-1 shows, the transportation cost for shippers using trucks increases $6,430 million per year. The impact on rail shippers was not estimated but is believed to be small because most of the potentially affected freight travels relatively short distances.

North American Trade Scenario

44,000-Pound Tridem Axle

This scenario would increase the payload weight for the four-axle SUT and the six-axle tractor semitrailer in addition to increasing the payload weight and cubic capacity for the eight-axle double-trailer combination.

As Table XII-1 shows, shippers who use these trucks experience significant transportation savings. Truck shippers who change to the newly allowed configurations and gross vehicle weights (GVWs) would save $10,922 million per year. Rail shippers who change from rail to truck would save $870 million per year. Rail shippers, who continue to use rail, obtain a $836 million discount due to competitive rate reductions.

51,000-Pound Tridem axle

This scenario would increase the payload weight for the

Table XII-1. Annual Transportation Cost Savings for Truck Shipments

	Scenarios					
	Uniformity	North American Trade: 44,000-pound Tridem Axle	North American Trade: 51,000-pound Tridem Axle	LCVs Nationwide	H.R.511	Triples Nationwide
Truck-to-Truck						
Dollars (millions)	$ (6,430)	$ 10,922	$ 13,277	$ 26,660	$ (22)	$ 19,820
Percent Change	-3.0	5.0	6.1	12.3	0.0	9.2
Rail-to-Truck						
Dollars (millions)	n/a	$ 870	$ 1,233	$ 782	n/a	$ 1,122
Percent Change	n/a	2.6	3.7	2.4	n/a	3.0
Rail Discount						

four-axle SUT and the six-axle tractor semitrailer in addition to increasing the payload weight and cubic capacity for the eight-axle double trailer combination.

As Table XII-1 shows, shippers who use these trucks experience significant transportation savings. Truck shippers who change to the newly allowed configurations and GVWs would save $13,277 million per year. Rail shippers who change from rail to truck would save $1,233 million per year. Rail shippers that continue to use rail would realize a $2,909 million discount due to competitive rate reductions.

Longer Combination Vehicles Nationwide Scenario

This scenario allows several new configurations at heavier weights and larger sizes than exist in the current fleet. As Table XII-1 shows, shippers who use these trucks experience significant transportation savings. Truck shippers who change to the newly allowed configurations would save $26,660 million per year. Rail shippers who change from rail to truck save $782 million per year. Rail shippers who continue to use the railroad obtain a $1,098 million discount due to competitive rate reductions.

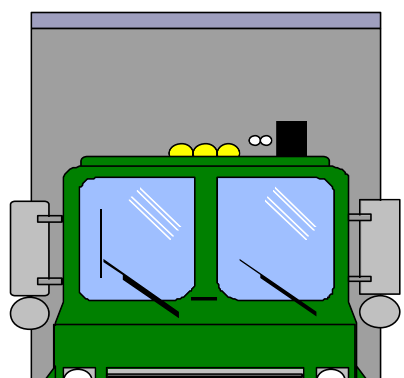
H.R. 551 Scenario

The H.R. 551 Scenario would decrease the cubic capacity for the existing five- and six-axle tractor semi-trailers. As Table XII-1 shows, the transportation costs for shippers using trucks increases $22 million. For this scenario the impact on rail shippers was not estimated but is predicted to be small because only cube limited freight, which typically does not travel by rail, is affected.

Triples Nationwide Scenario

This scenario allows triple-trailer combinations to operate nationwide with higher payloads and more cubic capacity than a five-axle tractor semitrailer. Table XII-1 shows an annual transportation cost savings of $19,820 million for truck shippers who divert to the triple-trailer combination and $1,122 million for rail shippers that divert to the triple-trailer combination. Rail shippers that continue to use the railroad obtain a $644 million discount due to competitive rate reductions.

APPENDIX A



Summary of Comments

Introduction

A draft of Volume III, the Scenario Analysis, for the U.S. Department of Transportation's (DOT) Comprehensive Truck Size and Weight (TS&W) Study was made available to the public in December 1998 for comment. Eighteen States, ten trucking industry associations or interests, and nine other interested parties submitted comments. Comments ranged from brief, general comments to extensive, detailed comments and recommendations. As many of the recommended technical clarifications and corrections as possible were incorporated in Volumes I and III. Recommendations for new or modified scenarios could not be accommodated, but the types of changes suggested have been noted.

This appendix is organized by chapter and significant issues that were highlighted or consistently cited in the comments. The issues are summarized in italics and the response or action taken is noted immediately following the comment. The actual comments are available on-line through the docket room site at http://dms.dot.gov under docket #4498.

