FHWA Study Tour for Highway/Commercial Vehicle Interaction

INTERNATIONAL
TECHNOLOGY

FHWA's Scanning Program

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Study Tour for

HIGHWAY/COMMERCIAL VEHICLE INTERACTION: NORTH AMERICA AND EUROPE

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EXECUTIVE SUMMARY

Introduction

Under the sponsorship of the Federal Highway Administration (FHWA), a team of representatives from government, industry and the research community made scanning trips through North America and Europe to discuss and report on current practices, technologies, and knowledge of the highway/commercial vehicle interaction. The North American trip was conducted in September–October 1994 and the resulting consolidated view of current issues surrounding trucks and highways was given increased perspective by the European trip, which took place in April–May 1995. Both trips included visits with government agencies, vehicle and component manufacturers, carriers, research agencies, and academe.

The studies were coordinated by the Transportation Technology Evaluation Center (TTEC) of Loyola College in Baltimore, Maryland, under contract to the Office of International Programs of the Federal Highway Administration. The delegations were led by Byron Lord, Chief, Highway Infrastructure Applications Division, FHWA Office of Technology Applications.

The North American trip included the United States, Canada and Mexico. A wide range of views were sought concerning the technical, regulatory, and policy issues surrounding highway freight transportation and the interaction between heavy vehicles and highway systems, including pavements and bridges. Particular emphasis was placed upon the influence of heavy vehicles on infrastructure wear and on highway safety.

Many of the issues discussed are critical to the formulation of policies for managing infrastructure preservation and development, controlling the size and weight of heavy vehicles, and improving the productivity and safety of highway freight vehicles. There are also important implications for intermodal freight systems.

The European trip included meetings in France, the United Kingdom, Belgium, the Netherlands, Germany, and Sweden. These meetings included representatives of national agencies, universities, and private companies, as well as the European Commission (EC) and the European Council of Ministers of Transport (ECMT).

Background

The United States, along with its trading partners, recognizes the economic significance of efficient highway transportation and is seeking improvements in highway freight productivity, more efficient national and regional intermodal transportation systems, the reduction of congestion, maintenance of mobility, preservation of the environment, the enhancement of the national economy, and the improvement of vehicle and highway safety. From an international perspective, more efficient means of the transportation of intermodal containers is of great significance, and the compatibility of truck sizes and weights takes on added importance under the North American Free Trade Agreement (NAFTA).

Highway freight vehicles have been the subject of considerable policy debate for some time, particularly as the demand for freight transportation has increased dramatically over the past 20 years. The serviceability of highway infrastructure, increasing highway maintenance bills, the impacts of heavy vehicles on roads and bridges, and truck safety are all issues that have attracted attention. The matter of trucks and roads has proven to be, and remains, a complex and politically sensitive subject.

Technologies for improving the physical interaction between trucks, pavements, and bridges, along with advances in freight logistics, intermodalism, and Intelligent Transportation Systems (ITS), can make a major contribution to meeting expanding demand for road travel and higher user expectations for highway quality under conditions of shrinking highway budgets. New knowledge and technologies relating to the highway/commercial vehicle interaction have a potentially important role in reevaluating alternative size and weight policies and vehicle configurations.

These issues lie at the interface of many industrial, governmental, and technological sectors. To make the review manageable, this report concentrates on factors and issues that could improve the productivity, safety, and external impacts of freight transportation.

Goals and Objectives

The overall objective of the Scanning Tour of North America and Europe was to **scan current practices, innovations, policies, rules, and compliance to identify options and issues in highway/commercial vehicle interaction technology.** The goals of the team included the following:

1. Building and strengthening the **state of mutual understanding among components of the transportation technology system**; i.e., road users, carriers and shippers, vehicle manufacturers, road builders, and regulatory agencies.

2. Assisting the **evolution of technology and policy initiatives, and benchmarking of current North American technology**.

3. Documenting information on both current practices in truck-pavement design and on new and emerging technologies that have potential for immediate or long-term application for **extended pavement and bridge life**, while allowing for **increased productivity** in terms of the amount of goods transported.

4. Evaluating specific vehicle, vehicle component, and pavement and bridge design effects on **highway infrastructure and vehicle life cycle costs.**

5. Identifying **trends in vehicle design, vehicle components, truck controls and regulations, and truck operational characteristics** in the context of their influences on pavements and bridges.

6. Identifying implications of vehicle and highway technologies and policy options with regard **to vehicle safety performance and highway safety.**

7. Promoting the development and **implementation of promising technology in the United States.**

Conclusions

The scanning team's report identifies a wide range of issues that influence the productivity, safety, and external impacts of the US freight transportation system. These issues involve national transportation policies; changing truck technology; the design and condition of the nation's pavements and bridges; the compatibility, optimization, and enforcement of size and weight limits; reducing user costs; more adequate recovery of infrastructure costs; further improvement of highway safety; exploitation of intermodalism and Intelligent Transportation Systems (ITS); and organizational factors that make it difficult to sufficiently assemble broad-based technical and policy input for legislative activity affecting freight transportation. The list below is an overview of the team's findings and conclusions, which are detailed in Sections 3 and 4.

1. Vehicle Configuration and Road Friendliness

The configurations and components of heavy vehicles are determined by existing constraints. These constraints include regulations (including size and weight), driver operational limitations, safety, and infrastructure design standards. The condition of the infrastructure can also cause changes to vehicle configurations. In every case, the laws of physics play a significant role in the options available to the designers and builders of heavy vehicles. Differences in these constraints (e.g., regulations; infrastructure condition; geometrics on regional, national, and international levels) also have significant potential impact on productivity and efficiency.

A high degree of inventiveness and creativity exists within the heavy vehicle industry, which is, seeking to advance the productivity and efficiency of the fleet. In addition to advances in vehicle configuration and components, efforts to optimize productivity address development of intermodal relationships, permitted and special-purpose vehicles, and regulatory exceptions. The result has been a myriad of vehicle configurations serving regional and national markets.

Truck design can contribute to reducing pavement and bridge wear for given weights of load. The use of suspensions that distribute the weight efficiently among axles in multiaxle groups and reduce dynamic loading is expected to reduce pavement wear. Air suspensions generally have superior performance characteristics, not only for reducing dynamic pavement loading but also for truck stability and control performance. However, truck suspensions can only be expected to perform well up to specific tolerable levels of road roughness.

New designs of tires that may improve vehicle handling and economy often cause higher pavement contact stresses. These tires, with smaller diameters, low profiles, and high inflation pressures, appear to be creating problems for road wear and lateral dynamic stability.

Further research is needed to quantify the effects of dynamic loading and its spatial repeatability on pavement wear, provide reliable means of assessing vehicles for road-friendliness, and better describe the tire/road interface.

While not entirely clear regarding the benefits of certain measures aimed at road friendliness, several countries have introduced such measures/incentives, through weight increases or fee reductions, in order to encourage innovative technological applications.

2. Global Competitiveness

Global trade and competitiveness have placed increased pressure on advancing transport efficiency and productivity. Containerized cargo has become particularly significant in intermodal transport, both for improved cargo security as well as opportunities for improved efficiency.

In Europe, vehicles involved in hauling containers in combined transport are permitted an increase in gross weight from 40 tonnes (88,100 lb) to 44 tonnes (96,900 lb). This concession, designed to promote intermodal transport, has been in place since the 1980s and has been retained in the most recent round of European Commission deliberations on size and weight limits.

3. Vehicle Performance Standards

A significant body of knowledge exists regarding vehicle performance, design, and configuration. This knowledge is quite advanced in its comprehension of the relevant variables, sciences, and effects; and offers significant opportunities to develop performance-based standards for heavy vehicles.

4. Enforcement

Levels of regulation and standards enforcement vary significantly among the countries visited. Enforcement or the lack of it significantly influences levels of compliance. While this may be intuitively obvious, it was made clear to the study team in both North America and Europe. ITS developments are likely to provide significant benefits in future heavy-vehicle permitting, monitoring, cost recovery, and enforcement.

5. Safety

Heavy vehicle safety continues to be a significant issue in every country visited. The need to quantify safety effects and causes continues to elude researchers and regulators. Accident-reporting systems do not contain sufficiently detailed, vehicle-specific information to isolate causes or to develop recommendations to prevent future occurrences. Additionally, the statistical infrequency of heavy vehicle accidents complicates this issue. In response to this problem, several countries are developing performance standards based on engineering standards to increase vehicular and infrastructure safety.

Size and weight limits have a profound effect on vehicle configuration and, hence, engineering performance. Vehicle engineering performance, exposure, and size have a pervasive but indirect influence on safety. Because this effect is interactive, it is difficult to isolate it with accident data.

Determination of this effect is also made more difficult by drivers' efforts to compensate for poor vehicle performance.

While larger and heavier vehicles are not necessarily less safe, it is vital that appropriate engineering performance standards continue to be met and that the better-performing vehicle configurations are encouraged.

Research is needed to achieve the following results:

- Determine clearer correlations between engineering performance of heavy vehicles and accident risks.

- Determine appropriate performance standards to apply to various classes of heavy vehicles.

- Develop improved accident databases to identify the engineering characteristics of trucks involved in crashes.

- Develop and implement innovative means of improving safety through truck design, including measures to improve both active and passive safety.

6. Comprehensive Freight Policy

A comprehensive national freight policy was recognized by the panel as essential to the development of integrated multi/intermodal transport efficiency. It was recognized there was a general lack of national freight policy direction in nearly every country visited. Effective truck size and weight policy cannot be developed outside the context of national freight policy.

7. Infrastructure Investment and Cost Recovery

Improved highway design and maintenance standards can contribute to reducing truck user costs and to improving productivity. Pavements designed and maintained to interface with the new generation of vehicle technology developments would allow the potential economic and performance benefits to be realized. Stronger, smoother pavements can lead to improved highway/commercial vehicle interaction.

Across the spectrum of the countries visited, a need for significant additional investment in highway infrastructure was identified. These investments were projected to meet the need to preserve and restore existing facilities, as well as to expand facilities to provide access to intermodal and other key links. In every case the resources needed exceeded the revenue streams currently available. The economic and financial benefits of increased transport productivity can be substantial; however, it is necessary to formulate fair and equitable cost-recovery mechanisms to sustained infrastructure service.

Panel Recommendations

The panel developed and prioritized recommendations based on findings and conclusions from both the North American and European scanning tours. The recommendations are presented in three categories: high-priority items to immediately advance toward implementation; medium-priority recommendations that should be further pursued in the intermediate term; lower-priority, but important, recommendations that deserve further study or research.

The following are high-priority recommendations of the Highway/Commercial Vehicle Interaction Panel:

1. Technologies for Transfer to The United States

The following technologies are recommended for evaluation for transfer to the United States and consideration for future implementation.

Distill conclusions on the viability of "road-friendly" truck components for implementation in United States size and weight regulations with particular focus on the following components:

- Review suspension systems (particularly air suspensions or equivalent) for truck and infrastructure friendliness. Evaluate benefits and limitations for US application and appropriate implementation mechanisms.
- Evaluate the advantages and disadvantages of wide, single-based tires for heavy trucks.
- Consider implementation of load sensitive, automatically deploying lift axles to replace existing manual lift axles (consider phaseout of existing lift axles).

2. Expanded Leadership

FHWA and AASHTO (American Association of State Highway Transportation Officials), as regulators and operators of highway infrastructure, should provide the national leadership necessary to make the freight transport system more efficient, including the development of a continuing, cooperative working relationship with public and private stakeholders to address inefficiencies in the nation's freight transportation system and to promote appropriate solutions.

3. Comprehensive Freight Policy

Develop a comprehensive national freight policy that includes the following factors:

- Safety.
- Infrastructure.
- Modal efficiency.

- Truck size and weight policy.
- Taxation.
- Intermodal movement (especially containers).
- International competitiveness.
- Environment.

As part of current Federal efforts and in cooperation with customers and stake-holders, any size and weight changes should be accompanied by provisions for the following:

- Bridge stress, pavement, and capacity consumption.
- Vehicle performance (including tire parameters).
- Safety enhancements.
- Cost recovery by permit to agencies incurring costs.
- Elimination of ratcheting.
- Access control by States.
- Interstate/international compatibility (including better LCVs).
- Rationalization of fee structures, including permit fees reflecting intensity and extent of use.
- Controlled rail diversion.

The following medium-priority recommendations are supported for consideration in the intermediate term:

4. Performance Standards

A performance-standards approach to size and weight regulations should be seriously considered. Performance standards should address acceptable vehicle operations and include consideration of safety and infrastructure impacts. Highway performance standards related to pavement design and rehabilitation should consider a truck-related pavement condition index and tire parameters. Implementation feasibility should be reviewed including institutional factors.

5. Cost Recovery

Existing cost allocation procedures for trucks should be benchmarked, and a rational procedure for cost recovery under any revised size and weight limits should be established. Appropriate charges for the operation of high-productivity vehicles should be established. States should have a size and weight permit review process to assess impacts on pavements and bridges and should assure appropriate cost recovery to the agencies incurring the costs.

6. Possible Short-Term Changes to Accommodate Intermodal Containers

In the interest of international compatibility of intermodal containers, consideration should be given to a specific change of US size and weight regulations for containers on tridem axle semitrailers, at appropriate gross vehicle weight (GVW) above 80,000 lbs.

7. Re-assessment of Bridge Formula

Existing Bridge Formula "B" should be reassessed with the intention of providing a more appropriate control on bridge stress, if possible. Any proposed change in truck size and weight limits should be screened to ensure compatibility with an appropriate bridge formula, the ratings of existing bridges, and bridge design standards.

8. Envelope of Allowable Vehicle Configurations

If performance standards appear feasible, policymakers should consider development of envelopes of allowable vehicle configurations for designated systems and subsystems, based on engineering and safety performance of both vehicles and infrastructure.

9. Enhanced Truck Accident Data

A national system should be developed to identify and evaluate all accidents involving large trucks. Such a system should include an improved accident/VMT (vehicle miles traveled) recording system sensitive to vehicle type, configuration, and design.

The following lower-priority but important recommendations are also supported for further study and research:

10. Researching "Road-Friendly" Vehicles

Truck and infrastructure research should be expanded to resolve questions concerning the extent of potential benefits to pavements and bridges of "road-friendly" vehicles.

The possibility of differential weight limits or fee schedules for "road-friendly" suspensions should be further explored. The issue of the maintenance of "road-friendly" suspensions should be further explored, especially the means of ensuring the maintenance of damping characteristics over time.

11. More Effective Enforcement

More effective deterrence from overloading should be provided in enforcement programs. The programs should include the factors listed below.

- An escalating fine structure with stiffer penalties for greater degrees of overload and repeat offenders.

- Education of judicial branches at all levels concerning the consequences of overloading for the infrastructure.
- Effective judicial enforcement.
- Application of ITS technology.

12. Standards for International Containers

More effective means of establishing and maintaining standards for the size and weight of international containers should be explored.

13. Public Education

A public education program should be developed to address heavy vehicle size and weight issues, particularly with respect to safety, intermodalism, and environmental issues.

1. INTRODUCTION

This report summarizes the findings, perceptions, and assessments of a study team, assembled under the FHWA International Technology Scanning Program and charged with scanning current practices, technologies, and knowledge of Highway/ Commercial Vehicle Interaction in North America (United States, Canada, and Mexico) and in Europe. The study team adopted a broad definition of the term "highway" and sought information concerning the total infrastructure (including pavements and bridges) as it relates with commercial vehicles.

In recent years, the United States and its trading partners have increasingly recognized the economic significance of efficient highway transportation and have sought major improvements in highway freight productivity. Deeper understanding of the physical interaction between trucks, pavements, and bridges can make a major contribution to meeting expanding demand for road travel and higher user expectations for highway quality under conditions of shrinking highway budgets. Other opportunities to bring about improved highway freight productivity lie in freight logistics, intermodalism, and Intelligent Transportation Systems (ITS).

Heavy freight vehicles have been the subject of considerable policy debate for some time, particularly as the demand for freight transportation has increased dramatically over the past 20 years. The following major issues have attracted attention: freight productivity, the serviceability of highway infrastructure, increasing highway maintenance costs, the impacts of heavy vehicles on roads and bridges, and truck safety. A considerable amount of research on these issues has been carried out and has contributed to policies that have been developed in the areas of size and weight limits, highway cost allocation, and cost recovery for highway infrastructure. The matter of trucks and roads remains a very complex and highly sensitive subject.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 clearly focused on the development of more efficient national and regional intermodal transportation systems, reduction of congestion, maintenance of mobility, preservation of the environment, enhancement of the national economy, and improvement of vehicle and highway safety. From an international perspective, more efficient means of transporting intermodal containers is of great significance, and the compatibility of truck sizes and weights takes on added importance under the North American Free Trade Agreement (NAFTA). New knowledge and technologies relating to highway/commercial vehicle interaction have potentially important roles in reevaluating alternative size and weight policies and vehicle configurations.

1.1 Task and Scope

The Highway/Commercial Vehicle Scanning Review covered technical issues and policy options of the highway/commercial vehicle interaction and sought input from the public and private sectors, the highway and vehicle communities, and from scientists.

The review included current issues and practices and future options for change, including the following:

- Accumulating data on interactions and relationships between vehicles and highways.

- Scanning of current practices, as well as new innovations being introduced, including policies, rules, organization, enforcement, and technology.

- Identifying options for the future, as well as any issues surrounding such options, for improving system productivity.

All of the technical issues and policy options considered involve trucks, their effects, and their interactions with other system elements. This review is concerned only with trucks of an allowable maximum gross weight of approximately 11,800 kg (26,000 lb) and upwards.

From the infrastructure point of view, there is no distinction among axle loads caused by (i) trucks carrying divisible loads (or freight); (ii) containers or non-divisible loads, such as machinery; (iii) special-purpose vehicles; and (iv) passenger vehicles (buses and coaches). Vehicles and their loads could have unlimited access to the road system, or could be restricted to Interstates, restricted to States or regions or restricted to routes. In this report, the words "truck," "commercial vehicle" or "heavy vehicle" are used in an interchangeable manner to denote all classes of vehicles that the review addressed.

The review included many components and attributes of the transportation system and the vehicles using it, as well as a number of disciplines in the technical and administrative spheres. This report concentrates on areas in which changes are taking place, or could take place, rather than fully documenting the status quo, which was not the purpose of the review.

The study team conducted investigations in North America and in Europe. Phase I of the scanning tour took place in September–October 1994 and included meetings and site visits in a number of key locations in the United States, including the Eastern and Western seaboards, the Midwest, Canada and Mexico. Phase II of the scanning tour took place in April–May 1995, when participants traveled to Europe and conducted meetings and site visits in France, the United Kingdom, Belgium, the Netherlands, Germany, and Sweden.

1.2 Objectives

As the subject of the scanning tour is both technically complex and politically sensitive, the study team gave careful consideration to specifying its overall objective. The Objective Statement adopted by the study team was

"Scan current practices, innovations, policies, rules, and compliance to identify options and issues in highway/commercial vehicle interaction technology."

The goals of the technology scanning review were as follows:

- Building and strengthening the state of understanding among individuals in the transportation technology system: road users, carriers and shippers, vehicle manufacturers, road builders, and regulatory agencies.

- Contributing to the evolution of technology and policy initiatives and to the benchmarking of current North American technology.

The study team set out specifically to

- Document information on both current practices in truck-pavement design and on new and emerging technologies that have potential for immediate or long-term application to extended pavement and bridge life which, at the same time, allow for increased productivity in terms of the amount of goods transported.

- Evaluate specific vehicle, vehicle component, and pavement and bridge designs affecting highway infrastructure and vehicle life cycle costs.

- Identify trends in vehicle design, vehicle components, truck controls and regulations, and truck operational characteristics that have impact on pavements and bridges.

- Seek out information on the implications of vehicle and highway technologies and policy options with regard to vehicle safety performance and highway safety.

- Promote the development and implementation of promising technology.

- Promote synergism, research cooperation and communication to support greater understanding of policy options.

1.3 Primary Issues

The scanning review concentrated on two main issues as they relate to highway freight productivity—consumption of highways in relation to truck use and safety performance of larger and/or heavier trucks.