Analytical Framework and Scenario Definition

Study Vehicles and Configurations

Both single-unit trucks (SUTs) and combination vehicles are analyzed in this study. The study scenarios include a broad range of commercial truck configurations: three- and four-axle SUTs; five- and six-axle tractor-semitrailers; 28- and 33-foot double trailer combinations; and longer combination vehicles (LCVs). The configurations are analyzed at gross operating weights based on assumptions about axle weight and bridge overstress criteria.

Comment: Many of the configurations selected for analysis are non-existent or atypical of those currently in use, or likely to be used in the foreseeable future, on a nationwide basis. This flaw in the analysis results in an exaggeration of the potential impacts.

DOT Response: Because each scenario was analyzed in extensive detail, only a limited number of scenarios could be analyzed in this study. With this limitation in mind, the Department decided that each scenario should reflect the upper range of potential impacts that might occur with the changes in TS&W limits assumed for each scenario. While gross vehicle weight limits assumed for certain vehicle classes are greater than the weights at which those vehicles typically operate today, all vehicles comply with current axle load limits. Exceptions to this are the vehicles under the North American Trade Scenarios with tridem axle load limits of either 44,000 pounds or 51,000 pounds, since there are no explicit tridem axle load limits in Federal regulations. The 44,000 pound limit was set to result in no increase in pavement consumption allowable bridge stresses. The 51,000 pound limit was set to accommodate the carrying of International Standard Organization (ISO) containers loaded to their maximum allowable weight, and it approximates Mexico's 49,000 pound limit and the range of tridem axle weights allowed in Canada. If lower gross vehicle weight limits had been assumed for various scenarios, impacts, both positive and negative, would be smaller.

Study Networks

Analytical networks were required to test the impact of the scenario TS&W limits on truck-to-truck and rail-to truck diversion of freight. The networks for the scenarios were limited to the National Network (NN) for large trucks, the National Highway System (NHS), and two limited systems of highways for the operation of LCVs. All configurations analyzed were assumed to operate nationwide.

Comment: Networks selected are inappropriate, too inclusive or exclusive, and not based in reality. For instance, the triple trailer network should be scaled back to all Interstates west of the Mississippi River (excluding urban area Interstates not currently in use) and east of the Mississippi should be Interstates and non-Interstate routes where triples currently operate and nine additional Interstates plus Interstate by-pass routes around major urban areas.

DOT Response: A wide range of networks was suggested in the various comments on this issue. Developing a broad consensus on the nature and extent of the analytical networks that should be analyzed in each scenario would have been very difficult. The network analysis was one of the most demanding parts of this study since minimum paths between all origins and destinations of commodity movements analyzed in the study had to be developed. It was not possible within the scope of this study to conduct sensitivity analyses to evaluate implications of more extensive or more limited networks. In general, the illustrative LCV networks were selected to provide access to major markets, but to avoid having LCVs go through congested metropolitan areas. Because the approach to developing LCVs networks was to select an interconnected system of access-controlled highways, two-lane highways in the West and certain turnpikes in the East that currently allow LCVs are not included in the illustrative networks. This does not mean that LCVs could not use those highways if TS&W limits were actually changed to allow such vehicles. In the West eliminating the two-lane highways from the networks could result in lower estimates of LCV use than if those highways had been included, but the exclusion of turnpikes in the East is not expected to significantly affect overall estimates of LCV use since good alternatives generally would be available.

Study Scenarios

The outreach process for the initial phase of the study was used to identify TS&W issues of concern to the States, general public and interest groups. These issues were incorporated into a limited number of illustrative TS&W scenarios. The scenarios are not intended to indicate the DOT's disposition toward particular TS&W policy options, but rather were developed to illustrate potential impacts across a broad range of possible TS&W changes. The analytical framework developed for the study is sufficiently flexible to permit the evaluation of many different options.

Comment: The capability of the model to reliably predict impacts on a regional, State or commodity basis is questioned.

DOT Response: The study was designed to estimate nationwide impacts of TS&W changes analyzed in the illustrative scenarios. Even though diversion is analyzed on a shipment-by-shipment basis and scenario impacts are analyzed using sample data on individual pavement sections and individual bridges, the analysis was not designed to provide reliable impact estimates below the national level. It would be possible to analyze scenarios at a regional level, but additional care would have to be taken in specifying the networks to make sure they are representative of major routes that likely would carry the majority of intercity truck movements. In general, the lower the level at which the analysis is conducted, the greater the detail required to produce results that would provide reliable bases for decisions on the desirability of TS&W policy changes.

Comment: The illustrative scenarios are not based on real-world current or future industry operations or practices and more realistic scenarios should be analyzed with more logical assumptions. Among the additional scenarios suggested for analysis are a Western-region scenario, a full-cost recovery scenario, alternative bridge formulas, and "quid pro quo" options that improve productivity and are tied to improvements in safety and operations.

DOT Response: As noted above, with the limited number of scenarios that could be analyzed in this study, the Department decided to analyze scenarios that illustrated the upper bound of likely impacts from various types of TS&W policy changes. The scenarios were not intended to represent options that could or should be implemented, but rather were intended to illustrate the likely magnitude of impacts from a given set of assumptions. Scenarios that included recovery of infrastructure and other costs could be analyzed, but would require additional analysis to predict the likely response by shippers and carriers to changes in cost. No specific alternative bridge formulas were analyzed, but bridge protection approaches would have to be carefully considered before options with some of the gross vehicle weights assumed in the illustrative scenarios could be implemented. The more detailed the scenario and the closer it is to a true policy option, the more important it is to involve States, shippers, carriers, and other affected groups in the analysis to be sure that likely responses to various options are understood.

Freight Distribution

Freight distribution information is critical to estimating the impact of TS&W changes on infrastructure, operations, the environment and safety. Of particular interest to the study is the shift of freight from one truck configuration to another, and from one gross vehicle weight (GVW) group to another as the result of changes to TS&W limits and shipper modal choices.

Comment: The assumptions for estimating diversion from rail-to-truck and truck-to-truck place too much emphasis on cost, and too little on service, as a factor in shipper decision making. This all or nothing decision rule in the model results in significantly overstated diversion.

DOT Response: Service variables are included in the model, although they ultimately are converted to dollar costs for purposes of comparing vehicle and modal alternatives. The diversion model went through an extensive review process involving academics and consultants familiar with transportation logistics. While the relative importance of service versus price varies widely among shippers, the experts believed that the values in the diversion model were representative. One indication of how well the model reflects actual shipping decisions is the fact that when the model was run against carload shipments in the Rail Waybill, it correctly predicted that shipments would go by rail rather than truck about 95 percent of the time. There was significant discussion among persons reviewing the model on the issue of whether an all or nothing approach should be used in estimating diversion or whether some threshold cost savings should be required before assuming a shipment would shift to another type of vehicle or another mode. In keeping with other assumptions in the analysis that were intended to estimate the upper range of potential impacts, it was decided to adopt an all or nothing approach and to assume shipments would divert even with only a very small price advantage.

Comment: A major problem with the model is it looks only at major railroads and no consideration is given to regional or short-line railroad operations typical of many States that are more likely to experience diversion because they transport a high volume of small shipments.

DOT Response: A major problem when looking at regional or short-line railroads in a study such as this is the lack of data, both operational and financial, of these classes of rail carriers. For the short-line railroads, many do not appear in the waybill as an originator or terminator of traffic. As a consequence, assessing freight flows is impossible. While the regional rail carriers are in the waybill, there are no available financial and operational data that would allow a financial impact analysis such as the one constructed for the Class I rail industry and the four selected Class I carriers. Regional railroads are not required to file R-1 financial and operational data, which contain detailed revenue and cost information, with the Surface Transportation Board. These data compiled by the Association of American Railroads in the *Analysis of Class I Railroads, 1994* were an essential component to complete the analysis. However, due to the profile of divertable traffic found in the study and the connectivity of the rail network, one could infer that there are likely additional effects that were not assessed in the study because of resource constraints.

Comment: The LCVs Nationwide scenario overestimates the truck-to-truck diversion because it does not give adequate emphasis to the costs incurred by carriers in distributing freight from staging areas to final destination. Nor does it consider costs of changing fleets and the impact of driver shortages on operations.

DOT Response: Assumptions in the LCVs Nationwide Scenario are based on the development of efficient operations to move freight from staging areas to final destination. Such efficiency would not happen overnight, but would require some time to evolve. Brokerage services could match drivers with loads to minimize the time a trailer waits in the staging area before being delivered. All carriers might not be able to achieve such high levels of efficiency, but it must be assumed that staging area operations would develop that would be more efficient than current operations at turnpike staging areas that are lightly used compared to the extent of use predicted in the scenario. Changing fleets would be a gradual process, depending on the extent to which various carriers wished to enter and compete in the LCV market. No attempt was made to estimate effects of operational considerations such as driver shortages that would be difficult to predict for the future with reasonable certainty.

Comment: The estimated impact on U.S. railroads is consistent with the Canadian railroad experience following implementation of changes to TS&W policy in the provinces in the late

1980s. However, U.S. railroads believe the financial impact is underestimated .

DOT Response: The railroad financial analysis conducted in this study is a static analysis based upon research about the rail industry by industry experts. Because it is a static analysis, it is unable to evaluate the long term, dynamic response of the rail shippers to any rate increase designed to capture lost revenues. It is also unable to capture rail carriers' response to maintain access to the capital markets or to maintain return on investment (ROI). As the study states and as commenters noted, the industry may shrink their systems to return ROI to acceptable levels. Such shrinkage would cause the loss of rail service on marginal routes. Another scenario would see the carriers attempting to increase rates. Such increases would be followed by a further reduction in rail traffic as shippers move to more attractive truck rates. The study acknowledges these possibilities and the difficulties in assessing each. However, to move beyond the study's findings and quantify future second and third order results from different scenarios would be highly speculative.