1.3.1 Highway Consumption

The use of highways, including pavements and bridges, by trucks leads to a certain amount of wear and tear on the infrastructure, which is variously referred to as "damage," "wear" or "fatigue." Trucks are heavy enough to cause a minute but quantifiable and cumulative loss of serviceability, premature onset of maintenance requirements, or reduction in remaining service of pavements and bridges. The nature of these effects on pavements is usually different from effects on bridges, and the term "highway consumption" is taken to encompass wear of both components of the infrastructure. The study team sought an independent understanding of the mechanisms of wear applying to pavements and bridges.

The study group was interested not only in the effects of truck wheel loads, or axle loads, but also in the extent of other lesser-known influences such as vehicle design, pavement design, pavement deterioration and maintenance (including the effect of the surface roughness), and vehicle operation (including speed of travel).

The team also quickly discovered that the conventional picture of the truck "damaging" the road is viewed differently in some quarters and that the effects of deteriorated road surfaces and "roughness" on truck operational costs and freight damage also needed to be considered in the scanning review. This introduced the concept of "road-friendliness" which addresses the vehicle and its response as well as the pavement surface and how it affects vehicle dynamics.

1.3.2 Truck Safety Performance

The presence of trucks in highway traffic means that trucks are involved in incidents and accidents (or crashes) that harm road users or damage property. Such incidents may also cause significant traffic disruption. Accident consequences are of particular concern in the formulation of transport policy because of the sheer size and weight of trucks, because they may be carrying hazardous materials, because they are using the nation's roads (or sometimes another nation's roads) for commercial gain, and because the consequences are often borne by other road users—car occupants, motorcyclists, bicyclists, and pedestrians. Significant consequences are also involved for truck drivers and damage to trucks and freight.

The study group learned that causes of truck accidents are often a complex chain of events and that the characteristics of the trucks themselves are only one source of contributory influence in crash causation. Nevertheless, the study focused on the safety performance of larger and heavier trucks on the highway system.

The study group was especially interested in data, experiences, and perceptions relating to the above aspects of truck safety performance. Commercial vehicle safety performance could be evaluated directly, based on accident statistics, or indirectly, by considering certain measures of engineering performance of trucks.

1.4 Questions Raised

The study team developed a list of key questions for pre-circulation to all participants. This list included questions and issues spanning the subject areas listed below and is reproduced in Appendix A.

- Safety.
- Pavements.
- Bridges.
- Commercial motor vehicles.
- Truck size and weight policy.
- Truck size and weight compliance and enforcement.

1.5 Panel Process and Activities

The review group determined that work is being carried out by many parties and this meant that a study tour would be an effective means of collecting and evaluating information and experiences. The tour allowed the team to obtain firsthand information from the most appropriate and expert sources, to work as a team, and to develop an interdisciplinary and common understanding of many issues.

Wherever possible, day-long meetings were arranged at strategic locations, allowing information to be presented comprehensively, questions to be asked, and group debate to take place. The team leader, Mr. Byron Lord, initiated the proceedings at each meeting and emphasized the following:

- FHWA recognizes the needs of the highways customer.
- FHWA is pursuing research not just into highways and trucks, but also into their interaction.
- The goals are to bring about safer, more productive service from the highway system and to provide this high level of service for many years.
- Innovative ideas, tomorrow's technology, benchmarking, and best practice are all important to the scanning review, but things that don't work are also of interest.
- The findings of the scanning review could be used to make a difference and, therefore, the information contained in this report should be effectively disseminated.

1.5.1 Study Team

The members of the study team were:

Byron Lord (Team Leader)	FHWA
Peter Sweatman (Report Writer)	Roaduser Research International
James L. Brown	Pavement Consultant
Phil Blow	FHWA (North America only)
Robert Clarke	NHTSA (North America only)
Bill Kenis	FHWA
Farrel Krall	Navistar International Transportation, representing SAE
Gary Maring	FHWA (Europe only)
Brian McWaters	Iowa Department of Transportation, representing AASHTO
Gustavo Manzo	Ministry of Communications & Transportation, Mexico (North America only)
Alberto Mendoza	Instituto Mexicano del Transporte (North America only)

Gedeon Picher	Maine Department of Transportation, representing AASHTO
Francisco Ruz-Villamil	Ministry of Communications & Transportation, Mexico (North America only)
Mike Ryan	Pennsylvania DOT, representing AASHTO (Europe only)

1.5.2 Meetings, Visits, and Participants

1.5.2.1 North American Tour

Meetings were hosted by the following organizations:

Government Agencies
FHWA, Turner-Fairbank Highway Research Center
National Research Council of Canada (NRC)
Secretariat of Communications and Transportation of Mexico

Private Sector
Edward C. Levy Company
Freightliner
Navistar International Transportation Technical Center
PACCAR International Technical Center
Silver Eagle
United Parcel Service

Universities
University of Michigan Transportation Research Institute
University of Washington

The following site visits were also conducted:

- Freightliner plant and test facilities, Portland, OR
- Navistar plant and technical center, Fort Wayne, IN
- PACCAR test facilities, Mount Vernon, WA
- Silver Eagle dolly plant, Portland, OR
- Edward C. Levy aggregate plant and vehicle fleet, Dearborn, MI
- highway reconstruction site, Lansing, MI
- highway travel, Dearborn, MI to Fort Wayne, IN
- Silver Eagle terminal, Portland, OR (including LCV triple trailers and C-dollies)
- UPS facility, Portland, OR
- NRC laboratories, Ottawa, Ontario, Canada
- toll roads, highways, and highway construction near Mexico City

Participants in the above scanning review meetings and visits included representatives of the following organizations:

Government Agencies
American Association of State Highway and Transportation Officials (AASHTO)
British Columbia Ministry of Transportation and Highways
Department of Agriculture Forest Service
FHWA, Transportation Studies Division
Indiana Department of Transportation
Instituto Mexicano del Transporte (IMT)
Mexican Department of Toll Roads and Bridges (CAPUFE)
Michigan Department of Transportation
National Highway Traffic Safety Administration (NHTSA)
Ontario Ministry of Transportation
Oregon Department of Transportation
Pennsylvania Department of Transportation
Washington State Department of Transportation

Private Sector
American Trucking Associations (ATA)
DINA Trucking
ICA
Independent Trailer, Inc.
Insurance Council of British Columbia
Mexican Association of Private Toll Roads (AMICO)
Mexican Chamber of Heavy Duty Transport (CANACAR)
Ortech Corporation
Trimac Transportation Services

Universities
Michigan State University
Oregon State University
University of Manitoba
University of Michigan
University of Washington
Washington State University

The names of all North American participants are given in Appendix B.

1.5.2.2 European Tour

Meetings were hosted by the following organizations:

Government Agencies
Commission of the European Union, Directorate General VII
European Conference of Ministers of Transport (ECMT)

Private Sector
BPW
Eurotunnel
Michelin
Port of Rotterdam
Volvo Truck Corporation

Universities
University of Cambridge
University of Hannover

The following site visits were also conducted.

- BPW axle-production plant, Wiehl, Germany
- Eurotunnel terminal facilities, Calais, France
- Michelin test track and technical center, Clermont-Ferrand, France
- Port of Rotterdam container facilities (ECT Delta Terminal), Rotterdam, the Netherlands
- Volvo plant and technical center, Gothenberg, Sweden

Participants in the above scanning review meetings and visits included representatives of the following organizations:

Government Agencies
Commission of the European Union, Directorate General VII
European Conference of Ministers of Transport (ECMT)
Laboratory for Roads and Bridges (LCPC), France
Organization for Economic Cooperation and Development (OECD)
Swedish National Road Administration
Swedish Road and Transport Research Institute (VTI)

Private Sector
BPW Bergische Achsen, Germany
Eurotunnel, France
Freight Transport Association, United Kingdom
Michelin, France
Michelin, US

SCETAUROUTE, France
VWB AKERI AB (carrier), Sweden
Volvo Truck Corporation

Universities
University of Cambridge
University of Hannover

The names of all European participants are given in Appendix C.

1.5.3 Itinerary

1.5.3.1 North America

The North American Scanning Tour was conducted September 24 to October 8, 1994, and included meetings and visits in the following cities of the United States, Canada, and Mexico:

Washington, DC
Ottawa, Ontario, Canada
Ann Arbor, MI
Fort Wayne, IN
Seattle, WA
Portland, OR
Mexico City, DF, Mexico.

1.5.3.2 Europe

The European Scanning Tour was conducted from April 25 to May 9, 1995, and included meeting and visits in the following European locations:

Clermont-Ferrand, France
Calais, France
Cambridge, The United Kingdom
Brussels, Belgium
Rotterdam, The Netherlands
Hannover, Germany
Wiehl, Germany
Gothenburg, Sweden

2. IDENTIFICATION OF ISSUES

2.1 Freight Transportation Policy Environment

Introductory Note: The information presented in this chapter represents material collected by the panel from a multiplicity of sources. It is presented to highlight issues and concerns that were identified.

2.1.1 North American Transportation Imperatives

The study group's issues and findings are highly significant because the movement of people and delivery of services and goods is a cornerstone of the US marketing economy. Demand continues to increase rapidly, and by the year 2000, total truck miles are projected by the American Trucking Association to have grown 25 percent from current levels, even if intermodal freight doubles. Intermodal transportation is increasing, and market forces are causing historical adversaries to work together to increase competitive opportunity.

Rapid changes in many aspects of US transportation are converging to influence the way trucks conduct business, affect highways, and affect road users. These changes not only affect the way truck transportation actually occurs, but also the way it is perceived.

Transportation logistics patterns are changing dramatically, serving the specific needs of the individual farmer, miner, and consumer, the decisions of the manufacturer, supplier, freight shipper, carrier, and retailer. There is no single set of size and weight limits, no single trend, and no single solution to current problems, and there is a need to be specific when describing and analyzing changes. It is important to differentiate between trucking segments—those limited by weight and those limited by volume (or "cube")—and to distinguish among vehicle configurations, such as tractor-semi-trailers, doubles, and triples. Similarly, it may be necessary to distinguish among different highway classes, pavement structural strengths, bridge designs, routes, and networks.

Transportation needs are ultimately driven by the economy—individuals' demands for employment, prosperity, safety, and quality of life. What does the highway/truck interaction mean to the economy? What does it mean to safety? What does it mean to traffic flow? These relationships are not well known and perceptions may be far from reality, and available highway funds are inadequate to meet demands. Truck accidents, while the number per vehicle mile traveled (VMT) continues to decrease, are in the news, and congestion is increasing.

Truck size and weight policy attempts to address these problems and to provide a balance for all competing interests. Optimum size and weight policy should encourage efficient, safe, and productive transport, while minimizing total transport cost and environmental impact. It preserves or enhances safety. It provides for cost recovery to agencies incurring costs. It promotes seamless transport of freight and containers with a minimum of handling. It encourages multimodalism and intermodalism. It meets the needs of industry, suppliers, carriers, customers, and the general public. Its attainment is elusive but worthy of pursuit, because of the magnitude of the impact of transportation across all facets of the economy. Relatively small positive changes can result in large savings to the public. Likewise, small unnecessary inefficiencies can result in very large avoidable costs and a burden the United States does not need in this time of scarce resources.

In further refining size and weight and other regulatory policies, there are some significant challenges to be met, some of which are listed below.

- Traditional concepts and perceptions of engineering disciplines (vehicles, pavements, bridges, etc.) need to incorporate evolving technologies and research.

- Jurisdictional boundaries among states and countries need to be bridged.

- Increased dialogue between the trucking and highway communities is needed. This is made more challenging by the diversity of the trucking industry and the large number of representative bodies and associations that need to be considered. There is also diversity in the highway community, with important roles played by state and local governments, as well as the Federal Government.

- Expectations must be realistic. Vehicle performance changes will not normally make dramatic shifts in accidents and road-friendliness. Positive incremental changes should be implemented over a long-term basis. ("Road-friendliness" relates to features incorporated into vehicles that decrease damaging impacts on pavements; e.g., air suspensions.)

- Development of technical answers, taking into account policy implications and a workable policy framework.

In this convergence of events further shaping the US transportation system, truck/highway interaction relationships may offer some promising solutions.

2.1.2 Trends and Issues in European Freight Transportation

Freight transportation in Europe has experienced rapid growth, total tonne/km having increased by 140 percent over the past 25 years; passenger transport has also seen a similar growth. Trends have not been uniform across Europe because transportation in the former Eastern bloc countries has actually decreased since 1989—transport efficiencies have accompanied political changes.

Industrial change and relocation of industries, plus other natural advantages of flexibility and responsiveness, have led to increased use of roads over rails. Price is no longer the only issue; service and just-in-time transport favor the road transport mode, despite policies and initiatives designed to improve the performance and usage of rail transport and government subsidies for railways. Rail capacity in Europe is limited and its performance has been affected by its public-sector ownership, in contrast to the US tradition of rail ownership in the private sector. The situation in Europe contrasts with the US situation in which deregulation and other factors have led to some gains in rail share and to increased intermodal transport. European Commission Directive 1991-440, addressing the separation of rail infrastructure and rail operations, with free access available to operators, remains a controversial issue. European freight transport is still heavily regulated among EU and other countries, and with bilateral agreements between countries. It has been estimated that in Europe a modal switch from road to rail of one year's transport growth would require a 50 percent increase in rail capacity.

Over the past 25 years, road safety in Europe has improved in absolute terms, but the rate of improvement has slowed over the past 10 years.

At the present time, traffic congestion, the environment, energy, and sustainable mobility are major issues in Europe. Three-hundred-kilometer traffic backups occur in Germany and local opposition to truck traffic in trans-Alpine areas and urban restrictions on truck movements occurs in many places. On major routes, the percentage of trucks is typically at 30 percent, with up to 50 percent in some corridors. At the same time, some research is being done to examine the positive external (i.e., employment, competitiveness) effects of transport. It is believed that the positive social effects of transport could be identified in economic terms.

The European Commission is coordinating the development of an integrated transport network linking all modes in the form of the Trans-European Network. However, there is limited funding at the European level, and the plan mainly acts as a strategic aid to national road construction and linking.

There is a general tendency in Europe to require users to pay for roads, which has led to increased use of tolls. Germany has traditionally not embraced tolls, and France has tolls for interurban, rather than urban, roads.

In Germany, the current modal split is 20 percent freight by rail, 20 percent by water, and 60 percent by road. Truck transport is the fastest-growing sector, partly due to the opening of the border to eastern Germany. Germany is currently investing approximately the same amount of funding in road and rail infrastructure, and there are currently about nine different rail projects linking east and west and about seven major road projects. First priority was given to improving passenger traffic, but projects are also included to assist freight traffic. The railways are now a public corporation, with both passengers and freight in one company. High-speed rail projects are being developed for passenger movement, which has freed up infrastructure for freight movement, including fast container trains.

2.2 Truck Evolution

2.2.1 Truck Market

North America

The U.S. truck-manufacturing industry is highly cyclical and tied to the economy. Some manufacturers are experiencing phenomenal growth and truck sales are at an all-time high. Manufacturers are running at peak production, and there is a backlog of orders.

Manufacturers of tractors and trucks tend to be globally organized, while trailer markets tend to be confined to a particular country. In the case of trucks towing trailers, or combination vehicles, the "truck" becomes functional only when the truck/tractor and trailer(s) are connected. The performance of the combination vehicle tends to be dominated by the trailer(s).

Many aspects of truck engineering are determined by customer needs, including those of shippers, carriers, and drivers. However, the single most powerful influence shaping today's truck configurations is size and weight policy.

Mexico also has a cyclical truck market for straight trucks over 11,350 kg (25,000 lb). The market peaked in the early 1980s and experienced another significant increase in sales in 1992–93, due to increased international trade. However, there was a significant decline in the market in 1994, coupled with an increase in the number of imported vehicles.

Even though Mexican sales of tractors have increased overall, they are still cyclical. The Mexican industry is developing rapidly, and new engine plants have been built as ventures with Freightliner, Volvo, and Scania.

In Mexico, there are 25 trailer plants, mostly Mexican-owned, which supply the domestic market and which also export to parts of Latin America and Africa.

Europe

The major truck manufacturers are engaged in global partnerships with strong European and North American involvement. The world market, of which the United States represents the largest component, experienced a trough in 1992, but sales of heavy trucks (with GVW of 16 t (35,000 lb) or more) are currently at an all-time high.

In order to reduce development and production costs, there is a trend toward reducing the time from major expenditure to marketing of new truck models from the current five years to three years; the comparable time period for new models of passenger cars is two years.

In Europe there was a perception that the profit margin on truck sales in the United States is small, due to a high level of competition and to deregulation of the transport industry.

In Europe, truck manufacturers control the specifications of trucks and components to a much higher degree and fewer trucks are custom-built. Another contrast in truck manufacturing is that European manufacturers tend to be vertically integrated, as distinct from horizontal integration in the United States. In the United States, component manufacturers have significant direct interaction with customers; in Europe, vehicle manufacturers tend to interact with the customer and design components together with customers.

2.2.2 Truck Design

North America

Truck manufacturers place a strong emphasis on vehicle performance quality, durability, reliability, and product cycle time. Highly developed analytical capability reduces product development time and in-service failures. Truck manufacturers are quick to implement new technologies and to react to customers' needs. Examples of significant new technologies are electronics/ ITS and road simulators. Road simulators can reproduce highway profiles (or roughness), which are used to determine ride quality, component durability, and performance life—all in the laboratory.

Highway roughness is a significant factor in truck design for durability, and manufacturers are able to predict relative damage to truck components in different countries, as dependent on road roughness. On the other hand, trailer manufacturers produce one model for various road conditions. Trailers tend to be built with a strong structure, but accessory components may have maintenance problems on rough roads.

Driver retention has become a significant issue for carriers and this has led to more comfortable and convenient trucks. Features of these vehicles include roomy cabs, integral "conventional" sleepers, and use of air suspension for the vehicle, cab, and seat.

Of course, trucks and trailers must be manufactured to meet safety and environmental standards and a well-established regulatory process is in place to bring this about for new vehicles. The enforcement of standards for in-service and for older vehicles is a more difficult issue.

With regard to the truck/highway interaction, the following new technologies being used in tractors are of significance:

- Air suspensions.
- Higher-pressure tires.
- Improved driver field of view.
- Antilock brake system (ABS).
- On-board computers and ITS technology (including the possibility of on-board scales).

Due to the strong influence of size and weight policy on trucking productivity, the tare weight of the truck or trailer remains of primary importance, and weight minimization is a key aspect of truck design.

Size and weight regulations have tended to bring about some standardization of truck and trailer wheelbase dimensions to optimize freight efficiency. This may cause more concentrated dynamic loading of trucks on pavements, but is not yet sufficiently understood.

Europe

European manufacturers have long placed a strong emphasis on truck design features that enhance the safety, comfort, and environmental impacts of trucks. This has been done at the expense of higher tare weight, and it appears that size and weight regulations in Europe have a less dominant effect on truck design and configuration than is the case in the United States.

European manufacturers produce a single model for all European markets, which is designed for the highest axle weight regime. While the customer has some degree of choice concerning componentry, regulations in Europe tend to reduce the variety in truck specifications as compared to the United States.

In Europe, air suspension has been the dominant fitment to new trucks for some time, and an estimated 80 percent of current sales of trailers in Europe utilize air suspension.

2.2.3 Truck Configuration

The term "truck configuration" describes a vehicle in terms of the number of axles, axle spacing, the number of units connected, and the way in which couplings are made. Truck configuration is almost totally determined by the commodity being hauled and, again, by size and weight policy. Truck configuration is likely to vary significantly by state, region, and country.

North America

Figure 1 shows a selection of truck configurations used in North America. The larger the truck in terms of total weight and number of axles, the more important is its precise configuration and the more critical become (i) vertical loads on all tires, (ii) side loads on all tires when the vehicle turns, and (iii) the ability of the vehicle to turn, track, and stop.

What effect does truck configuration have on pavement wear? Figure 2 shows asphalt pavement wear as expressed in pavement consumption units of equivalent passes of a single 8,170 kg (18,000 lb) axle with dual tires, or equivalent single axle loads (ESAL) versus total truck weight for different truck configurations. When the pavement wear per vehicle is assessed against the payload capacity, which gives a measure of the efficiency of a vehicle configuration, it is especially apparent that the tractor-semitrailer with 6 axles (3S3) is a more efficient configuration than the 5-axle vehicle (3S2). This is illustrated in Figure 3.