Comment: The model needs to estimate diversion from truck-to-rail since the uniformity scenario would reduce truck weight limits, diversion of freight to rail could increase and the assertion that diversion is likely to be relatively minor is unsubstantiated.

DOT Response: Currently there are no reliable data for pricing the movement by rail of freight presently moved by truck as such pricing is largely market-determined or set strategically by the railroads. Future improvements to the model will include improved ability to estimate potential truck-to-rail diversion. Such shifts from highway to truck are likely to increase, regardless of whether changes in TS&W limits such as assumed in the Uniformity Scenario are made. Improved intermodal freight efficiency and increasing highway congestion will be important forces acting to shift freight traffic from truck to rail in some freight corridors.

Pavement Impacts

The condition and performance of highway pavements depend on many factors. The focus of this study was not on analyzing all factors associated with truck-pavement interactions, but rather to concentrate on factors most relevant to impacts of TS&W policy changes. While dynamic truck-pavement interaction has been the focus of considerable research in recent years, it was not considered in this study since the results are inconclusive where TS&W policy is concerned and the effects appear to be of secondary importance relative to static axle loads when considering impacts of TS&W policy changes.

Comment: The study analysis should include the effect of tire pressure and type, the effect of temperature (freeze/thaw), the influence of various distresses in rehabilitation, and the effects of mixing variables.

DOT Response: Tire pressure and type, climatic effects, and interactions among these and other factors are all important considerations in estimating pavement deterioration. They are not as important in estimating effects of changes in TS&W limits on pavement distress and pavement rehabilitation needs because these factors are independent of changes in TS&W limits. For instance, an implicit assumption in all scenarios analyzed for this study is that there would be no changes in tire pressures or tire type resulting from the scenarios. Since axle load limits are assumed to remain unchanged, interactions between axle load and some of the factors mentioned in the comment are no greater than under current TS&W laws. Temperature and other environmental factors are explicit variables in the pavement deterioration models used in the study. Thus any changes in traffic by environmental region are captured in the pavement analysis.

Comment: The use of the Highway Performance Management System (HPMS) data is problematic as it is inconsistently reported among the States.

DOT Response: While the Department recognizes that there are inconsistencies in the reporting of pavement data in the HPMS, the Department uses that database for several major policy studies such as the biennial report to Congress on the Conditions and Performance of the Nation's Highway and Transit Systems and the Federal Highway Cost Allocation Study. Considerable editing of pavement-related data in the HPMS database is done before the pavement analysis is conducted, and results are shown only at the national level. If the analysis were conducted at the State level and differences among the States were important issues, inconsistencies in reporting might be of more concern, but at the national level the HPMS database is the best source of nationwide pavement data available. The Federal Highway Administration recently completed a major review of the HPMS database with the active participation of many State representatives. Issues related to the consistency with which various data items are reported were addressed, and changes will be made to improve the accuracy and consistency of pavement and other data items.

Comment: The use of the National Pavement Cost Model (NAPCOM) in the analysis is questioned as it does not use the AASHTO fourth power law but rather an exponent which usually would be less than four, thereby producing more benign estimates of distress. For example, use of the AASHTO fourth power law produces more damaging effects for the use of tridem axles than the NAPCOM model.

DOT Response: The NAPCOM model considers 13 separate pavement distresses that are among the most important in decisions by States to rehabilitate or reconstruct pavements. These distresses are estimated using tools much more advanced than the empirical relationships developed for a single region of the country in the AASHO Road Test. In particular, they take into account material properties and the actual mechanisms by which pavement distresses develop under loads by single, tandem, and tridem axles. Each of the different distresses has a different relationship between axle load and pavement damage. While most relationships are below the fourth power relationship originally estimated from data from the AASHO Road Test, several distresses have more than a fourth power relationship. Recent statistical analyses of the original Road Test data have shown that the relationships between axle load and pavement damage found in the Road Test are closer to a third power than a fourth power relationship.

Bridge Impacts

The impact of a truck on a bridge varies, primarily by the weight on each group of axles on the truck and the distance (spacing) between axles and axle groups. The number of axles in each group is less important than the distance between adjacent groups. The study analyzed the impact on bridge structural requirements that could result from changes to TS&W limits.

Comment: A concern with the North American Trade scenario is the lack of a specified axle spacing for tridem axles. The negative impacts of shorter wheelbase straight trucks operating at higher weight limits could have significant impact on shorter span bridges. Providing exceptions to the Federal formula B severely hampers efforts for nationwide uniformity.

<u>DOT Response:</u> The analysis of tridem axles for the North American Trade Scenarios was based on a spacing of nine feet between the two outer axles of the tridem group, as discussed in Chapter V. At the 44,000 pound limit there would be no increase in bridge stress, however for the 51,000 pound limit there would be a considerable increase in bridge stress.

Comment: The use of strict replacement costs for bridges that rate deficient under the stress models is excessive and causes an overstatement of actual impact of heavier trucks and also results in overstatement of delay costs. The inclusion of user delay costs is questionable and adds a new element to the analysis.

<u>DOT Response:</u> The Department is aware that not all bridges identified as being structurally deficient would have to be immediately replaced before LCVs could be allowed to operate and that options other than replacement may be possible for some bridges. Research, in fact, is underway under the National Cooperative Highway Research Program to evaluate in more detail relationships between heavy trucks and bridges. That research will provide a basis for making some assessments of potential State responses other than replacement. Previous DOT and Transportation Research Board (TRB) studies have all made the same assumption as was made in this study that structurally deficient bridges would have to be replaced, and this is consistent with other assumptions in the report which attempt to set the upper range for potential impacts. User delay costs in and around work zones are very real costs to truckers and motorists alike when bridges are replaced, repaired, or reinforced and would be important considerations in making any improvements that might be necessitated by changes in TS&W limits. Likewise, the added air pollution caused by traffic congestion around work zones is a real cost, perhaps not to motorists, but certainly to those whose health is affected by air pollution. Whether or not user delay and air pollution costs should be included in any cost recovery systems that may be implemented to recoup additional costs associated with changes in TS&W limits is open to debate. Cost recovery mechanisms generally do not consider those costs at present.

Comment: Structural and bridge engineers have been moving away from a working stress method toward "reliability-based" procedures that more directly ensure structures provide a uniform level of safety, rather than tolerate a uniform level of stress—Load and Resistance Factor Design (LRFD). Software packages based on LRFD are almost non-existent at this time. The new procedures should at least be discussed within the study.

<u>DOT Response:</u> Indeed today, engineers design most bridges using the Load Factor

(LFD) or Load Resistance Factor Design (LRFD) methods. However, the analysis to determine whether or not a bridge is overstressed is not directly related to the design or rating method. The analysis compares the total (live load plus dead load) moment of the scenario vehicles to the total moment produced by the rating vehicle as reported in the National Bridge Inventory (NBI). The total moment, of course, is only a function of span length, dead load, axle loads and axle spacings. For example, if a bridge were designed by the old Working Stress Design (WSD) method to be an HS20 bridge, but its rating, for example, using the LRFD method is HS23, then the analysis compares the total moment of the scenario vehicles on each span of the bridge with the moment generated by an *HS23* vehicle.

Where the design method *does* affect the results is in the estimation of dead load. We computed dead loads based on designs using the WSD method. Since the NBI does *not* report the design method, WSD derived dead loads are the most appropriate to use since most *existing* bridges were designed using the WSD or similar method,

Roadway Geometry

The impact of changes to TS&W limits on highway geometry may require improvements to curves and intersections on the existing highway system to safely accommodate longer combination vehicles (LCVs). The relationship between vehicle turning characteristics and roadway geometry is incorporated into the analysis of illustrative scenarios by vehicle configuration and networks.

Comment: The assumptions used for determining the number and cost for staging areas are flawed. First, the construction of a staging area every 15.6 miles in rural States and areas is not necessary. In the western States LCVs have been operating safely without staging areas for 40 years and if there are costs included for the western States, they should not have been. Second, the cost per area in the study is extremely low based on experience of States— one State indicated the cost to construct one area ranged from $1.0 million to $10.8 million and the total cost for interchanges and staging areas in this State would be $1.5 billion. The nationwide total cost is given as only $4.5 billion for improvements and construction.

DOT Response: The LCVs assumed in the LCVs Nationwide Scenario are longer and heavier than those generally being operated in the Western States and there would be many more LCVs in the Western States under assumptions of the LCVs Nationwide Scenario than there are today. While some States might choose to allow vehicles with the dimensions assumed in this scenario to have limited access off Interstate Highways and other freeways, the assumption in this study was that scenario vehicles generally would not have access off the limited system of highways available for their use. The issue of spacing, costs, and need for staging areas is discussed in greater detail in the final report than in the draft. Also, assumptions used in estimating staging area costs were reviewed and costs were increased in the final report.