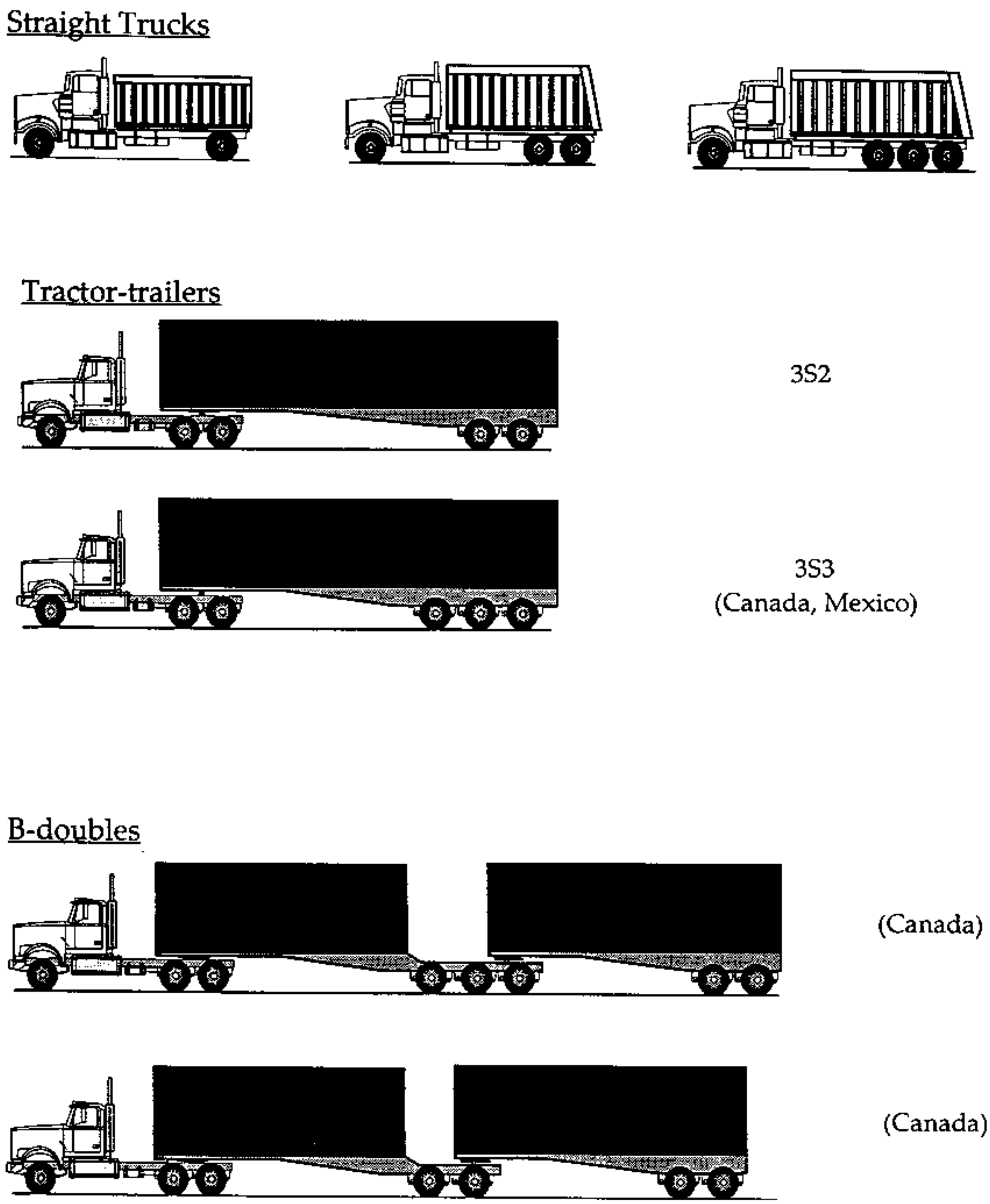
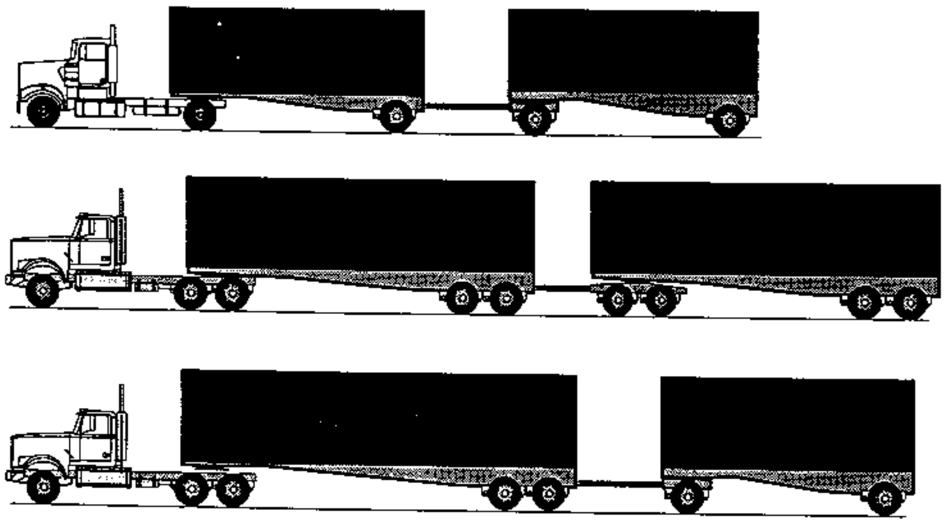


Figure 1. Truck Configurations Used in North America.
(Drawings courtesy of Roaduser Research.)

A-doubles



C-trains

(Canada)

Figure 1 (cont.). Truck configurations used in North America

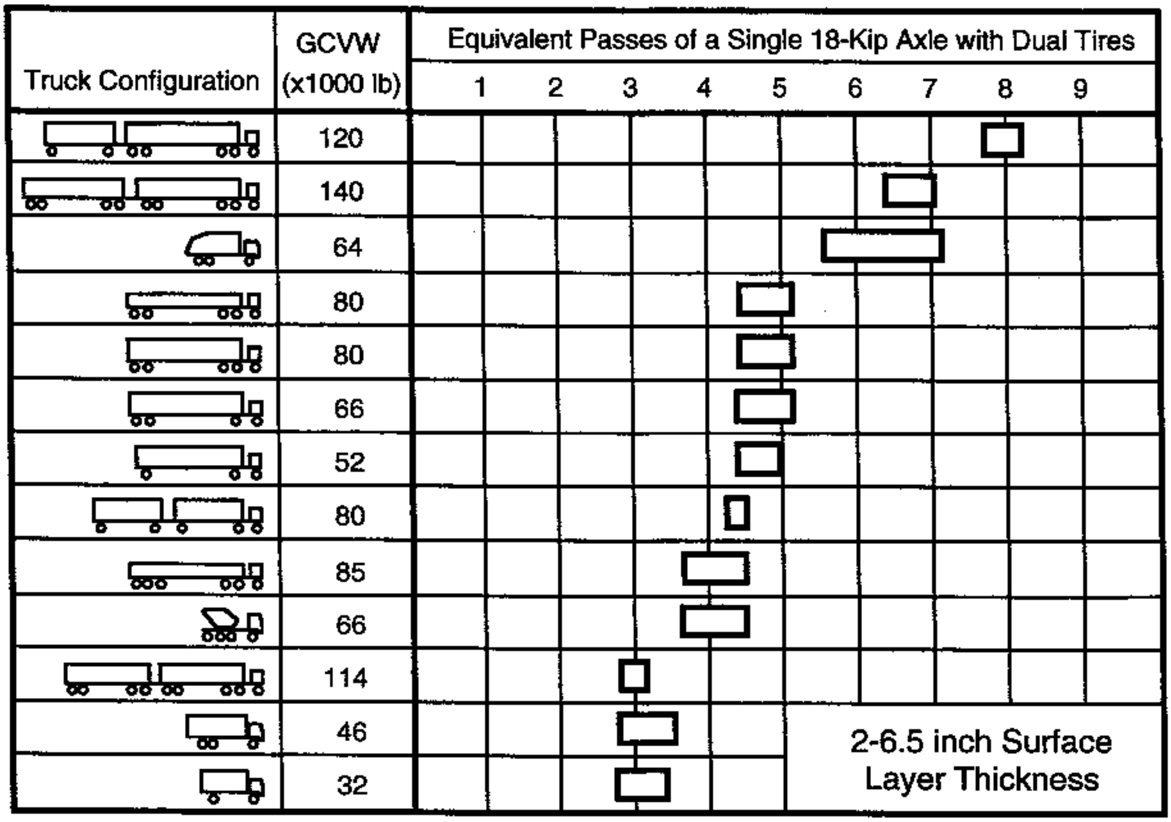


Figure 2. Asphalt Pavement Fatigue by Gross Vehicle Weight and Vehicle Configuration.

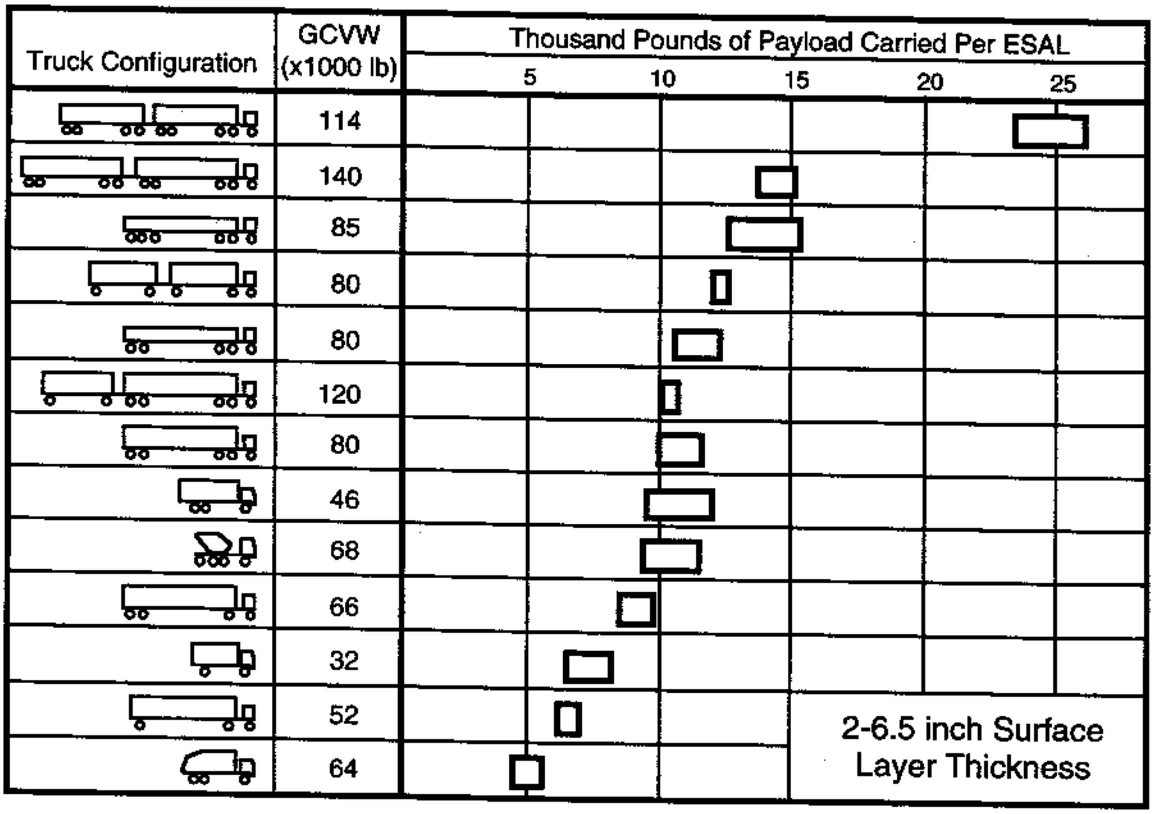


Figure 3. Payload Per Unit Asphalt Pavement Fatigue by Gross Vehicle Weight and Vehicle Configuration.

What effect does configuration have on safety? It is not necessarily true that larger or heavier vehicles will be more unsafe. Accident data are insufficient to compare the safety records of many of the less prevalent truck configurations. However, it *is* possible to assess the engineering performance of any truck configuration. The B-double (see Figure 1) is generally the most stable and best performing of the larger multiple-trailer configurations, and the use of this configuration has increased in Canada. However, B-doubles have not been adapted to all types of operation.

The use of sophisticated computer models has enabled the development of improvements to the configuration of larger trucks. One significant innovation is the C-dolly which provides a more rigid coupling between two or three trailers while still allowing proper turning. Figure 4 shows a typical C-dolly with double drawbars and single, self-steering axle. While operational experience with early versions of the C-dolly, especially in Canada, indicated some problems, subsequent design revisions have occurred to correct early developmental problems. Research in the United States involving field experience of truck configurations with and without C-dollies shows C-dollies to be practical and appealing to drivers, with some increased operating costs.

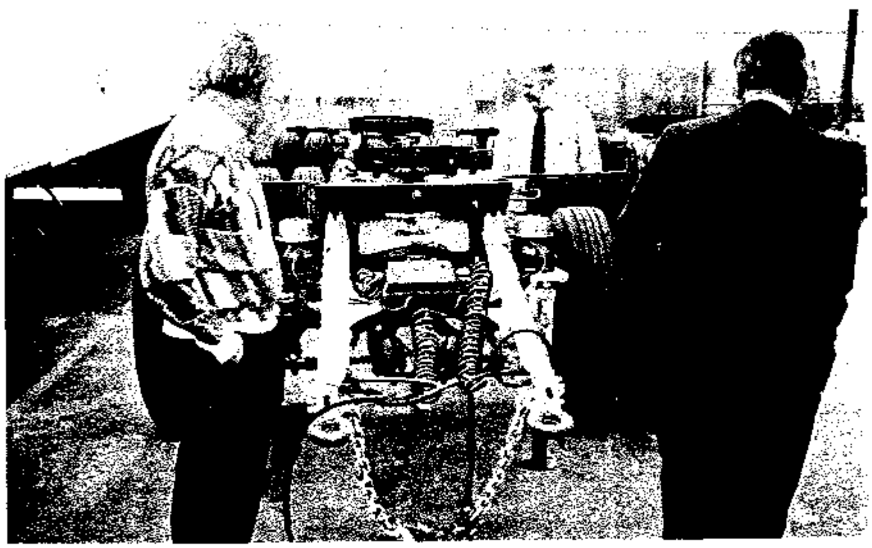


Figure 4. Typical Design of Modern C-Dolly.

Testing and simulation have shown that C-dollies reduce the destabilizing lateral motions at the rear of multi-trailer combinations. This effect has been scientifically studied and is termed "rearward amplification."

It is recognized that the design of dollies, which are relatively low cost items, can be instrumental in improving the operational and safety performance of large, multitrailer trucks. A number of innovative dolly concepts are being developed and marketed, often with the intention of reducing rearward amplification. The design goals of these dollies may include alignment, tracking, roll stability, stability under braking, and shock reduction.

Other, less sophisticated modifications to vehicle configuration have occurred, motivated by maximization of payload, subject to prevailing size and weight policy. The addition of more axles to semitrailers has worked well over the years, in going from one axle to two axles (tandem) to three axles (tridem or triaxle). This has contributed to more efficient use of pavement life for freight movement. However, the use of more than 3 axles on semitrailers has usually been found to create a need for lift axles or steering axles, to allow the truck to turn. Trailer self-steering axles can have a significant effect on the engineering performance of the vehicle combination. It is important to distinguish between self-steering axles, which may provide reduced lateral control, and steerable axles, which are designed to provide lateral control under all conditions. The Canadian experience with self-steering axles has indicated that there can be problems with the tracking and stability of trailers with self-steering axles, but the concept of steerable axles can be designed to preserve the engineering performance of the vehicle.

In Michigan, semi-trailers with up to 8 axles and a significantly lower load per axle have been operating for about 50 years. More typical is an 11-axle train with a 3-axle semi and a 5-axle trailer shown in Figure 5. Other truck configurations with a total of 11 axles are also in use in Michigan, and there are about 1600 such trucks in Michigan, approximately 6-7 percent of Michigan trucks. The Michigan 11-axle tractor-trailer was introduced to reduce transportation costs in certain industries. These configurations remain in use for certain commodities and there is a need to lift axles when turning with these configurations. Bridge retrofitting became necessary to accommodate these vehicles, and their free, statewide use would require heavy investment prior to deployment.

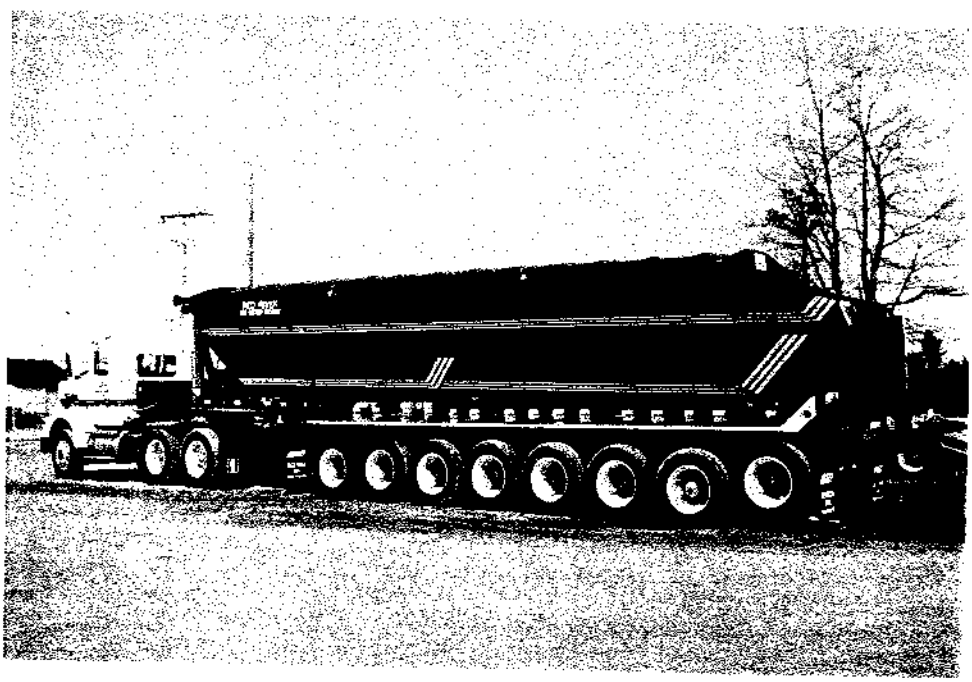


Figure 5. Typical Michigan 11-axle Train Configuration.
(Photo used with permission of Edward C. Levy Company)

A further example of straightforward variation to truck configuration in order to maximize productivity is the Longer Combination Vehicle (LCV), examples of which are included in Figure 1. LCVs, particularly triples, offer increased freight volume capacity for carriers of light freight, plus the advantages of reduced fuel consumption and reduced air pollution.

By way of example, triple trailers represent 1-3 percent of the trucks running in Oregon. Experience there appears to have been satisfactory, although these vehicles are confined to selected routes and certain operations and may have the benefit of better drivers or company management. It is difficult to directly compare the safety merit of LCVs with other, more common truck configurations such as the 5-axle tractor-semitrailer (3S2). Double-trailer and triple-trailer LCV configurations do not perform as well in certain aspects of engineering/safety performance, such as rearward amplification.

Europe

The predominant line-haul configurations in Europe are the tractor-semitrailer and the truck-trailer (or "road train"), illustrated in Figure 6. Most tractor-trailers in Europe consist of a 2-axle tractor hauling a triaxle trailer fitted with wide single tires. Relatively few tandem-axle semi-trailers are in use, and relatively few 3-axle tractors are in use. One exception to the latter statement is the United Kingdom, where 6-axle tractor-semitrailers pay lower registration charges, based on lower road wear per laden vehicle.

Truck-trailers in Europe predominantly consist of 3-axle trucks hauling 2-axle or 3-axle center-axle trailers. Center-axle trailers have rigid drawbars and no steering axles. A minority of trailers hauled by straight trucks are short 2-axle or 3-axle A-trailers.