Comment: The sample size for the analysis of intersections and interchanges is too small to draw conclusions from. If the intersections can't handle the current trucks as stated, then how are the *trucks getting through ?*

DOT Response: While cost estimates for potential intersection and interchange improvements could have been refined with analysis of a larger sample, the Department did not believe that such a detailed analysis was justified for this study of purely illustrative scenarios. In practice, before LCVs or other longer vehicles were allowed to operate, most States would likely conduct a detailed assessment of the adequacy of intersections and interchanges to accommodate the specific types of vehicles that might be permitted if TS&W limits were changed. The Department believes the analysis of intersection and interchange improvement needs estimated with the limited sample used in this study adequately illustrates the nature and relative magnitude of the problem nationwide. Problems in specific States might be more or less severe than those estimated from the sample, but the Department believes the study presents an adequate assessment of the dimensions of the problem nationwide.

Comment: Premising an analysis of scenario offtracking on a model which permits offtracking right to the edge of shoulders, or to lane lines or centerline, is not a responsible approach. Likewise, the allowance for encroachment into one, same-direction lane for intersections and ramp terminals is unacceptable.

DOT Response: This comment calls for a standard higher than that used in practice today since many conventional tractor-semitrailer combinations cannot make turns at intersections without encroaching into adjacent lanes. To apply this higher standard for all traffic could result in significant costs to redesign and reconstruct interchanges and intersections. Assumptions simply reflect standard practice for vehicles in use today. Some jurisdictions might choose to apply higher standards to LCVs than to existing vehicles, but speculating what those standards would be and how widely they would be adopted was beyond the scope of this study.

Safety

Most studies on the safety of larger and heavier trucks, and whether allowing increases in TS&W limits would degrade safety, have taken one of two approaches to address the question: crash data analyses or comparative analyses of safety-related engineering performance characteristics of various truck configurations. Multiple factors contribute to truck crashes and isolating crash rates as a function of TS&W variables is difficult. There are, nevertheless, several key trends evident relative to truck safety, in general, and TS&W policy choices in particular. These trends are discussed in the study, however the analysis does not estimate crash rates for the LCVs analyzed in this study because those vehicles generally are larger and heavier than vehicles currently in use and because they are assumed to operate in much different environments than they currently operate in.

Comment: Citing the crash history of LCVs based on the western States experience would be misleading since the highway system characteristics are high quality, relatively low traffic density roads and do not reflect the likely result in urban areas with high volumes of traffic.

DOT Response: As noted above, the Department did not believe that the crash record of LCVs currently in use in the Western States and on Eastern turnpikes would be representative of LCV crash rates if vehicles were operated at the weights and dimensions assumed in the LCV Nationwide Scenario and on the nationwide network of highways assumed in that scenario, some of which are very heavily traveled.

Comment: The analysis fails to include important factors influencing truck crashes, such as truck maintenance and performance, effect of work zones and weather, driver performance and fatigue.

DOT Response: While these factors certainly affect crash rates, there was no basis for estimating the extent to which the effect of the factors would be different than the effect of those factors on crash rates of trucks in use today. The assumption is that maintenance and performance would be at least as good under the LCVs Nationwide Scenario as it is today. Work zones certainly would have to be designed differently than they are today to accommodate longer vehicles, but if that were done, it is not clear that the work zones would be any more of a problem than they are today. While companies operating LCVs today may use their best drivers to operate LCVs, if there were many more LCVs in operation, it would be difficult to maintain the same experience and skill levels as we have today. Uncertainties such as these are among the reasons the Department did not attempt to estimate specific crash rates for LCVs as they were assumed to be operated in this study.

Comment: Applying accident history based on previous years does not accurately depict the "real world" today. There appears to be a need for further study on the effects of TS&W changes to safety.

DOT Response: The report discusses the need for additional data and analysis of impacts of changes in TS&W limits on crash rates and other indicators of highway safety. However, there will always be some uncertainty about the relative safety of operating larger and heavier vehicles in environments in which they have not been allowed to operate before.

Comment: Problems of overtaking LCVs on two-lane highways, passenger car instability caused by LCV wind turbulence on all types of highways, and intimidation factor caused by the sheer size of LCVs should be discussed, as well as lower acceleration increases the potential for traffic conflicts on grades, when merging at freeway interchanges, and at many rail/highway grade crossing.

DOT Response: These and related issues are discussed in Volume II.

Comment: The decision-support capability goals of the study fails to be achieved without established crash rates for the vehicles analyzed, and an effort should be made to establish these. Additionally, DOT should fund an effort to collect the safety data necessary to produce reliable LCV crash rates for the types of highways these vehicles operate on routinely.

DOT Response: The Department agrees that having crash rates for each of the different types of vehicles would be desirable, but as discussed above, reliable crash rates could not be estimated for LCVs operating at the weights and dimensions and on the nationwide network assumed in this study. The study does present new information on the relative stability and control properties of various vehicle configurations that are important considerations in any decisions to allow longer and heavier vehicles. The scenarios analyzed in this study do not make specific assumptions about enforcement, permit systems, inspections, driver qualifications, or other regulatory measures that might be desirable in practice to promote the safe operation of larger and heavier vehicles. More detailed specifications of such safety regulations and how they would be enforced would allow safety implications of TS&W policy changes to be estimated with greater certainty. One comment expressed the opinion that in the "real world," regulation cannot guarantee the safety of inherently more risky vehicle types -- the Department agrees that if everything else is equal, an inherently more risky vehicle can be expected to have higher crash rates than less risky vehicles. However, if regulations are adequately enforced the risks can be reduced and better quantified so that improved decisions can be made.