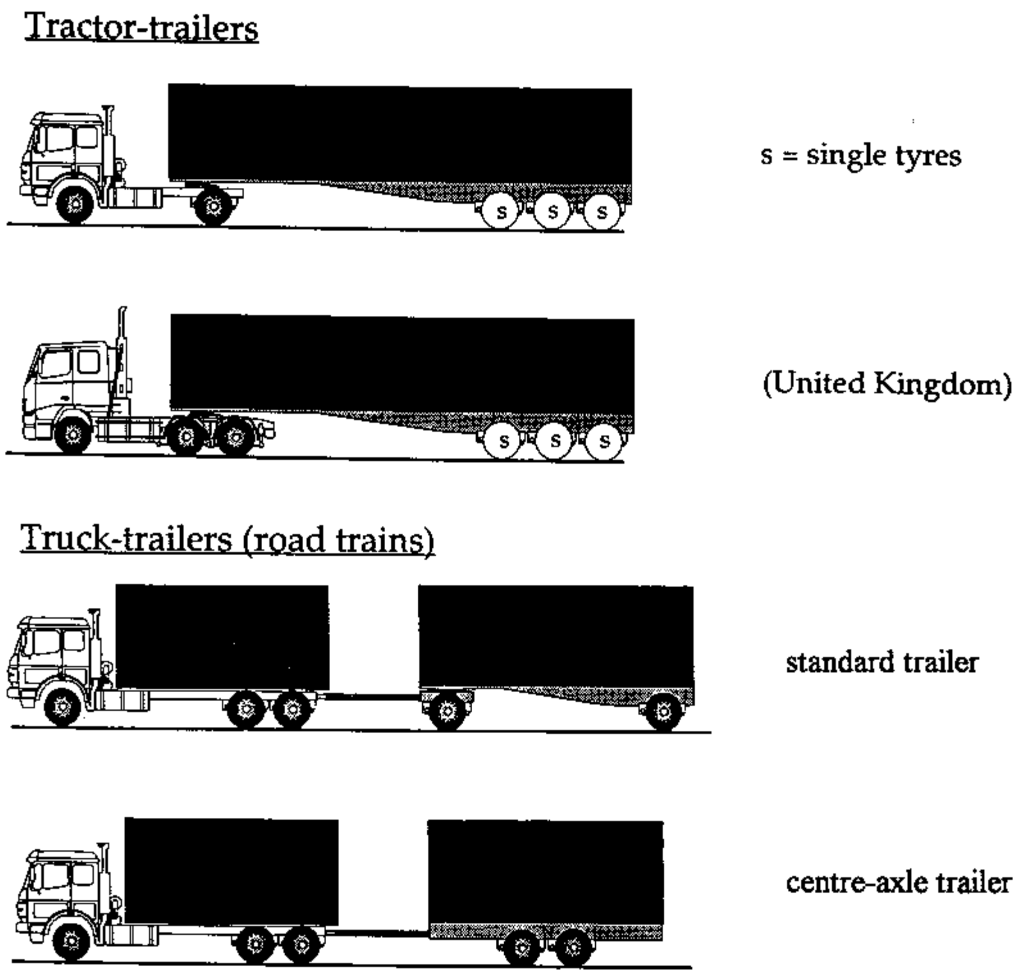


Figure 6. Typical Line-haul Configurations Used in Europe.
(Drawing courtesy of Roaduser Research.)

The European perception is that single-drive tractors are more productive, because of lower tare weight and reduced transmission energy losses. However, these single-drive axle tractors are made viable by the considerably higher single-axle weight limits applicable in Europe, as compared to the United States. In Europe, limits of 11 t to 13 t (24,000 to 28,600 lb) apply, while the US limit is 9.1 t (20,000 lb).

In order to improve the productivity and efficiency of 3-axle tractors, European manufacturers offer a 6×2 configuration, with tandem rear axle, in which only one of the rear axles is driven. These vehicles are also being marketed in the United States.

The mix of tractor-semitrailers and truck-trailers varies among countries in Europe. For example, the United Kingdom and France have large numbers of tractor-semitrailers while, Germany has tended to emphasize truck-trailers. There is a current trend in Germany to more tractor-semitrailers and to convert from A-trailers to center-axle trailers when truck-trailers are used.

Larger vehicle combinations are rare in Europe, although in Sweden the most common vehicle is a 24 m (79 ft) truck-drawbar trailer combination. A-doubles are rare and limited to a maximum speed of 40 km/h (25 mph), but then only if they fulfill performance criteria for stability. This vehicle configuration is perceived to have lower stability and braking performance.

2.2.4 Truck Components

Truck suspensions and tires have profound effects on truck/highway interaction. Both of these truck components are subject to continual research and development, and both components influence almost all areas of truck/highway interaction, especially pavement wear and the ability of the truck and trailer(s) to track, turn, and stop.

Truck brake technology has an important effect on the safety performance of trucks. The design and durability of braking systems is subject to continuous research and development, and some new concepts in truck brakes are approaching implementation.

2.2.4.1 Suspensions

North America

Today's criteria for designing suspensions include cost, weight, durability, ride quality, stability, ease of maintenance, mobility, and road-friendliness. Although cost remains an important issue, considerable emphasis is placed on truck/highway interface issues such as ride quality and road-friendliness. Ride quality for the driver has traditionally been addressed through the use of suspended cabs rather than the design of the pavement/suspension interface.

There is a pronounced trend toward air suspension on new tractors, but adoption of air suspension on trailers has been slower. Taking into account all existing vehicles, the preponderance of the current truck and trailer population runs on mechanical springs, which lack the performance options possible with air suspensions. Some types of mechanical suspension, including walking-beam tandem suspensions, respond poorly to high levels of road roughness. Most mechanical tandem suspensions are of the so-called "four-spring" type.

Air suspensions have the ability to maintain a constant ride height and a generally constant bounce frequency regardless of load. This constant-frequency behavior is achieved because the stiffness of the air spring automatically adjusts to the load being carried. There are many performance advantages to this feature of air springs.

With air suspension, damping of bounce motions is required, and shock absorbers are needed to provide this function. Maintenance of the shock absorbers is essential to maintaining the performance of the air suspension system. Rougher roads place greater stress on the shock absorbers.

One problem with springs used in four-spring suspensions is that interleaf friction increases effective spring stiffness, and the spring sometimes becomes locked, causing the truck to bounce on the tires, which do not have the necessary stiffness and damping characteristics. Lubrication of the spring leaves will improve performance, but this is a high-maintenance item. There are also some technological changes occurring to overcome some of these problems, including the use of shear pads and composites to create a more predictable spring.

There are also some innovative technologies for intelligent suspensions that adapt to road and vehicle conditions. Active and semiactive suspensions effectively provide variable stiffness and damping, dependent on the nature of sensed vehicle responses. Active suspensions can be designed to continuously optimize a selected vehicle response, usually ride quality. However, such suspension systems are not yet a production item on heavy trucks.

Europe

Suspension technologies have developed with the objectives of reducing operator costs, improving vehicle performance, and meeting regulatory requirements implemented at the level of the European Union. Throughout Europe, air suspension has been the dominant choice for new trucks for some time, and an estimated 80 percent of current sales of trailers in Europe utilize air suspension. The primary incentives for air suspension and reasons for its high usage are low service (compared to mechanical suspension), lower noise, better ride, and increased cargo-friendliness.

Because certain increases in axle-load limits are permitted for vehicles fitted with air suspension or equivalents, there has been an accelerated trend toward the use of air suspension. The primary reasons for the trend are the air suspensions' improved vibration environment and load handling. Truck manufacturers are producing air suspensions with very low natural frequency and very high damping; in addition to being "road-friendly," these suspensions provide good ride quality. Mechanical suspensions, which are equivalent to air suspension in terms of frequency and damping are also being produced by European truck manufacturers.

European trailer and suspension manufacturers are using sophisticated design techniques, such as finite element analysis, for the design of modern air suspensions. The design concept depends on the riding height, which influences the way in which suspension compliance and damping are provided. It is necessary to introduce a certain level of compliance in either the trailing arms or bushings. The geometric disposition of the shock absorbers has an important effect on suspension damping; the best damping and lowest trailer body vertical acceleration is obtained when the shock absorber is located behind the axle.

Other technological developments with air suspensions have occurred in the areas mentioned below.

- A single leveling, or height-control, valve for each axle group.
- Load-sensitive shock absorbers that adjust the level of damping according to load.
- Two-part pistons within the air bags, which reduce the possibility of suspension damage when the vehicle is lifted.
- The use of a thicker axle beam with air suspension, due to additional stresses from the anti-roll effect, caused by the use of the axle as a torsion bar.

It is not yet possible to use air suspension in all types of operations, and vehicles such as dump trailers are not wellsuited to air suspension.

Suspension life-cycle costs are generally a little lower with air suspension than with mechanical suspension, and tire life tends to be longer with air suspension. However, maintenance of air suspensions is important, and the rubber bushings, shock absorbers, and, eventually, the air bag need to be replaced at appropriate intervals. The component most susceptible to wear in-service is the shock absorber.

There is no longer a price premium on air suspensions in Europe. The market dominance of air suspension has tended to make the mechanical suspension a more costly option.

Other trailer suspension technologies available in Europe include automatic lift axles and self-steering axles. Lift axles are sometimes used on triaxle groups; in some cases the leading axle is a lift axle, and in some cases the trailing axle is a lift axle. European regulations specify that an axle can only be lifted in such a way that axle-load limits are not exceeded and this requires an automatic system designed so that the axle automatically drops when the axle group load exceeds 16 tonnes (35,200 lb). In some countries, security features are added to the lift axle control system so that automatic deployment cannot be interfered with.

Self-steering axles are sometimes used on triaxle groups, in order to improve vehicle maneuverability and to reduce tire wear—the trailing axle is self-steering. This increases the inside turning radius by approximately 10 percent for a typical tractor-semitrailer, and tire wear patterns tend to be evened out between axles. Overall, tire life may be improved by a factor of two. However, there is a significant cost penalty for self-steering axles, and they tend to be used only on high-cost vehicles such as tankers.

2.2.4.2 Tires

North America

The industry has moved to radial tires, which have stiffness and tracking characteristics very different from the old cross-ply tires. There are additional trends toward smaller, lighter, stiffer radial tires that require higher inflation pressures. In general, these higher inflation pressures lead to higher contact stresses on pavement surfaces. However, actual contact stresses vary within the tire's "contact patch" and are not necessarily equal to the inflation pressure, because they are also influenced by the stiffness of the tire structure, or carcass.

Some newer designs of tires offer significant benefits for the truck, but may tend to cause problems for the highway. While significant benefits are sought in increased tiretread life, reduced weight, reduced rolling resistance, and enhanced cornering and braking, these tire designs may place higher and more localized vertical and lateral stresses on the pavement surface.

Technologies generally known as Central Tire Inflation (CTI) now exist to control tire pressures from the truck cab, to lower tire pressures under some circumstances and to monitor tire pressures using ITS technology. There is research evidence that controlled, lower pressures reduce pavement damage, especially on aggregate surfaces, but effects may be small on thick, strong pavements. However, it would appear that only a small benefit may be derived from controlling the balance of tire pressures, especially with duals, and in more accurate control of overinflation. Overinflation affects pavement stresses and underinflation may affect safety. This truck technology adds significant cost and maintenance penalties, but could eventually provide some benefits to both the truck and the highway.

Europe

Tires used in Europe differ from those commonly used in the United States in terms of sizes, profiles, and tread patterns. European usage tends toward lower profiles, larger tire sizes, and involves the widespread use of wide single tires on trailers. Low-profile and small-diameter tires are in demand in order to lower the height of the loading deck, thereby increasing cubic capacity. Different tread designs are used for steer tires (rib, for directional stability), drive axle tires (traction, deep tread), and trailer axle tires (shallower tread). New tire technology is moving to lower rolling resistance, and this will involve high inflation pressures of up to 900 kPa (130 psi) in the new smaller tires.

European customers see a number of advantages for wide singles in the place of duals, including reduced tare weight (by 380 kg (840 lb) for a triaxle group), reduced rolling resistance (by up to 25 percent for a 40 t (88,100 lb) vehicle), approximately 3 percent better fuel consumption, improved roll stability and safety, and the environmental benefit of less tire recycling. However, the wide single has less tire life than duals. The overall cost advantage of the wide single tire in Europe is estimated to be 23 percent. About 80 percent of European trailers are fitted with wide single tires.

The new generation of wide single tires is being designed with an extremely low profile—aspect ratio of the new tires is expected to be 45 percent. It should be noted that higher tire pressures imply smaller contact areas and an increased probability of greater pavement wear.

2.2.4.3 Road-Friendliness

Research Initiatives

World-wide research is under way to provide scientifically based means of assessing the road-friendliness of trucks. Road-friendly trucks are those that, for a given weight of load, cause less pavement wear. This is usually brought about by the use of suspensions that distribute the load well among the truck wheels and reduce dynamic loading of the pavement.

It has been known for some time that air suspensions provide superior distribution of the load among the truck wheels. However, this does not necessarily mean that dynamic load peaks, or "impact loads," on individual wheels or axles will be well controlled. Dynamic loading of the pavement is relatively complex and has three important characteristics.

1. How big are the peak wheel loads when the truck bounces and the axles oscillate?

2. How many times do these peaks recur after the truck hits a rough spot on the pavement surface?

3. As truck after truck passes over the pavement with varying wheel configurations and speeds, do these peaks tend to occur at the same places in the pavement?

Independent testing has been carried out in many countries to rank suspensions, mainly for the first of these characteristics, and has confirmed the superior performance of air suspensions, provided they have effective damping. Walking-beam suspensions have the worst performance and four-spring suspensions have intermediate performance. Because they are always fitted with shock absorbers, which introduce rapid damping, air suspensions are superior on the second characteristic, provided that the suspension is maintained properly.

The latest research is examining the third characteristic. Although incomplete, it raises the question that air suspensions may create more repeatability in dynamic loading, depending on pavement roughness. Some testing of the effects of intelligent suspensions has also been conducted, and it seems that further development of these systems is needed to provide significant gains in road-friendliness.

At this time, the relationship between dynamic loading and pavement wear is not fully understood, especially in the quantification of pavement wear. This is the subject of current research in a number of countries and is being examined in the DIVINE Project, an international cooperative research project being carried out by the Organization for Economic Cooperation and Development (OECD).

European Practice

Community Directive 86/360/EEC, which is an amendment to the base weights and dimensions in international transport Directive 85/3/EEC, fixed the weight of a single-driving axle at 11.5 tonnes, as of January 1, 1992. When this Directive was adopted, it was recognized that road-friendly suspensions may assist in harmonizing axle weights among member countries. It was decided that the definition of "road-friendliness" should account for the following factors: tires (dual or wide single), tire contact pressure, tire pressure distribution, suspension, and damping.

In a subsequent amendment to 85/3/EEC, the Commission examined, when setting the weight of the vehicle drive axle at 11.5 tonnes, the possibility of reducing damage to the transport infrastructure, taking into consideration "new vehicle construction techniques;" e.g., dual tires and air suspension or equivalent.

European regulations allow 19 t (41,900 lb) on road-friendly tandem-axle groups and restrict non-road-friendly tandem groups to 18 t (39,600 lb).

Directive 89/338/EEC, which became effective in January 1993, was drafted to require 2-, 3-, and 4-axle vehicles operating at maximum gross weights to have a drive axle equipped with dual tires and air suspension or equivalent. The matter of equivalence to air suspension was subsequently addressed by an EEC working party.

Directive 92/7/EEC, also effective January 1993, defines the equivalence of non-air suspension to air suspension. In developing 92/7/EEC, it was recognized that it will be necessary, at a later stage, to have common standards for single axles and tandem axles. Directive 92/7/EEC applies to driven axles (either single or bogie axles) and requires the following:

- Dual tires.
- Hydraulic dampers on each axle.
- Sprung mass frequency no greater than 2.0 Hz.
- Mean damping ratio (D) more than 20 percent of critical damping (with dampers fitted).
- Damping ratio of the suspension, when all dampers are removed, of no more than 50 percent of D as calculated with dampers fitted.

(Note: The damping ratio is a natural logarithmic function measuring decay and is derived from the amplitudes of successive peaks of oscillation in the same direction, as derived from a prescribed test procedure.)

Simple procedures, using step or drop tests, are specified for measuring the required suspension parameters.

European regulations allow 19 t (41,900 lb) on road-friendly tandem axle groups and restrict non-road-friendly tandem groups to 18 t (39,600 lb).

European truck and trailer manufacturers test their suspensions according to the Directive 92/7/EEC. Current truck air suspensions have frequencies as low as 1.2 Hz and damping as high as 35 percent, and European manufacturers also offer mechanical suspensions that meet the 92/7/EEC requirements for equivalence to air suspension.

The current trends toward lowering the height of trailers, to increase volume, and toward the use of low-chassis trucks, may cause problems for dynamic wheel forces because spring travel is reduced and tires are becoming smaller, with higher inflation pressure.

2.2.4.4 Braking

After many years of research and development and consideration of their cost-effectiveness, antilock brake systems (ABS) are now well accepted by regulators and manufacturers alike, in both Europe and North America. Legislative requirements for ABS are now in place in Europe and in the United States. Antilock brakes will become mandatory on truck tractors manufactured in the United States, effective March 1997.

New developments in brake technology include the following:

- New designs of s-cam drum brakes for reduced maintenance and improved in-service performance.
- Disc brakes for improved fade-resistance and improved balance between tractors and trailers.
- Electronically controlled brakes (brake-by-wire) for improved response and balance between tractors and trailers.

2.2.5 Truck Dynamic Response Simulation

Computer simulation of truck vertical dynamics, which encompasses bouncing, dynamic loading and ride quality, is well advanced. It has become possible to realistically simulate most relevant aspects of truck/highway interaction. Libraries of data describing truck parameters for simulation purposes are available along with internationally accepted pavement-surface descriptions.

Similarly, computer simulation of truck tracking, turning, stability, rearward amplification, braking, and acceleration is highly developed, and good truck data is available.

New-generation simulation techniques, specifically developed for multi body dynamics, are allowing custom models to be developed with a speed and reliability not previously possible. The addition of graphic interfaces is producing a new generation of powerful and user-friendly truck simulations.

2.2.6 Truck Performance Standards

The use of performance-based standards for trucks is being widely discussed and there is strong interest in the concept. Performance-based standards seek to define key truck performance attributes, provide a means of measuring or assessing these aspects of performance, and establish quantitative performance criteria that must be met. Performance-based standards are an alternative or complement to conventional prescriptive size and weight limits. For example, instead of regulating the overall length of trucks, the turning circle or swept path could be controlled. This is more relevant to the actual performance and the actual impact of trucks in the highway system, provided that the constraints of existing roadway geometrics are well represented by the swept path criterion adopted.

North America

To support such a performance-based regime, a large body of knowledge is required, and researchers have already developed a performance-prediction approach involving computer simulation, truck component measurement, and truck experiments. However, considerable deliberation and evaluation is necessary to decide which performance measures should be used and what criteria are acceptable. It is also unclear where performance-based standards fit into the regulatory system.

Nevertheless, based on current research and development carried out in the United States and Canada, the performance measures shown in Table 1 have been suggested by a variety of authorities as being appropriate for application to vehicles with GVW greater than 80,000 lbs.

Table 1. Suggested Performance Standards for Vehicles of GVW >80,000 lbs (North America)

Performance Standard	Criterion	Significance
Static rollover	0.35-0.40 min.	Basic to all trucks, Dynamic roll stability in evasive maneuvers
Rearward amplification	1.7-2.0 max.	Evasive maneuvering of multitrailer vehicles, Dynamic roll stability of rear trailers, trailing fidelity
Dynamic load transfer ratio	0.60 max.	Evasive maneuvering of multitrailer vehicles, rollover of rear trailers
High-speed transient offtracking	0.8 m max.	Evasive maneuvering of multitrailer vehicles, trailing fidelity
High-speed steady state due offtracking	0.46 m max.	Maneuvering of long vehicles, outboard offtracking, rollover to curb trip, check against poor C-dolly design
Friction demand	0.1 max.	Maneuvering of heavy, multiaxle vehicles, power jackknife in low-speed maneuvering, excessive straight line stability at speed
Braking efficiency	0.7 min. (or equivalent)	Emergency-stopping capability, stability and controllability, stopping distance (brake proportioning relative to load proportioning) problem for laden/unladen situation
Low-speed offtracking	6 m max.[1]	Road space required at intersections
Acceleration/hill climbing	20 mph	Must be maintained on all grades operated

[1] Other criteria have been proposed.

These performance standards are currently being evaluated in the FHWA Comprehensive Truck Size and Weight Study and would exist in addition to all current Federal Motor Vehicle Safety Standards (FMVSS), which already include a requirement for minimum stopping distance under emergency braking. The proposed braking efficiency requirement is supplementary to FMVSS 121 requirements and would not substitute for them.

Of potential performance standards, static rollover, which is strongly affected by the truck's center-of-gravity height, is generally considered to be the most important. Another important area for a performance standard is truck suspensions, and a Society of Automotive Engineers' (SAE) subcommittee is being formed to develop this issue.

Europe

In Europe, there are approximately 40 Directives in place for various aspects of truck design and performance. Quantitative performance standards are in place for (i) the low-speed turning performance of heavy vehicles—the maximum inner radius and the minimum outer radius are specified, and for (ii) the tractive performance of heavy vehicles—a minimum tractive ratio of 25 percent of gross weight is required.

Dynamic stability and tracking performance are not specifically considered, although the tractor-semitrailer is thought to be more stable than the road train.

2.2.7 Interregional and International Compatibility

Introductory note: There is really no compatibility among North American practices of policies as each evolved independently within their own conditions and constraints. This information is presented to represent each country's practices. Even within countries, significant variations can be found.

The truck populations in the United States, Canada, and Mexico are as follows:[1]

	Truck - Tractors		Straight Trucks (3 or More Axles)	
United States	1,240,309	(77.9%)	4,614,028	(80.6%)
Canada	87,283	(5.5%)	269,253	(4.7%)
Mexico	264,448	(16.6%)	841,059	(14.7%)
	1,592,040	(100%)	5,724,341	(100%)

Truck design attributes for tractors and straight trucks are generally quite similar in all three countries. U. S. truck manufacturers who offer products in each of the countries build common truck models, and the same basic technology is offered for the three countries.

Although basic truck models and technology are quite similar for the three North American countries, there are some differences in typical component specifications, as noted below:

[1]Source: North American Transportation, Bureau of Transportation Statistics, US DOT. Revised May 1994.

	United States	Mexico	Canada
Rear Axle Rating	15,440-18,160 kg (34-40,000 lb)	20,880 kg (46,000 lb)	20,880 kg (46,000 lb)
Suspension	Air and 4-Spring	Walking Beam	Walking Beam
Transmission	10 Speed	16 Speed	13-18 Speed

Where trucks are required to haul higher gross weights, specifications could change somewhat. For example, typical tractor specifications for 11-axle Michigan vehicles (up to 74,460 kg (164,000 lb) gross weight) include a 19,980 kg (44,000 lb) rear axle group, a 9,080 kg (20,000 lb) front axle, compared to a typical 5,450–6,360 kg (12-14,000 lb) rating, and an engine power increase to 400/450 hp, compared to a typical 350/400 hp engine. In other respects, these tractors are generally similar to the typical US highway tractor.

Mexico has made major advances in vehicle emission controls. For example, trucks manufactured in Mexico by DINA in 1994 are designed to comply with US Environmental Protection Agency (EPA) requirements. Canadian and US carriers are purchasing DINA trucks for operation in Mexico, and Mexican-manufactured buses that comply with US DOT requirements are being exported to the United States.

Trailers do differ among countries, and trailer manufacturing is largely domestically based, reflecting variations in limits among the three countries. Trailer lengths used in the United States are as follows:

14.63–16.17 m (48–53 ft) semis	for selected routes
8.54 m (28 ft) doubles	for selected routes
8.54 m (28 ft) triples	for selected routes

By comparison, Canadian trailer lengths are:

14.63–16.17 m (48–53 ft) semis
8.54 m (28 ft) trailers in A-doubles
up to 9.4 m (31 ft) trailers in B-doubles and C-doubles

Predominant Mexican trailer lengths are:

12.2 m (40 ft) semis
12.2/9.15 m (40/30 ft) trailers used in doubles.

With regard to the largest truck configuration generally permitted on the national system in each country, the comparison is as follows:

United States: no overall length minimum limit, but semitrailer length limit required by federal law to be no less than 14.63 m (48 ft) (with most states at 16.17 m (53 ft) and up to 18.3 m (60 ft) in some states) and, similarly, twin 8.5 m (28 ft) trailers.

Canada: 3S3 tractor semitrailer/23 m (75.5 ft) overall length/46,500 kg (102,400 lb).

Mexico: 3S3 tractor/semi/trailer/19.5 m (64 ft) overall length/56,300 kg (124,000 lb).

Note that the key vehicle in Canada and Mexico is the 3S3 while in the United States the most common vehicle is the 3S2.

Configurations of LCVs restricted to routes or regions in each country compare as follows:

United States: Triple trailers/29–35.39 m (95–116 ft)/40,860–59,470 kg (90,000–131,000 lb)

Canada: A, B, and C trains/23 m (75.5 ft)/53,120–62,650 kg (117,000–138,000 lb)

Mexico: Double trailers/31.11 m (102 ft)/59,000 kg (130,000 lb)

In the United States, access for LCVs varies considerably between regions and states. Canada is the only country with significant numbers of B-trains, and these vehicles are able to operate nation wide, although these B-trains are shorter than US LCVs.

As part of NAFTA, the three countries have committed to reviewing compatibility of truck size and weight. A report of their initial recommendations is due in January 1997.

2.3 Infrastructure

2.3.1 Highway Systems

North America

The United States and Canada have mature and relatively stable highway systems that are complemented by nationwide rail services. The Mexican highway system is currently in a state of evolution and development and is supported by a less extensive rail system. The following figures indicate the extent of the highway networks in each country.

The US highway network system mileage may be broken down as follows (figures for 1992):

Proposed National Highway System (NHS)	257,000	km (160,000 miles)
Interstate System (included in the NHS)	70,840	km (44,000 miles)
Minor Arterial and Major Collector	1,183,350	km (735,000 miles)
Total	1,440,350	km (895,000 miles)

The Canadian highway mileage breakdown is as follows:

Freeway	14,800 km	(9,200 miles)
Federal Paved Rural	49,400 km	(30,700 miles)
Federal Paved Urban	84,700 km	(52,600 miles)
Provincial Paved	128,300 km	(79,700 miles)
Total	277,200 km	(172,200 miles)

The federal highway system mileage for Mexico breaks down roughly as follows:

Principal Highways	48,300 km	(30,000 miles)
Feeder Routes	88,550 km	(55,000 miles)
Rural Routes	104,650 km	(65,000 miles)
Total	241,500 km	(150,000 miles)

The Mexican road network that supports most of the commercial relationships between Mexico and its NAFTA partners accounts for nearly 20,000 km. Of this road network, only 4,000 km have four or more lanes (very few segments have more that 4 lanes). The remaining 16,000 km are two-lane, two-way roads, with very restricted vertical and horizontal alinement conditions.

Europe

National highway systems are usually divided into classes with regard to management and funding. In Sweden, the road network is divided into two road classes according to the strength of bridges and pavements. In France, the three levels of highway financing and administration are listed below.

- Toll roads, with high levels of service (good maintenance, safety) and typical speeds of 130 km/h (81 mph).

- Free "national taxation" roads with typical speeds of 90 km/h (56 mph).

- Lesser roads that are supported by regional taxes.

The Trans-European Network adopts uniform standards developed by the EEC and includes significant developments in new technologies such as telematics.

2.3.2 Pavement Design and Construction

North America

It is apparent that there are different interests, concerns, technologies, and conditions of pavements in the United States, Canada, and Mexico.

The Canadian Provinces are relatively independent and conduct their own design, analysis, and management of pavements. Each province has its own level of expertise and priorities in each of these area, and pavements are in relatively good condition.

In the United States there are not only 50 State jurisdictions but also many local jurisdictions that have ownership of the public roads, and condition of the roads varies significantly across the country and within each region. There is a wide variation in the use of design procedures as well as selection processes in constructing and rehabilitating pavements across the country. Materials and construction techniques are important and vary widely. There is also a large variation in the amount of funding devoted to pavements across the country.

Many of the US States are still in the process of implementing pavement-management systems. There are many high-technology computer models to simulate pavement response; however, these models remain uncalibrated for actual pavement performance. Efforts are under way in the United States through the Long-Term Pavement Performance study (LTPP) to provide this calibration. What appears to be missing is a practical transfer to the user/practitioner.

Even within States, there appear to be significant barriers to the management of the total pavement system. For example, most States have separate budget for construction and for maintenance. It is also clear that in many States, various sectors responsible for truck and infrastructure issues do not communicate fully, and there are varying degrees of political influence for the funding and selection of road projects. This political influence is of potential concern because of the emphasis placed more on programming process and less on technical evaluation.

There is a simplistic view that pavements should be built stronger, but the design life-cycle cost of the pavement is the real issue. Basic pavement design criteria should include pavement-design life, design reliability, minimum time to first overlay, minimum time between overlays, and minimum serviceability index (condition). These criteria should be set taking into account availability of funds for future overlays, competing current needs for highway user fees, and consequences of early failure.

While heavy vehicles are an important consideration in pavement and bridge design and maintenance, this influence is often implicit rather than explicit. It is interesting to note that, in States where trucks heavier than national averages are operating, there appear to be no special pavement-design requirements. However, bridge designs and weight limitations are considerably more specific with regard to the influence of trucks.

Mexico is unique because the federal government has responsibility for the design and maintenance of the roads. However, Mexico does not have a dedicated road fund and roads must compete within the general budget process for allocation of funds and resources. As the Mexican economy expands, use of the roads will expand and a greater emphasis will be necessary to prolong a serviceable condition of roads in Mexico. The development of concession, or toll, roads in Mexico has permitted the application of private-sector investment.

The general structural and riding condition of Mexican roads appears to be lower than that in the rest of North America, although there are some excellent roads in Mexico. As a result of economic conditions, Mexico has experienced a significant deterioration in the maintenance of the system. Environmental effects, involving aging and moisture, are also significant for Mexican pavements and bridges; although, in general, environmental effects are much more benign than in the United States and Canada, particularly regarding freeze and thaw.

The original purpose of the initial transportation network of Mexico was for communication and linkage, and the first network was modest in scope, structure, and investment. Partly due to the initial test procedures available, Mexico has developed a system with many poor materials in place. However, the need for improved technology has been identified and acted upon. The use of a long-term approach to road building and maintenance in Mexico will benefit all of North America. There is a need to restore the existing networks and develop new pavements with the improved technologies now available. Enforcement of new size and weight regulations will also contribute to arresting the deterioration of the highway network and involves the implementation of surveillance systems within the network as well as development of mobile monitoring capability.

Europe

Pavements throughout Europe are of a generally high design standard, although there is little harmonization of pavement design methods among European countries. While the desirability of setting road design standards for a Europe-wide network is recognized, there would be a large cost for change. The European Commission does control road design standards for countries such as Portugal and Spain who receive subsidies from the European Union in return for meeting certain road standards.

Total life-cycle costs are an important consideration and additional initial investment will be considered in order to minimize the total cost. For example, total life-cycle costs are an important consideration in France, and an additional investment of up to approximately 10 percent may be considered in order to minimize total pavement costs.

2.3.3 Pavement Condition and Maintenance

North America

Pavement management systems are being used throughout North America and more emphasis is being placed on the design of rehabilitation and overlay treatments. Testing equipment such as the falling weight deflectometer (FWD) can be used to determine rehabilitation requirements. Research is under way to find methods of extending pavement life to extend level of service, including the use of new materials and additives. Life-cycle cost analysis is essential but is proving difficult to implement in some jurisdictions.

There are indications that, throughout North America, the highway industry is not fully aware of the needs and concerns of the trucking industry regarding the riding quality provided by highways. Highway quality attributes have not been quantified by either the highway engineering or trucking interests. A question which needs to be answered is: What does the trucking industry, including drivers, carriers, shippers, and manufacturers, want in terms of pavement quality and cost-effectiveness and productivity?

It is known that trucks respond to long wavelengths in the pavement profile more than other classes of road user. However, the influence of pavement construction and maintenance techniques and the profile quality of the pavement on the truck/pavement interaction is not completely known. An important step toward a better understanding of this interaction would be the use of a truck-related pavement roughness index to provide relevant pavement data. The National Cooperative Highway Research Program (NCHRP) Project 1-33 is researching the issue at this time.

In Mexico, important new national maintenance policies are being formulated covering technical monitoring of highway systems and allocation of resources to roads. These policies specifically recognize the key role of the highway system in providing material support and sustainability for national economic and social development. Total transportation costs are recognized as the real issue and objectives have been established for maintenance of the commercial network to provide for freight flows. This includes prioritizing highway sections based on the value of the freight using the road.

Europe

European practice is to undertake pavement maintenance prior to serious deterioration. In France, the condition of the network is monitored extensively, with one third of the total network being monitored each year. Roughness is measured in three wavelength ranges (0–3 m, 3–11 m, and 11–30 m (0–10 ft, 10–36 ft, and 36–98 ft)) which are considered to be relevant to different aspects of vehicle-highway performance—safety, ride comfort, and structural condition.

Almost all European countries are involved in long-term pavement-performance monitoring, although relatively frequent maintenance schedules make it difficult to see long-term behavior.

2.3.4 Truck Effects on Pavements

North America

NCHRP research has taken leading-edge simulation models of trucks and pavements and coupled them together in order to probe the dynamic interaction of trucks and highways. In this model, a length of road 366 meters (1,200 ft) is created with realistic unevenness, and pavement damage is computed by distance along the road. This research confirmed the dominant influence of truck weight on pavement damage but also placed this in context with other truck/pavement interactions that were not previously understood.

While weight is dominant, the axle loads are more important than the gross loads. Tires and suspensions have a lesser effect than weight and the lateral tracking of trucks, while the degree to which it is concentrated in the wheelpaths has a strong influence. Air suspensions reduce peak predicted pavement strains. Dynamic loading increases with pavement roughness and is greatest at speeds around 60 mph. However, these relationships also depend on pavement type and suspension type.

These pavement-damage relationships have not yet been validated experimentally, but measurements of pavement and vehicle responses have indicated broadly similar conclusions with regard to the effects of truck suspension, tires, and pavement roughness. Some research has found that the low-frequency bouncing of trucks has a measurable effect on pavement strains, and these higher strains tend to occur in the same places in the pavement with the passage of each truck along the highway. It appears that this repeatability occurs for all truck suspensions and may be more pronounced for air suspensions. Although the repeatability is not precise, it seems to be sufficiently close to increase the anticipated pavement damage. The US truck industry is leading some of this research, has developed a potentially powerful research tool in the form of the road simulator, and is evolving methods to replicate on-highway vertical dynamics in the laboratory.

In reality, truck effects on pavements are difficult to isolate and generalize, and current perceptions tend to relate to situations involving intensive heavy-vehicle usage of pavements. For example, there are concerns throughout the United States about rutting of bituminous pavements. Tire loads and contact pressures are considered to be important influences in this form of pavement wear. Truck traffic tends to be concentrated on certain routes and corridors, and some Interstates have 40 percent trucks in the traffic stream. International trade with Canada and Mexico is also increasing truck movements in certain corridors.

While trucks are frequently perceived as causing pavement wear, buses are not often considered. Buses appear to have a strong role in causing pavement wear in cities, where pavements can often be in poor condition.

Europe

In the United Kingdom, road wear attributed to heavy vehicles is estimated to cost £850 million per year. Research being conducted by Cambridge University and the Transport Research Laboratory (TRL) is investigating the truck-pavement interaction in order to better understand the wear caused by heavy vehicles.

The effect of dynamic loading is being investigated both experimentally and using computer simulation. Investigations of pavement wear are concentrating on the condition of the most worn 5 percent of the road length. Parametric studies of the vehicle-pavement interaction indicate that the asphalt thickness has a major influence on the relative effects of dynamic loading, static loading, variations in pavement thickness, and temperature effects. The combined effects of pavement roughness, variations in layer thickness, and dynamic loading contribute to approximately 40 percent of rutting, while static load accounts for the remaining 60 percent.

Dynamic loads and variations in layer thickness both have a highly significant effect on fatigue damage (cracking), although these influences are reduced on thicker, stronger pavements.

While computer models show air suspension to reduce pavement wear, they also indicate that current air suspensions are far from optimal and would need to have significant reductions in stiffness and increases in damping in order to be the most road-friendly. The greatest scope for improvement in air suspension characteristics is on trailer axles. In order for these improvements to be obtained in practice, means of ensuring the roll stability of the vehicle would need to be incorporated into the design of air suspensions.

Although air suspensions have a number of advantages when new, it has been shown that it is possible for poorly maintained air suspensions to cause higher dynamic loading than mechanical suspensions.

Improvements to mechanical leaf spring suspensions have also been investigated. Reducing interleaf friction, plus the addition of hydraulic dampers, could reduce pavement wear by about 5 percent.

Pavement wear caused by dynamic loading is strongly influenced by spatial repeatability of dynamic loading—the extent to which peak dynamic loads tend to concentrate at particular points in the road. Testing and computer simulation have shown that spatial repeatability is affected by vehicle speed and suspension characteristics. There are indications that approximately half of the truck fleet produces dynamic loading which is sufficiently repeatable as to have a significant effect on pavement wear. The indication from this research is that spatial repeatability is an important contributor to pavement wear.

Research is being carried out on the effects of active and semiactive suspensions on pavement wear. Active suspensions are defined as requiring a large amount of energy input, while semiactive suspensions need only control energy dissipation in the suspension. It is estimated that the addition of a semiactive damper to a suspension which is already optimized would provide a further 5 percent reduction in pavement wear.

Consideration is being given to appropriate means of testing trucks for road-friendliness. Testing and simulation studies have found the following:

- It is not appropriate to simulate high-speed operation in a low-speed test—a test-track length of at least 200 meters (656 ft) is needed.

- While it is possible to use a standard semitrailer to test tractors, the use of a standard tractor to test semitrailers is less appropriate.

- The step test in the EEC Directive for equivalence to air suspension is not always reliable.

- The validity and reliability of laboratory tests increases when more complex nonlinear methods are used for characterizing suspensions.

Fundamental research into bitumen properties shows that bitumen properties dominate the behavior of the asphalt mix and that the modeling of whole-life road performance requires detailed consideration of permanent deformation in all layers and fatigue damage in asphalt.

German research has found that dynamic loads are relatively high and that the friction in leaf springs is a significant problem. This friction reduces spring deflection and there is a need to overcome this problem because it should be possible to have a smooth road and obtain the benefit of this in terms of reduced dynamic loading.

Research into the pavement contact stresses under tires has shown that the pressure is not uniform in the contact patch. As the load and deflection increase, the stresses in the shoulders increase relative to the center of the tread (crown). Longitudinal and lateral stresses also vary through the contact patch. Horizontally applied shear stresses are thought to be important, although they are not always considered in pavement design—positive and negative longitudinal stresses are applied, plus lateral stresses, with the tire tending to pull inwards from each shoulder.

Wide single tires produce average approximately 1.5 times as much rutting damage as duals, according to various studies. This ratio depends strongly on pavement characteristics and seems to be less on stronger pavements.

2.3.5 Truck Effects on Bridges

North America

Bridge stresses are generally low, even for highest legal axle weights, and the dead weight of the bridge can contribute 30–40 percent of the total stresses for long bridges. There are relatively few recognized fatigue failures in bridges and most relate to bridge decks. However, there is a cost related to stressing bridges beyond design criteria, even though these criteria are conservative in terms of fatigue and failure.

It is also necessary to consider the large number of older bridges in use, and a new study has found fatigue cracking in steel bridges, which does not occur in prestressed concrete bridges. While the structural capacity of older bridges is a serious concern in relation to truck use, it is possible in certain cases to retrofit bridges to increase their capacity. It is also true that the actual as-constructed capacity of bridges often exceeds the design capacity, because of conservative assumptions made in the design process.

In Michigan, all but 10 of 4,500 bridges have been built or renovated to accommodate the heavier-than-average 11-axle trucks. This was estimated to add only 4 percent to *initial* bridge costs; however, strengthening existing infrastructure is projected to be very costly.