Traffic Operations

Longer and heavier trucks generally disrupt traffic flow more than conventional trucks. The degree of disruption depends on the vehicle's length, turning radius, offtracking, and ability to accelerate. Characteristics of the highway also affect the impact of longer, heavier trucks on traffic flow. Impacts would be greater on heavily traveled highways with tight corners and curves, steep grades, and closely spaced interchanges, than on lightly traveled highways in flat terrain with good geometrics and few weaving and merging areas. Changes in delay, and associated costs or savings, resulting from changes in TS&W policies are projected for the five illustrative scenarios.

Comment: The distribution of highways by percent grade taken from HPMS is not representative of conditions in particular States. Some States have a much higher percentage of highways with steep grades that could cause added problems for heavier trucks that cannot accelerate as well as conventional trucks.

DOT Response: Analyzing highway characteristics on a State-by-State basis was beyond the scope of this study, and characteristics such as percent grade were not factors used in developing the illustrative networks analyzed in this study. An implicit assumption of the study is that if heavier vehicles were permitted under revised TS&W limits, those vehicles would be required to have engines powerful enough to maintain some minimum level of performance on grades. If TS&W changes were implemented, such factors would be important considerations in designating routes where specific types of vehicles would be allowed to travel.

Comment: The experience with LCVs has been in primarily rural areas, yet the network map for the LCV scenario includes extremely congested corridors, such as I-95. Extensive studies should be conducted in each urban area, such as the Baltimore-Washington area, before considering any changes. It may be helpful to compare congestion levels for areas with LCV experience to congested areas.

DOT Response: As with highway geometry discussed above, States would have to evaluate congestion levels and other traffic characteristics in designating networks that would be available for particular types of vehicles. Where possible routes that go around rather than through congested metropolitan areas were selected for the illustrative networks for this study, but the assumption that a continuous nationwide network serving major markets would be available for LCVs meant that some congested areas could not be avoided. These networks were purely illustrative and many more route-specific factors would have to be considered in practice in designating highways on which longer, heavier trucks could operate.

Comment: The effects of starting and stopping heavy loads are magnified in urban areas and the study PCE appear understated. The PCE used in the study are drawn from the latest version of the TRB Highway Capacity Manual which has repeatedly underestimated the congestion effects of heavy trucks. Understatement of this factor could significantly affect the results of the triples nationwide scenario of reduced congestion and delay costs.

<u>DOT Response:</u> The study assumes that heavier trucks would have more powerful engines, which currently are available on the market, such that their weight-to-horsepower ratios would be no worse than those of conventional tractor-semitrailers. As discussed in Chapter IX, the trend in engine selection today is toward more powerful engines. This is an important assumption since PCE are more sensitive to the weight-to-horsepower ratio than to the length of a truck. The study also assumes that a heavier truck would have more axles and that its braking ability would be no worse than vehicles in use today. The PCE used in this study were not from the TRB Highway Capacity Manual but were estimated using procedures that are now being used by a consultant who is revising the truck PCE portion of the Highway Capacity Manual. The Department believes that assumptions used in estimating PCE for different vehicle classes are based on both industry and State practices and that the PCE are not understated. Of course, under extreme conditions of grade or traffic congestion the average PCE used in this study would not apply, but it was not possible within the scope of this study to use different PCE values for each individual roadway section.

Energy and Environment

The study scenarios were evaluated in terms of 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-miles-of-travel—VMT). Other significant variables include vehicle weight, speed, and truck operational parameters.

Comment: The treatment of this highly complex area is so schematic that the discussion provided has almost no value. A long-term perspective is especially important to assessing the environmental impacts from pressure to build new highways and expand the current system to accommodate increased truck traffic, relocation of firms, changing shipping patterns, shifts in land use patterns and greater sprawl.

<u>DOT Response:</u> The Department agrees that a long term perspective is essential and that planners and decision makers must consider environmental consequences of public and private decisions related to freight transportation. Many of the factors cited in this comment, however, are not directly related to TS&W policy changes and thus were not explicitly evaluated in this study.