New bridge design codes tend to be more conservative for short-span bridges and less conservative for long-span structures. This is not expected to change bridge costs significantly.

Trucks' use of bridges is generally controlled by a bridge formula, table or graph. In the United States, Bridge Formula "B" is used for the Interstate System and some States have used it to control LCVs and truck travel on State highways. The bridge formula is a simplified way of ensuring that certain levels of truck weight are spread over the appropriate number of axles at least a certain distance apart. Bridge Formula "B" is known to have several drawbacks, particularly its failure to remain true to its founding principles—no overstresses beyond 1.05 times design stresses on HS-20 bridges and beyond 1.30 times design stresses for H-15 bridges. Bridge Formula "B" tends to allow excessive weights when trucks have a higher number of axles and higher gross weights.

A search for a more adequate formula or table is under way in the United States. The Texas Transportation Institute (TTI) generated a formula that preserves the principles mentioned above and shows promise for more adequately controlling truck loads on bridges. Under the TTI Formula, it is possible to have gross weights greater than the current US cap of 36,320 kg (80,000 lb) without introducing excessive stress, as illustrated in Figure 7. Care must be taken in using the TTI Formula that highway pavement consumption is properly controlled by the use of a sufficient number of axles and/or axle groupings. The 3S2 class of trucks is currently limited by the 36,320 kg (80,000 lb) cap rather than Bridge Formula "B."

It is common practice for States to issue overweight permits for non-divisible loads that exceed the limits of Bridge Formula "B," both on a routine basis and also after checking and rating bridge capacities for occasional loads on key routes. Sometimes accompanying restrictions such as lower transit speeds or disallowing other vehicles on the bridge at the same time have to be specified.

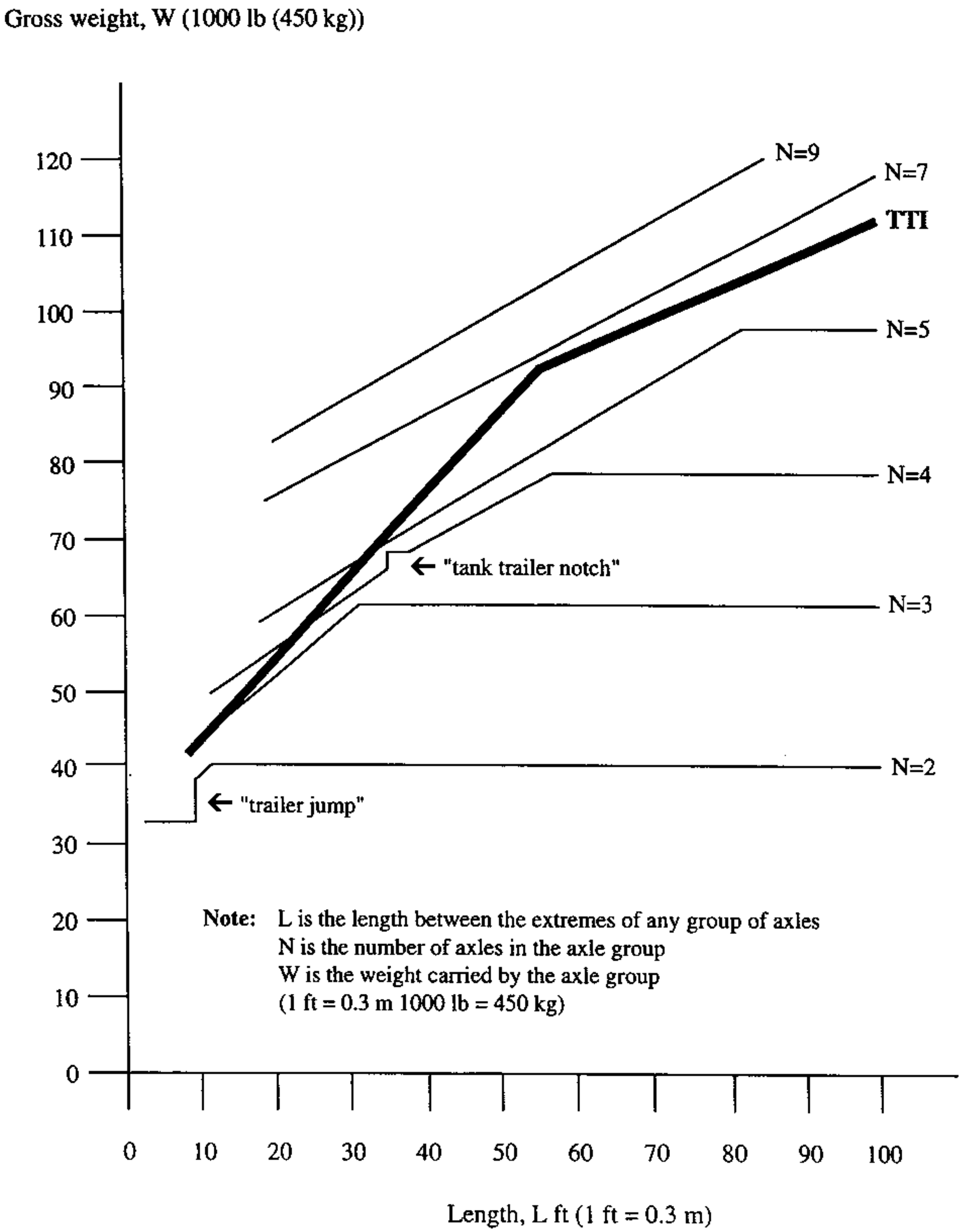


Figure 7. Comparison of Bridge Formula "B" and TTI Formula.

Europe

In France, bridges are designed for military loadings and are much less of a problem for heavier loads than pavements are. Bridges on major highways are relatively new and are not a major limitation on truck weights. France also has relatively high axle weight limits, with 13 tonnes (28,500 lb) permitted on single axles. France uses limit-state design for bridges and weigh-in-motion (WIM) data, and dynamic loads are taken into account in the design of bridges.

Total life-cycle costs are considered, including the use of reliability theories. France has a systematic bridge inspection program—fatigue and corrosion are important for steel bridges, while reinforcement corrosion is the main problem for concrete bridges. Residual lifespan of steel bridges is calculated based on monitoring of traffic, and monitoring is conducted for innovative or problem bridges.

Germany has about 34,000 bridges on federal roads, the majority of which are reinforced concrete bridges, with only 6.5 percent steel bridges. German National Industry (DIN) standards are in effect for the design of bridges, including live loads and design trucks.

While design standards apply, there are no standard designs—every bridge is effectively a prototype. German bridge design is assisted by traffic data that is published every year for approximately 100 sections of motorway.

The Eurocode Program–European Traffic Model is used for vehicle classification. No routine bridge monitoring is in place, but major inspections are conducted by engineers every 6 years. There is no formal bridge management system. However, a non-destructive testing program is underway, especially for prestressed concrete bridges with modules for a bridge management system are being developed.

2.4 Size and Weight Regulations

Setting a truck size and weight limit has very broad potential implications and cuts across many issues, including impacts on roads, bridges, productivity, accident risks, collision avoidance, accident severity, traffic flow, environmental protection, and mobility.

Truck size and weight limits are complex and detailed in their expression and wide in their variation among nations, states, and regions. They are also subject to lobbying, "ratcheting," local variations by permit, and periodic review. ("Ratcheting" is defined as an incremental increase in size or weight without a corresponding recovery of additional costs to the agency incurring the costs.) The study team did not set out to compile an exhaustive review of size and weight limits. Rather, this report attempts to identify the key issues.

2.4.1 United States Regulations

The gross weight cap of 36,320 kg (80,000 lb) in the United States is lower than other North

American and European countries. This has contributed to international compatibility problems, especially with international containers. The weight cap and the bridge formula restrict tridem-axle usage for vehicle configurations such as 3S3 tractor-semi-trailers and B-trains which have been found to be positive influences in the truck/highway interaction.

Partly due to the practice of "grandfathering" of State size-and-weight legislation, there is a high degree of incompatibility among States, with gross weight limits varying from 29,510 kg to 74,460 kg (65,000 lb to 164,000 lb). Some States allow movement of containers over 36,320 kg (80,000 lb) and the majority of States allow exemptions and variations in weight limits, often motivated by local economic and political influences.

As mentioned, ratcheting of limits involves the application of political pressure for incremental increases in weight limits without due recovery of incremental costs. There is, however, a view in the trucking industry that the strength of the infrastructure could, ideally, be adjusted to cope with much higher truck weights and that the limits are safety constraints. Beyond or, at least, in addition to safety, availability of financing is the ultimate constraint.

Higher limits could be tolerated and charging issues could be addressed. This is already being done with overweight permit conditions and fees in many states, although true cost recovery commensurate with the added highway wear caused is not currently being achieved for many of these permits. Cost recovery at the local level seems difficult and enforcement would be challenging.

Following the successful Canadian Royal Transport Association of Canada (RTAC) model (see Section 2.4.2), performance-based standards could be considered to establish an envelope of truck configurations that would interact acceptably with the highway, have higher safety performance properties, and offer productivity advantages to trucking operations. To be most effective, however, this would need to be done at the national level. Because such envelopes of vehicles are based on performance standards, this approach is particularly suited to harmonization across regions that may have different size and weight limits. Increased emphasis on envelopes of acceptable or preferred vehicle configurations would have the effect of taking some of the focus away from the limits themselves and contribute to the flexibility and differentiation necessary to improve the productivity of the nation's diverse trucking operations.

Although currently subject to a freeze on expanded operations, LCVs remain a key subject of debate within the overall size and weight issue. The AASHTO subcommittee on Truck Size and Weight of the Joint Committee on Domestic Freight Policy is investigating control measures such as revocable permits and revision of the bridge formula. The subcommittee has also advocated full cost recovery, safety enhancements for trucks over 36,320 kg (80,000 lb), the development of a national policy that recognizes regional differences, and the collection of more data on LCVs. It must be recognized that changing the basis of size and weight policy to a performance-based regime would mean that some current LCV configurations may not meet standards based on current recommendations for truck performance.

Size and weight policy is also influenced by the broader issues of national production, trade, modal split, intermodalism, and the environment. The FHWA is currently studying size and weight policy options in this context and is drawing on the extensive body of international research literature on the subject. Further consideration is being given to land transport standards under NAFTA, particularly the implications for size and weight policy for the United States as well as its trading partners.

2.4.2 Canadian Regulations

In the 1980s, Canada made pioneering efforts to include considerations of vehicle performance in size and weight policy. In response to the problem of the variations in limits among the provinces, an envelope of Canadian vehicles that could operate at the same limits throughout the country was developed. These vehicle configurations were based on performance standards and have become known as the RTAC vehicles.

This policy led to an increase in the use of the 3S3 16.17 m (53 ft) tractor-semitrailer (the trailer has a tridem group) that operates at 43,580 kg (96,000 lb) GVW, has improved productivity, and can be road-friendly. In terms of its appearance and operation in the road network, the 3S3 vehicle is similar to the current 3S2 US vehicle. This vehicle is also appropriate for carrying the heavier 40-ft containers. Another successful vehicle used in Canada is the B-train, which also has a tridem axle group.

The effects can be illustrated for the Province of Manitoba over a 20-year period:

	1974	**1994**
3S2	99%	58%
S3	0%	21%
B-train	0%	9%
other	1%	12%
	100%	100%

Acceptance of tridem axle groups across Canada was one of the main benefits of the performance-based approach adopted by RTAC. A uniform technical understanding was critical to achieving a uniform policy. This technical understanding encompassed pavement wear, vehicle stability, and control and safety.

Another area in which the Canadians provided some technical leadership is larger combination vehicles. Following analysis of the stability and control of various configurations, differential gross weight limits were introduced to allow better productivity with more stable vehicles. The gross weights allowed on various 8-axle configurations are shown below:

A-train double 53,120 kg (117,000 lb)
C-train double 58,570 kg (129,000 lb)
B-train double 62,650 kg (138,000 lb)

The RTAC recommendations were implemented in the Memorandum of Understanding (MOU) on Vehicle Weights and Dimensions that became effective across Canada on July 1, 1989. By 1992, a shift was observed from the use of 7-axle A-doubles towards the use of 8-axle B-doubles on the Canadian National Highway System. Increased use of the 3S3 tractor-semitrailer was also observed, along with reduced use of the 3S2 tractor-semi-trailer. Projections to the year 2002 indicate a substantial increase in 8-axle B-double usage, further increase in the use of 3S3 tractor-semitrailers, and reduction in the use of 5-axle semis and straight trucks.

2.4.3 Mexican Regulations

Mexican size and weight limits were reviewed in 1980 and again in 1994. While the earlier review primarily considered pavement damage, bridge limitations and evidence of fatigue damage were major factors in the latest review. In Mexico, gross weight limits depend on road class (A, B, or C). Significant changes have been introduced recently. For A-roads, gross weight of the 3S2 increased from 41,500 kg (91,400 lb) to 44,000 kg (97,000 lb), while the 9-axle double trailers combination was reduced from 77,630 kg (171,000 lb) to 61,740 kg (136,000 lb). The gross weight limit for the 3S3 is now 48,580 kg (107,000 lb), which is higher than in Canada and well above the US 36,320 kg (80,000 lb) cap.

The 1994 size and weight study was comprehensive and encompassed information on the value of loads, prioritization of roads, and information for standards and regulations. Such studies require surveys, which may have reliability problems related to the fact that Mexico currently has no national motor vehicle enforcement system of weighing and no checking stations for trucks.

It was found that 5-axle and 6-axle trucks carry out most of the transport task, while 9-axle doubles have relatively little use because they are mainly suited to high-cube freight, relatively little of which is hauled in Mexico. In terms of commodities, a large amount of freight is raw material of low value—manufactured goods are in the minority. Because so much dense freight is hauled, Mexican trucks and trailers tend to be reinforced to permit the maximum cargo- carrying capacity. The share of different truck configurations in Mexican highway haulage is reflected in the following figures:

	tons	**ton-miles**
5-axle	33 percent	29 percent
6-axle	29 percent	38 percent
9-axle	2 percent	2.5 percent

Economic analysis of optimum weight limits was carried out for conditions in Mexico. Taking into account vehicle-operating costs and infrastructure costs, the optimum gross weights were found to be:

5-axle	50,000 kg (110,000 lb)
6-axle	60,000 kg (132,000 lb)
9-axle	90,000 kg (198,000 lb).

While economically efficient, implementation of these high limits would place a financial strain on road construction and maintenance, and some means to return funds to the highway sector would need to be found. As a result, these limits were not implemented.

2.4.4 International Compatibility of Limits—North America

Each jurisdiction approaches size and weight regulations differently. Limits in the United States tend to be controlled by the bridge formula, while Mexico controls by vehicle configurations and axle groups and Canada tends to set the vehicle configuration, which then dictates the appropriate weight limits.

At this stage, only a "lowest-common-denominator" vehicle could travel unimpeded through all three countries. Mexican limits and, to some extent, Canadian limits result in a shorter, heavier vehicle than the in United States.

Weight Limits

For gross weight, there are significant differences among countries. For the 5-axle truck, the largest viable vehicle common to all three countries, gross weight limits are as follows:

US	36,320 kg (80,000 lb)
Canada	39,500 kg (87,000 lb)
Mexico	44,000 kg (97,000 lb)

Note: These comparisons show clearly the lower weight limits in the United States. However, it should be borne in mind that permit limits allowed on a State-by-State basis can be much higher, with 45,400 kg to 47,220 kg (100,000 lb to 108,000 lb) being very commonly permitted for 5-axle vehicles carrying non-divisible loads.

With regard to longer combination vehicles, predominant configurations vary among the three countries and gross weights vary significantly, as follows:

US	A-train double trailers	48,100–74,500 kg (105,000–164,000 lb)
Canada	A-train double	53,000 kg (117,000 lb)
Mexico	A-train double	59,000 kg (130,000 lb)

Aside from the wide variation in LCV limits within the United States, there is some commonality among the three countries with regard to LCV weights.

Dimension Limits

For the largest vehicles generally allowed on selected networks in each country, the overall length limits are as follows:

United States: No overall length minimum limit, but semitrailer length limit required by Federal law to be no less than 14.63 m (48 ft) (with most states at 16.17 m (53 ft) and up to 18.3 m (60 ft) in some states) and, similarly, twin 8.5 m (28 ft) trailers.

Canada: 23 m (75.5 ft).

Mexico: 19.5 m (64 ft).

Mexico is clearly more restrictive on overall length, due to existing geometric limitations, and it is not possible to run many US trailers within the Mexican limit using typical US tractors with sleeper cabs. Some US trailers, when connected to typical US tractors, also cannot meet the Canadian overall length limit of 23 m (75.5 ft).

In the case of longer combination vehicles, the following overall length limits apply in each country:

United States: No national limit, states vary from 29–33.9 m (95–111 ft) cargo-carrying length often limited to 29 m (95 ft)

Canada: 23 m (75.5 ft)

Mexico: 31.1 m (102 ft).

For LCVs, there is some commonality between the United States and Mexico, but Canada is much more restrictive on overall length.

2.4.5 European Commission Regulations

The European Economic Community's regulations for size and weight, principally under Directive 85/3EEC, now apply to 15 countries. Overall, there are nine Directives affecting size and weight limits, and they apply only to international transport. Many countries have higher limits and intra-country operations may be carried out at higher limits.

Under current EEC Directives, the gross weight limit is 40 tonnes (88,100 lb). Vehicles carrying ISO containers and engaged in "combined transport" (hauling to or from rail lines) are permitted 44 tonnes (96,900 lb) gross weight. The following axle weight limits apply under EEC Directives:

Steer axle	No specific limit
Single axle (driven)	11.5 t (25,300 lb)
Tandem axle	18 t (39,650 lb)
Tandem axle (air suspension or equivalent)	19 t (41,850 lb)
tridem	24 t (52,860 lb).

Current EEC dimensional limits are:

Overall Length	
tractor-semitrailer	13.6 m (40.9 ft)
road train (truck-trailer)	18.75 m (60.2 ft)
Load Length	
semitrailer	12.0 m (39.4 ft)
road train (truck-trailer)	15.65 m (51.3 ft)
Width	2.5 m (8.2 ft)
Height	4.0 m (13.1 ft)

A new Directive has been proposed that would allow the following increases in weight and dimension limits:

- Maximum gross weight of 44 t (96,900 lb) over 6 axles.
- Width increase to 2.55 m (8.37 ft).
- Road train overall length increase to 18.65 m (61.2 ft).

However, even though it would potentially have reduced truck miles by 5 percent, this proposal has encountered significant opposition and has not been passed by the European Parliament. Several countries are strongly opposed to the weight increase; in particular, rail interests are opposed, and there is a strong lobby in favor of "green" trucks that would be kinder to the environment and would be safer. There are also concerns about bridge limitations in certain countries, including Germany. On the other hand, Sweden and Finland currently have significantly higher weights and oppose being forced down to 44 tonnes.

The European transport industry continues to strive for a gross weight increase to 42 t–45 t (92,500 lb–99,100 lb), and there is also a drive for dimensional increases for road trains (to 19 m, or 62.3 ft, in overall length). It is still not possible to carry 45 ft containers on European roads.

Optimization of volume continues to be a driving force in the European transport industry—with smaller tires and higher ceilings in trailers the maximum load height increased from 2.5 m (8.2 ft) to 2.7 m (8.85 ft). While the road train has always had a cube advantage over the tractor-semitrailer, the gap has been narrowed over recent years.

While the EEC size and weight regulations have been implemented in a relatively uniform manner in European countries, the United Kingdom and Ireland were temporarily exempted from introducing the current 40 tonne (88,100 lb) gross weight limit, because of the need to upgrade bridges. This derogation will end in 1998. Sweden has the highest gross weights, with 60 tonnes (132,000 lb) permitted for the largest 7-axle combination vehicles; these vehicles are 24 m (78.7 ft) in overall length and 2.6 m (8.53 ft) wide.

2.4.6 Enforcement of Limits

Truck weight enforcement remains a problem in all countries because fixed weigh stations can be bypassed. New technology is being developed and used in order to increase the efficiency of weight enforcement. Weigh-in-motion (WIM) technology is now maturing to the extent that accuracy and reliability is improved, but it is still necessary to slow traffic to ensure sufficient accuracy for weight enforcement. Weigh-in-motion is not used for axle-weight enforcement purposes in the United States, but is used for screening of overweight vehicles which are then directed to a static weighing device of accredited accuracy. WIM equipment is also being integrated with automated devices to check length and height dimensions. Many States have employed mobile enforcement teams to supplement permanent weighing installations.

On high-volume truck routes, WIM is useful in minimizing traffic and safety problems. Trucks often need to be stopped at border crossings for other reasons, such as registration and safety checks, and ITS technologies are expected to solve some problems in these areas.

WIM can be undetectable to truckers and provides the most realistic picture of truck loading. For example, the use of bridge-based WIM systems in Michigan has provided information on the vehicle configurations and commodities that tend to be the worst overloaded. The data indicated that 11-axle trucks tend to be overloaded, that belly axles are the worst-offending individual axles, and that certain commodities tend to be involved in overloading.

Weight enforcement is currently in its infancy in Mexico and surveillance methods are currently being reviewed with the intention of using the most efficient combination of fixed and mobile enforcement methods and to the possible involvement of the private sector. A recent survey of truck sizes and weights in Mexico found that 51 percent of 6-axle trucks exceeded the gross weight limit and that 65 percent of tridem axle groups and 52 percent of tandem axle groups were overweight. It was also found that 61 percent of 6-axle vehicles were overlength and 84 percent of 9-axle vehicles were overlength. These results were attributed to new vehicle models and outdated standards and limits.

Overloading is considered a major problem in Europe and the available resources for enforcement are limited. There would appear to be less emphasis on enforcement in Europe than in the United States. However, France is actively collecting WIM data, which indicates that overloading is prevalent; and Germany, a major through-zone for long-distance trucks in Europe, is increasing its checks of load documents. There are increased penalties for overloading in Sweden, and offloading is required if the overload exceeds 10 percent.

In Europe, overloading is common on the single-drive axle in 5-axle tractor-semitrailers because it is difficult to load these vehicles with the correct load distribution among the axles.

2.4.7 Strategies for Optimizing Limits

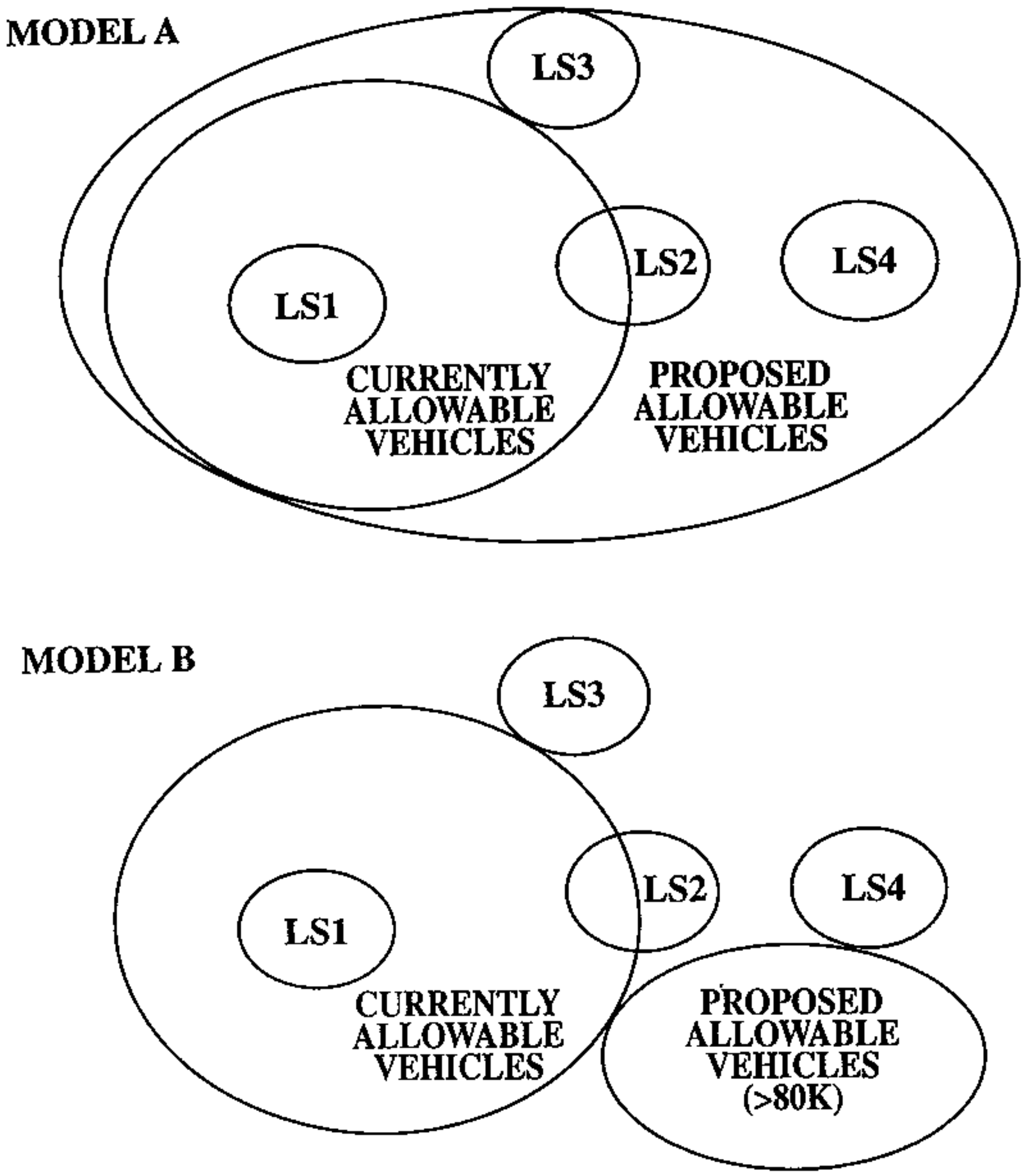
Because truck configurations are strongly influenced by size and weight limits, it is important to try to predict the changes in the truck fleet that may occur as results of any change in limits. Some techniques have been developed for doing this, but it remains difficult to predict the rate of penetration of new truck configurations under new limits. With regard to encouraging the use of B-doubles, the Canadians found that a clear message, coupling preferred configurations with load benefits, produced increased usage of the preferred vehicle. This effect was blunted by other changes to dimension limits which produced unexpected results—it was found that concurrent increases to semitrailer lengths made it attractive for some carriers to convert from A-doubles to semis, rather than to B-doubles.

Ideally, an iterative analysis procedure should be followed to arrive at more effective size and weight limits. This should start with productivity and safety objectives, and include the assessment of truck performance as well as road performance and cost recovery. It is essential that engineering performance be understood prior to legislative action.

At the least, changes in limits should avoid known problem areas, as shown in Figure 8. Model A illustrates the effects of non-selective size and weight limit increases, and Model B represents increases restricted to better-performing vehicle configurations. Strategically, a regime of new, more productive, better-performing vehicles should be investigated. This new regime of vehicles should out-perform many current vehicles. It could also mean that some currently-used LCVs would have to be modified.

One potential problem with developing an envelope of acceptable vehicle configurations is the great diversity of US trucking needs. The Canadians created only four classes of envelope vehicle and more flexibility would eventually be required in the United States. In considering the adoption of this approach in the United States, the technical challenge and cost involved in developing vehicles which actually perform better should not be overlooked. There is also potential for *restricting* innovation by developing overly specific truck designs and configurations.

While it is necessary to consider size and weight strategy on a broad basis, and this should probably include performance-based standards for vehicles, the implementation of such standards would probably mean the purchase of new trucks and trailers for the expanded operation of more productive vehicles and fleets. Because there is a large investment in the existing national trucking fleet, carriers prefer to make incremental changes to improve productivity while minimizing the need for reinvestment in new vehicles and equipment. This demands careful consideration of the required balance of outcomes. There is a strong view among those interviewed that a win-win situation should be sought—serving the productivity needs of truckers and reducing highway costs, while improving safety performance. There is another view that, in the short term, it may be acceptable to simply charge for any incremental pavement and bridge consumption over and above the current 36,320 kg (80,000 lb) vehicle without changing its design. This option may not, however, adequately address safety-performance concerns.



KEY

LS1 - existing designs with poor performance
LS2 - designs with poor braking efficiency
LS3 - designs with poor rollover thresholds
LS4 - designs with poor directional responses

Figure 8. Set Diagrams Illustrating the Effects of Selective and Non-Selective Size and Weight Increases

Some suggested there may be a role for States or regions to operate as size and weight "laboratories," trying out productivity, safety, and infrastructure initiatives. Care would be needed in properly evaluating the impacts of such experiments and expanding such experiments to other States.

Whatever strategies for change may be considered, the trucking industry has requested any changes be swift and clearly expressed, so that truck-purchasing decisions can continue to be made. There is some concern that the more complex the size and weight process, the slower will be the implementation and the greater the industry uncertainty, which would have its own negative effect on the economics of the trucking-supply industry.

2.4.8 Productivity and User Costs

North America

There is little doubt many in the United States trucking industry want increased weight limits, revolving around raising or removing the gross-weight cap, compatibility among States, and increased flexibility in regulations. These are all ways of reducing truck-operating and shipper costs.

The annual costs of operating the nation's trucking fleet are at least as significant as the annual costs of building and maintaining the highway system. There are significant benefits in reducing trucking costs, and the trucking industry is investigating the costs of poor roads to operators. Rough roads reduce the life of the vehicle chassis and key components, and the additional weight needed to ensure truck durability may cost a truckload carrier up to US$1000 per year. Rough roads also have an adverse effect on the performance and occupational health of an aging population of US truck drivers.

The scanning team was presented some examples of increased trucking productivity to serve regional or State-specific needs. Two are listed below.

- The 74,460 kg (164,000 lb) Michigan limit, introduced in the 1940s to accommodate the steel industry, is the ultimate example of raw productivity improvement. This has now been extended to other commodities, giving the State of Michigan a competitive advantage and encouraging a corridor of industrial development. However, this does not suit all truckers, and the vast majority of Michigan trucks are 5-axle vehicles, not 11-axle vehicles.

- The LCVs developed in the Northwest to serve regional economic needs.

Europe

The European trucking industry is expressing strong demands for more highways. However, there is little dialog between the trucking industry and highway managers with regard to the industry's needs for ride quality and level of service. The design and maintenance standards for highway systems are set by highway administrators with little specific input from users.

The greatest level of customer involvement in the management of highways probably occurs for toll roads, where the views of users are obtained on a regular basis. While most complaints are not about pavement quality, users do require smooth riding conditions.

2.4.9 Cost Recovery

North America

Industry officials advocate better roads and the industry states a willingness to pay its fair share of use-occasioned highway costs. A number of cost-allocation studies have been carried out at both the State and Federal levels. Truckers should pay an equitable share of infrastructure costs and there is a strong view that they are currently underpaying at the higher weights. Truckers and other highway interest groups argue against road-use taxes going to deficit reduction and other diversions.

The FHWA is currently conducting a national cost allocation study. State officials have encouraged development of methodologies that can be transferred to the States.

In Mexico, various methods of user charges and taxes are being studied, but there is no specific mechanism for earmarking such funds for road building. It is interesting to note that toll-road fees, particularly the relationship between cars and trucks, are not based on pavement damage, but are set more on commercial considerations—recovery of investment in too short a period with overly optimistic projection of usage.

Europe

There is a perception that trucks are underpaying for infrastructure use in Europe, while cars are overpaying. Truck charges are based on infrastructure wear and do not account for external costs such as environmental effects. Charges on trucks are expected to increase in some form. There is some harmonization on toll road charges for trucks, with about seven countries having a single toll system called Vignette. However, neither fuel tax nor registration charges are shared among countries. The long-term goal is to track trucks across borders and charge proportionately.

While the benefits of returning road-use charges directly to highway budgets are widely recognized, the tendency in Europe is to move away from dedicated funding. Although attempts have been made for about 10–12 years to establish dedicated funding sources under the EEC, this has proved to be a major problem, primarily because the public views it as another tax—there are already many charges for autoroute use, including fuel tax, tolls, and now a tax on the toll.

Road users believe they have subsidized the rail system for many years. Dedicated funding is being advocated as appropriate means of redressing infrastructure deficiencies in Eastern Europe.

A number of attempts to harmonize circulation taxes have been made over the past 20 years. The United Kingdom maintains relatively high charges, while those in the Netherlands are relatively low.

2.4.10 National Freight Policy

United States

Federal Government policy on freight transportation is being reviewed in response to rapidly increasing demand for freight and the fact that the United States has a mature infrastructure which, though not completely fixed, will inevitably be slow to change. This requires rethinking the regulatory framework within which the freight industry operates.

There is a current movement for a seamless, multimodal freight system that would involve some elements of cooperation among modes—the most appropriate mode being used for different types of operations—and for the removal of existing bottlenecks in the system. There is also a need to reevaluate the financing mechanisms for the national highway network and to maintain the economic treasure that is the Interstate System. In relation to the changing environment of freight policy, there are significant opportunities to depart from the current methods and to depart from the old ways of incremental changes where, due to constant pressure and evolution, small changes have occurred from time to time. There is currently an opportunity to come up with a new way of setting freight policy.

A major series of research projects concerning national freight policy and size and weight is currently being carried out by FHWA and AASHTO. These projects take into account the fact that interrelationships regarding commercial vehicle/infrastructure interaction are extremely complex and very connected, involving shippers, carriers, and infrastructure owners and managers. The projects are investigating the impacts of size and weight policy on trade, productivity, safety, other modes of transport, energy consumption, and the environment.

Europe

European road transport is regulated by a quota system applying to carriers that wish to travel in three or more countries and to cross borders without barriers. The Commission of European Communities authorizes national ministries to distribute these authorizations to carriers.

European intermodal policy includes the concept of charging commercial vehicles for externalities.

2.5 Safety

It is unusual for a truck factor or some aspect of the truck's performance to directly cause an accident. Accident causes usually involve a combination of factors, including some key triggering events that are most often precipitated by the behavior of drivers. It is not clearly understood how factors associated with truck size, weight, controllability, and stability contribute to precipitating crashes. Nevertheless, size and weight regulations indirectly affect vehicle performance and safety more than any other vehicle design factor. Size and weight policy not only affects vehicle performance and potential crash risk, but also affects exposure to trucks in the highway system.

In general, there is insufficient accident data to predict the effect of size and weight regulations or different vehicle configurations on crash potential. The necessary quantity and depth of accident data required to do this are not available.

In response to the insuffiency of detailed accident data, efforts are under way to base size and weight decisions on engineering performance data—the measurement or prediction of certain performance characteristics of vehicles that are believed to be safety-related. A good example of such a performance characteristic is rollover threshold, which is closely related to the truck's center of gravity height. However, rather than abandon accident analysis as a source for decision making, the feasibility of conducting improved accident collection and analysis should be continued.

North America

One notable attempt has been made by US Federal Government and industry, Trucks Involved in Fatal Accidents (TIFA), to derive finer detail from truck fatal accident statistics, the class of crash that is usually investigated and reported most extensively, and combine this with truck-trip information. This study, which considered 5-axle trucks only, showed the following results:

- Limited access facilities are much safer for 5-axle trucks.
- Bobtail tractors have much higher risk, primarily attributable to instability, especially on wet pavements.
- 36,320-kg (80,000-lb) trucks have a higher risk than trucks below 22,700 kg (50,000 lb). The difference is attributed to stability property differences; e.g., higher center of gravity.
- Some aspects of engineering performance seem to have a strong influence, particularly braking efficiency, rollover threshold, and rearward amplification.

Concerns which have been identified with the safety of trucks in general include:

- The longer stopping distance and directional capability of trucks compared with cars.

(Although significant advances have been made to improve braking through the use of ABS technology, which will be required, per the amended FMVSS 121, on all truck tractors, effective March 1997 and on all other vehicle types by March 1999.)

- Truck crash-worthiness—truck occupant protection and reduction of aggressivity in truck/car frontal collisions; e.g., underride.
- The conspicuousness of trucks at night, and the potential role of reflectorized treatments applied to the sides and backs of trucks, to improve conspicuousness.
- Effects of driver fatigue on accident causation.

The American Trucking Associations (ATA) has stated that it regards safety as its first priority and supports the following ongoing safety initiatives: commercial driver's license, drug testing, increased roadside inspections, antilock brakes, industry safety audits, road-watch programs, incident management programs, bans on radar detectors, and the elimination of commercial-zone exemptions.

It should be pointed out that the trend in truck safety has been favorable. During the period 1982–94, trucks involved in fatal accidents decreased by 39 percent, and truck-occupant fatalities by over 50 percent, while VMT increased by 43 percent. In multivehicle accidents involving trucks, the other driver is more often responsible, and the majority of crashes are caused by driver errors, not equipment defects.

Further initiatives involving the use of better-performing truck configurations will probably require some form of encouragement. It may be unrealistic to expect the trucking industry to adopt safer, more expensive component options such as C-dollies or air suspensions without some incentive for the use of these improved vehicle components. These have an associated cost or a tare weight penalty, in relation to current equipment.

In Mexico, safety is receiving increased attention, and initiatives are being developed in the areas of control over driving hours, requirements for hazardous materials vehicles, improvement of road geometry, and bus driver qualifications.

Europe

In Europe, trucks are generally not seen as a major safety problem. This situation is partly brought about by a long history of truck-safety innovations and controls on truck drivers, particularly the mandatory use of tachographs.

European highways represent a relatively high-speed environment, with high speeds permitted on motorways in several countries. There is a move toward moderate speeds in Europe and 120 km/h (74 mph) is being recommended as a uniform European speed limit.

Antilock brakes have been optional for years and are now virtually a standard design feature of trucks throughout Europe. Cab crashworthiness standards were pioneered in Sweden many years ago, along with rear impact standards. European drivers seem to have learned to derive the benefits from ABS. Reciprocal driver licensing is in place throughout Europe, with uniform licensing requirements in all countries.

However, means of collecting truck accident data vary among countries. Due to the severity of truck accidents, there is a need for better and more uniform data on truck crashes throughout Europe. European truck manufacturers are actively involved in the collection of truck-crash data and in the introduction of new safety features in trucks. For example, Volvo is researching both active and passive safety.

Initiatives to improve active safety include the driver cabin environment, vehicle handling and stability, braking, and lighting. It is believed that about 1,300–1,350 mm of space is required for the driver to perform well, and that cabin temperature and noise significantly affect driver performance. Research into the use of ultraviolet headlights is being undertaken to increase driver vision.

Passive safety is being addressed in relation to the reduction of truck driver injuries in single-vehicle accidents and in collisions with other trucks. Interior surfaces are being modified to be more driver-friendly. While seat belts have been effective in reducing truck driver fatalities, research is proceeding for the introduction of air-bag restraints to be used in conjunction with seat belts in trucks.

Passive safety is also being addressed through the use of lowered and energy-absorbing front bumpers, aimed at reducing the severe consequences of truck collisions with other road users. European legislation is being prepared for such bumpers. In truck collisions with lighter vehicles, the occupants of the other vehicles are significantly at risk unless some countermeasures are adopted.

The engineering performance of trucks has also been researched extensively in Europe by truck manufacturers and universities. A draft International Standards Organization (ISO) proposal has been prepared for the testing of lateral stability of trucks; this proposal incorporates various criteria, including rearward amplification and yaw damping.

Existing European truck configurations, truck-trailer, truck-center-axle-trailer, and tractor-semi-trailer, have been studied for their engineering performance quality. The tractor-semitrailer is very stable in terms of oscillatory stability, but has some other disadvantages. There is some tendency to use steerable or self-steering trailer axles, but self-steering axles reduce stability; it is preferable to use a positively steered axle, or force-steered axle.

The center-axle-trailer road train has only one articulation point, but the roll constraint is removed. Damping is low and poor geometry may result in zero damping—the combination could also become oversteering. It has been found that yaw damping increases with shorter rear overhang to the hitch and with shorter trailer wheelbase. Trailer movements are transmitted to the truck. This configuration is not considered to have desirable engineering performance. It has become popular for volume freight and is considered to be a product of size and weight regulations.

The truck-trailer has the extra articulation point, and therefore rearward amplification has been found to be relatively high under the European 18.35-m length limit. Greater length and longer wheelbases would be desirable in order to improve the engineering performance of this configuration.