Comment: Given the extensive body of regulations covering emissions, mandated use of low sulfur fuels, CAR diesel in California, smoke testing *laws and regulations in several States, some correlation is being drawn on several fronts which contradicts the statement that little information exists.*

DOT Response: The Department worked closely with EPA in estimating the nationwide costs associated with highway-related air pollution for the *1997 Federal Highway Cost Allocation Study*. Nationwide models used by EPA include only a limited number of truck classes; all of the truck classes analyzed in this study are part of the same vehicle class in the EPA models. The Department will continue to work with EPA to develop relationships between truck transportation and air pollution costs. As new information is developed, it will be incorporated into future departmental TS&W studies.

Comment: The conclusion that there is no increase in VMT in the HR 551 analysis is incorrect. Even if the status quo is maintained, the increases in freight volume will mean that there will be increases in VMT and energy consumption and degradation of air quality.

DOT Response: All impacts estimated in this study are changes from the base case. The base case forecasts include increases in truck VMT associated with growth in the economy. The TS&W changes in H.R. 551 are not estimated to have a significant impact on base case VMT, energy consumption, or air quality.

Rail and Shipper Costs

The principal transportation modes for movement of intercity freight are motor carriers, railroads, barges, and pipelines. The bulk of intercity freight is transported by motor carriers and railroads, in both tonnage and revenue. Railroads transport more bulk traffic than trucks and compete with trucks for certain commodities and intermodal traffic. Changes in TS&W limits could have financial effects on the railroad industry and selected railroads resulting from changes to shipper choices in mode of transportation for goods. Shippers strive to minimize costs related to transportation and inventory. A change in TS&W regulations may directly alter a shipper's logistics costs associated with transportation and inventory.

Comment: There is a pro-rail bias in the study methodology which assumes rail productivity improvements are static. During the past decade there have been great improvements in rail productivity while truck productivity has been restrained. The study should also include a chapter on the effects of rail practices on truck operations to balance the discussion.

DOT Response: Chapter XI on rail impacts discusses the issue of rail productivity improvements and the fact that many rail analysts expect that significant future productivity improvements will require large infusions of additional capital. While some of those capital investments to improve productivity certainly can be expected, the nature and magnitude of future railroad productivity increases would be highly speculative. Except for changes in allowable vehicle weights and dimensions, no other productivity enhancements are estimated for the trucking industry either. While the analysis does not provide for railroads to improve productivity to respond to increased competition from changes in TS&W limits, it does assume railroad would lower prices all the way to variable cost if necessary to retain traffic. In practice they could not be expected to keep prices that low in the long run. This study is not intended to be a comprehensive assessment of truck-rail competition in the future, but rather is intended to show the full range of potential impacts of changes in Federal TS&W limits, including potential impacts on the railroads.

Comment: Four recent rail mergers might affect the outcome of the analysis and should be taken into account.

DOT Response: There is a discussion of the recent rail mergers in Chapter XI on rail impacts, and an explanation of why results of those mergers could not be considered explicitly in this study. As more information becomes available on long run effects of those mergers on costs and railroad efficiency, those factors can be considered in future departmental TS&W studies.

Comment: The shipper model assumes the only consideration for decision making is transportation cost. The true behavior of shippers has not been captured in the study. The time factor may be more important to shippers, depending on the commodity. Highly efficient manufacturing and distribution functions depend on close integration of all the elements of the supply chain, including transportation. Timely pickups and deliveries are important to efficiency in manufacturing and distribution. More discussion on shipper concerns should be included in the study to be commensurate with the importance of trucking productivity gains benefitting shippers and the national economy.

DOT Response: The TIC model does consider factors other than simple transportation cost. Time enters into the analysis in virtually every stage of movements from pickup and delivery to transfer times at intermodal terminals to average times for LCVs to assemble and disassemble at staging areas. Logistics considerations certainly would be important in decisions regarding whether to shift from conventional tractor-semitrailers to LCVs because of the additional time required to assemble and disassemble LCVs at both ends of the trip. The outreach process for this study included discussions with many different types of shippers which are documented in working papers developed for this study.

List of Commenters

State	Industry & Industry Associations
Connecticut DOT Florida DOT Georgia DOT Idaho DOT Illinois DOT Indiana DOT Iowa DOT Maine DOT Maryland DOT Michigan DOT Minnesota DOT Mississippi DOT Montana Lt. Governor Montana DOT Nevada DOT New Jersey DOT New York DOT Texas DOT Vermont DOT Wisconsin DOT	Association of American Railroads American Trucking Associations Distribution and LAL Carriers Association Mississippi Trucking Association Motor Freight Carriers Association Norfolk Southern Corporation National Automobile Transporters Association National Industrial Transportation League National Small Shipments Traffic Conference, Inc. Owner-Operator Independent Drivers Association, Inc. Railway Association of Canada Transystems **Other Interested Parties** Advocates for Highway and Auto Safety Coalition Against Bigger Trucks Insurance Institute for Highway Safety Western Highway Institute
Academia	**Private Citizens**
Montana State University	George Herndon Peter Samuel