Road trains could be less safe than tractor-semitrailers, because lateral stability is reduced by the additional articulation point. However, insufficient accident data are available to determine whether the lesser engineering performance of European road trains translates to increased crash risks.

Research is being conducted into the compatibility of braking between trucks and trailers, and the adequacy of current European braking regulations is under consideration. Another innovative truck-safety system being researched by Hannover University is on-board measurement of skid resistance via monitoring of tire microslip between driven and non-driven axles.

2.6 Intermodalism and Intelligent Transportation Systems

United States

Containerized cargo has great potential for intermodal means of transportation, but the sizes and weights of containers are subject to influences outside the control of the United States. Many of these containers originate in other countries, where they could be subject to different size and weight rules. Current size and weight rules restrict the movement of containers and may therefore be restricting intermodalism. It is not possible to haul heavier containers on standard, 5-axle tractor-semitrailers and remain within current weight limits, except where States permit them as non-divisible loads.

Another avenue to improve the efficiency of intermodal transfers is the use of ITS transponders on containers. Standardization and uniformity of transponders is a key issue in furthering the use of transponders on containers or vehicles. This issue is currently being addressed by FHWA, AASHTO, ITS America, SAE, and the trucking industry in general.

Innovations in the use of containers for new applications promote intermodalism. For example, in Michigan, automobiles are now being shipped in containers. This has proved to have further efficiency gains in relation to on-site storage at dealers' premises. Michigan is also investigating specific truck routes for intermodal vehicles and is also building a new tunnel for double-stacked container trains through to Canada. This tunnel is expected to divert container traffic from other roads.

Currently, containers are built to a variety of standards for dimensions and weight capacity, and this creates difficulties for uniform vehicle size and weight policies. In order to assist with the reform of size and weight policies and limits, it is important to develop intermodal compatibility throughout North America and also globally.

ITS/CVO demonstration projects have been under way for some years, linking electronic license plates, WIM installations, AVI and AVC, and vision technology. These projects have shown benefits in reducing delay at border crossings, preventing overweight vehicles, and tracking cargo. The productivity benefits to truckers are being evaluated.

ITS developments are also expected to have a profound effect on truck safety. On-board monitoring devices, enhanced cruise control, and fatigue-recognition devices are examples of truck-related ITS technologies currently under development.

Europe

Intermodalism in Europe is supported by the higher gross weight limit of 44 tonnes (96,900 lb), applied to vehicles carrying containers in combined transport.

The Port of Rotterdam, as part of its world-class container facilities, has a terminal in which containers are handled entirely by automation. This is the first of its kind and truly provides an automated highway for freight.

The majority of European containers to and from Rotterdam are handled by road, with fewer going by inland waterway, and the fewest by rail.

There is no concerted effort on the part of the European Commission to develop ITS in Europe. ITS is primarily being driven by industry, and some success is being achieved in development common standards for toll technology.

2.7 Organizations

North America

Because size and weight policy influences so many functional responsibilities of government, shippers, and trucking industry groups, there is not a single home for determining optimum size and weight policies. This is demonstrated most clearly by the fact that it is difficult to identify, at Federal or State Government levels, where the key issues of (i) infrastructure wear and (ii) safety come together to produce factually based size and weight policies. It is important to incorporate trucking industry information in determining such policies, and there is a need for industry cooperation in this regard.

While these issues and information sets are not brought together in a clearly identifiable manner in any North American country on a continuous basis, periodic reviews that encompass many of the relevant issues are conducted.

The Transportation Association of Canada (TAC, formerly RTAC) provides one example of a policy-interested, technically based organization covering the interests of the federal government, provinces, railways, and research organizations; and which engaged the trucking industry to join in the major technically based RTAC weights and dimensions study, carried out in the mid-1980s. It was this study that created the cross-Canada envelope vehicle configurations and associated performance standards that have received so much attention in this scanning review.

The RTAC study was in turn supported by the National Research Council's Center for Surface Transportation Technology (NRC-CSTT), which operates on a scientific basis, deliberately separate from direct government control.

The University of Michigan Transportation Research Institute (UMTRI) is an autonomous research institute mainly concerned with vehicle performance and safety that relies primarily on contract research for its funding.

Europe

The Commission of the European Communities (EEC) consists of 20 Commissioners, appointed for terms of five years, each responsible for a particular portfolio, or Directorate-General (DG). Most of the EEC's work occurs within the Directorates and most of the trade offs between disciplines are done at the national level. The term "European Union (EU)" applies to the totality of the European economic and social entity, and embodies the Commission, Council of Ministers, and the Parliament. The Commission only addresses economic issues. The European Commission (EC) takes an essentially reactive role. It does not have a mandate to seek out and research potential improvements in productivity or safety.

The trucking industry has strong input at the national level. In addition, the Commission invites the major European industry associations to become involved in the development of proposals. The International Road Union (IRU) is the major carrier-lobbying organization and is based in Geneva, Switzerland.

The European Conference of Ministers of Transport (ECMT) has about 30 members, including Eastern European countries (the United States and Canada are associate members). ECMT carries out synthetic research for bridging technology and policy and covers all surface modes of transport. There are working groups on road, rail, and combined transport. Much of the work involves aligning European regulations with European Union regulations.

Each European country has unique aspects and organization dealing with truck issues. The Swedish Department of Transport, the Swedish Road and Traffic Research Institute (VTI), and Volvo Truck Corporation are a good example of beneficial, long-term cooperation in researching and addressing many truck performance, safety, and infrastructure issues.

3. UNITED STATES PERSPECTIVE ON ISSUES IN HIGHWAY/COMMERCIAL VEHICLE INTERACTION

The scanning group's consolidated findings in relation to the goals and objectives of the scanning tour (see Section 1.2) are presented in this section. These findings convey the team's collective opinion.

To provide a further perspective on these findings, and to provide a flavor of the many interesting observations gathered during the scanning tour, pertinent comments arising during meetings and deliberations are included in *italics*. ***These comments came from informed individuals, but do not necessarily represent the group's collective findings.***

3.1 Role of Size and Weight Limits

3.1.1 Influence of National Freight Policy

Regulations controlling truck size and weight limits have very broad potential implications and cut across many otherwise unrelated issues, including impacts on trucking productivity, roads, bridges, safety, traffic flow, environmental protection, and community mobility. Size and weight limits are an important component of a comprehensive national freight policy that needs to account for infrastructure life-cycle costs, user benefits, user costs, external costs, environmental impacts, and safety.

Interrelationships regarding commercial-vehicle/infrastructure interaction are extremely complex and very connected, involving shippers, carriers, infrastructure owners and managers. Current FHWA projects are investigating the impacts of size and weight policy on productivity, safety, highway infrastructure, other modes of transport, energy consumption, and the environment.

3.1.2 Compatibility

From an international perspective, each North American jurisdiction approaches size and weight regulations differently. Gross weight limits in the United States tend to be controlled by the bridge formula and 80,000 lb cap, while Canada and Mexico tend to work from axle-weight limits for particular axle groups and vehicle configurations, resulting in higher payloads. US weight limits are also low by European standards. On the other hand, the United States has the most liberal length limits, providing advantages for carriers of light freight, with Canada being more restrictive and Mexico considerably more restrictive. With regard to larger combination vehicles (LCVs), which may be restricted to certain routes or regions within each country, US gross weight limits (with the exception of Michigan) are lower than those in Canada and Mexico, and length limits are similar in the United States and Mexico, with Canadian LCVs being more limited in length.

"Many different truck sizes and weights are allowed in the various regions within North America."

"At this stage, only a 'lowest-common-denominator' vehicle could travel unimpeded through all three countries."

A further perspective on US gross weight limits is provided from Europe. US regulations for a 5-axle tractor-semitrailer limit gross weight to 36,320 kg (80,000 lb) and US Bridge Formula "B" requires 15.5 m (51 ft) extreme axle spacing, while in Europe 40 t (88,100 lb) is permitted on a 5-axle vehicle with no extreme axle distance requirement.

Within the United States, the gross weight cap of 36,320 kg (80,000 lb) significantly restricts increases in trucking productivity. This limit restricts the use of vehicle configurations such as 3S3 tractor-semitrailers and B-doubles which have been found to be positive influences in the truck/highway interaction. Partly due to the practice of "grandfathering" of State size and weight legislation, there is a large degree of incompatibility among States—gross weight limits vary from 29,500 kg (65,000 lb) to 74,460 kg (164,000 lb), depending on the number of axles. Some States allow movement of containers over 36,320 kg (80,000 lb) and the majority allow exemptions and variations in weight limits, often motivated by local economic and political factors. Permit limits allowed on a State-by-State basis can be much higher than 36,320 kg (80,000 lb), with 45,400 kg to 47,200 kg (100,000 lb to 108,000 lb) being very commonly permitted for 5-axle vehicles carrying non-divisible loads.

"Any review of TS&W regulations should assess the benefits and costs of not changing the regulations as well as the benefits and costs of changing them."

"The process of permitting oversize and overweight trucks varies within the states and within North America. There are very few agencies that use a weight distance tax to tax the amount of overweight and exposure in issuing a permit."

The United States also has a history of ratcheting of limits. "Ratcheting" involves the application of political pressure for incremental increases in weight limits, without due recovery of incremental costs. Unless improved forms of size and weight analysis can be developed and base conditions can be firmly established, it is likely that pressure for ratcheting will continue. There is a view in the trucking industry that the strength of the infrastructure may, ideally, be adjusted to cope with much higher truck weights and that the corresponding level of safety performance needs to be established.

The US trucking industry is seeking increased weight limits, revolving around raising or removing the gross weight cap, compatibility among States, and increased flexibility in regulations. These are all ways of reducing truck-operating and shipper costs.

It may prove difficult to address the above issues unless organizational problems are also considered. Because size and weight policy cuts across so many functional arms of government and trucking industry groups, it does not have a single home and tends to be reviewed periodically in an *ad hoc* manner. Industry cooperation with government agencies at the local, State, and Federal levels needs to be increased.

3.1.3 Potential Means of Change/Search for Optimization

Performance-based standards can be used to establish an envelope of truck configurations that are deemed to interact acceptably with the highway and offer productivity advantages to trucking operations. This would have to be done at the national level to ensure uniformity and could be based primarily on engineering performance related to infrastructure consumption and safety. Because the envelope of preferred vehicles is based on performance standards, this approach is particularly suited to harmonization across regions which may have different size and weight limits. The development of performance standards and associated vehicle configurations should take into account the flexibility and differentiation needed to improve the productivity of the nation's diverse trucking operations. Performance envelopes could be developed for (i) nationwide vehicles, (ii) vehicles carrying containers, (iii) permit vehicles carrying non-divisible loads, and (iv) LCVs.

> *"The methods to assess truck performance already exist—they now need to be used effectively in underpinning size and weight policy."*

> *"A basis for setting performance standards is the selection of an appropriate level of risk for each performance measure, as was done in Ontario with respect to its bridge formula."*

Appropriate size and weight limits for vehicles in the preferred envelopes could be developed in an iterative manner, taking into account engineering performance in relation to current vehicles, productivity improvements, safety, effects on the infrastructure, and appropriate cost recovery for road consumption. An overall goal of improved productivity together with reduced road wear and improved safety is a feasible option.

The likely effectiveness of adopting less ambitious goals is a somewhat controversial issue. Some believe that a more gradual, incremental approach such as making way for the 6-axle tractor-semi-trailer and the Western double at appropriate weights, would be preferable, together with revokable permitting of vehicles above 36,320 kg (80,000 lb).

Whatever strategies for change may be considered, the trucking industry has requested any changes be swift and clearly expressed, so that truck/purchasing decisions can continue to be made with minimal disruption to the market place. Industry uncertainty would have its own negative effect on the economics of the trucking/supply industry.

3.2 Major Truck-Highway Interaction Issues

3.2.1 Productivity

The total annual costs of operating the nation's trucking fleet are at least as significant as the annual costs of building and maintaining the highway system. Relatively small changes to size and weight limits and payloads will generate significant benefits in reducing trucking and shipper costs and these benefits are generally passed on to consumers in terms of lower prices for goods. While some types of carriers and commodities benefit from increased weights, the productivity of others is limited by volume. Currently, the greatest potential for larger productivity improvements in the United States trucking industry appears to reside with increased weights rather than dimensions.

In terms of size and weight policy, the best means of approaching increased productivity is through the use of performance-based standards and iterative consideration of engineering performance of vehicles, infrastructure effects, and cost recovery.

Some specific local initiatives for increased productivity, such as the Michigan 74,460 kg (164,000 lb) limit and Oregon's use of triple trailer LCVs, provided useful information to the scanning group, but such experiences are difficult to generalize on the national level.

User costs related to road conditions have become an issue for the trucking industry and the industry is currently investigating the costs of poor roads to carriers. Rough roads also have an adverse effect on the performance and occupational health of an aging population of US truck drivers.

3.2.2 Infrastructure

Infrastructure funding is a key issue for both highway providers and highway users. Cost recovery is an important component of highway funding, and truckers are prepared to invest in roads and the industry states its willingness to pay its fair share. This is not solely a technical issue, but cost recovery is an indispensable element of size and weight policy.

> *"The United States has an extensive existing pavement system with set subgrade conditions and may not be able to increase axle loads; other options need to be looked at."*

> *"Funding is insufficient for needs. Agencies are forced to use short-term strategies which are not cost effective in the long term. This results in unnecessary waste. Harmonizing the infrastructure with vehicles at increased productivity levels, with adequate safety, and minimum environmental impact is desirable."*

> *"Current infrastructure has been severely taxed by age, increased freight over that anticipated, slow replacement funding and the growth in vehicle weights and dimensions."*

Road management approaches that explicitly take into account the needs of the industry and consider the national economic significance of freight operations in the programming process are desirable. Communication with the trucking industry is needed to explore their requirements for pavement quality, cost-effectiveness, and productivity.

> *"Good design usually goes with a good pavement maintenance system due to the feedback involved. Some jurisdictions only have a pavement management system, not a maintenance management system as well."*
>
> *"Mexico bases resurfacing priority on the value of products carried by trucking on the road. This is an interesting concept."*

The design life of pavements is a key issue. Basic pavement design criteria should include pavement design life, design reliability, minimum time to first overlay, minimum time between overlays, and minimum condition (serviceability) index. These criteria should be set taking into account availability of funds for future overlays, competing current needs for highway user fees, and consequences of early failure. Life-cycle costs need to be fully considered in pavement management.

Pavement condition monitoring and early intervention have an important place in minimizing the cost of highway maintenance.

While heavy vehicles are an important consideration in pavement design and maintenance, this influence is often implicit rather than explicit. However, bridge designs and weight limitations are considerably more specific with regard to the influence of trucks. This has tended to create a stronger role for bridge limitations in controlling size and weight policy. It is therefore important to reexamine these bridge limitations in a manner commensurate with their key importance to the productivity of trucking operations.

There are concerns throughout the United States about rutting of bituminous pavements on routes heavily trafficked by trucks. Truck loads and tire-contact pressures are considered to be important influences in this form of pavement wear. In cities, where pavements can often be in poor condition, buses can be a significant contributor to pavement wear, as may special permit vehicles and garbage haulers.

> *"Regarding road damage, the following classes of vehicles frequently cause a highly disproportionate amount of road damage: Special-Permit Vehicles, Garbage Haulers, Transit Buses."*

There are relatively few fatigue failures in bridges and most bridge wear relates to bridge decks. It is also true that the actual as-constructed capacity of bridges often exceeds the design capacity. While it is necessary to consider the large number of older bridges in use, whose structural capacity is of real concern in relation to truck use, it is possible, in certain cases, to retrofit bridges to increase their capacity.

Bridge Formula "B" is required for the Interstate System. The Bridge Formula is a simplified way of ensuring that certain levels of truck weight are spread over axles at least a certain distance apart. Formula "B" is known to contain several drawbacks and a search for a more adequate formula is underway. For example, the Texas Transportation Institute (TTI) has generated a formula that preserves the principles underlying Formula "B" and which shows promise in more adequately controlling truck loads on bridges. Under the TTI Formula and Bridge Formula "B, " it is possible to have gross weights greater than the current US limit of 36,320 kg (80,000 lb) without introducing excessive stress. Axle weights and the 80,000 lb cap currently inhibit higher weights for 5-axle tractor/semitrailer combinations.

3.2.3 Safety

Size and weight policy not only affects vehicle performance and potential crash risk, but also affects exposure to trucks in the highway system. While size and weight regulations probably affect vehicle performance and safety more than any other vehicle design factor, the effect on safety is indirect and difficult to predict. Available accident data are generally inadequate to predict with precision and statistical certainty the effect of size and weight regulations, or different vehicle configurations, on crash likelihood. Even though the necessary quantity and depth of accident data required to do this is not available, future availability should be pursued. Accident causation usually involves a combination of factors, including some key triggering events which are most often precipitated by the behavior of drivers. Issues of truck size, weight, controllability or stability contribute to crashes, but are difficult to isolate in the available crash data.

> *"Many constraints are placed on tractors, but trailers and their hitches are the major determinants of truck combination dynamic characteristics. The trailers significantly influence the safety of the entire truck combination."*

> *"It is still important to pursue the idea of conducting an analysis of the best available truck accident data and to initiate efforts to improve the current state-of-the-art method of collecting and analyzing truck accident data."*

A sound approach for size and weight decisions is to take into account engineering performance data; that is, the measurement or prediction of certain performance characteristics of vehicles that are believed or indicated to be safety-related. Trucks, especially those being considered for increased limits, should be able to achieve a certain performance level without having to rely on special skill or effort on the part of the driver. A prime example of such a vehicle performance characteristic is rollover threshold, which is closely related to the truck's center of gravity height. Research has provided a proven range of tools for assessing the safety-related engineering performance of trucks. These tools represent a significant opportunity for developing enlightened size and weight policy.

> *"There is a lot of technical expertise in truck modeling."*

The safety of trucking operations is a high priority for all parties involved in highway transportation, and coordinated efforts to improve truck safety over the past decades have been remarkably successful. Further truck design innovations to improve safety have been developed in

Europe and could be adopted in the United States. However, safety issues will continue to arise when the widespread operation of larger or heavier vehicles is proposed. These issues should be resolved within a rational context of (i) standards for engineering performance related to both safety and infrastructure effects, (ii) productivity benefits, (iii) infrastructure wear, and (iv) cost recovery. The lack of a clear policy framework for including safety, productivity, and infrastructure wear considerations limits implementation.

> *"Canadians allow greater weights for better performing vehicles. Weight limits are progressively greater for 'A' Trains, 'A' Trains with 'C'-Dollies and 'B' Trains, respectively."*

3.3 Opportunities For Improved Interaction

3.3.1 Current Practices

Due to the strong influence of size and weight policy, the tare weight of the truck or trailer remains of primary importance and weight minimization is a key aspect of truck design. It is unlikely that significant further tare weight reductions will be available to assist in improving productivity.

Experience in Canada and Mexico has shown that the tractor-semitrailer with 6 axles (3S3) is generally a more efficient and better-performing configuration than the 5-axle vehicle (3S2). The use of more than 3 axles on semitrailers has usually been found to create a need for lift axles or steering axles to allow the truck to turn—trailer steering axles can have a significant effect on the engineering performance of the vehicle combination. The B-double is generally the most stable and best performing of the larger multiple-trailer configurations and use of this configuration has increased in Canada.

> *"The single most significant change resulting from the Canadian RTAC weight and dimension study was implementation of tridems; i.e., 6-axle tractor-trailer combination units."*

> *"There should be provision for 6-axle tractor-trailer with increased gross in the 90K range."*

> *"The Canadian belly axle was born of inadequately-expressed size and weight standards and varying interpretations by the provinces and is exhibiting adverse performance. Further, lift axles in general are being discouraged in Canada."*

> *"Truck technology is being integrated among the United States, Canada, and Mexico in that US trucks are exported in a generic form."*

The State of Oregon's experience with triple-trailer LCVs has apparently been generally satisfactory, although relatively few such vehicles are operating and they are confined to selected routes and certain operations. Conventional double-trailer and triple-trailer LCV configurations do not compare as favorably in certain aspects of engineering performance, such as rearward amplification. However, the use of C-dollies and B-trains can significantly improve the engineering performance of LCVs.

> *"Research for FHWA has shown that C-dollies will not pay for themselves without a payload increase. Canada allows a 5,000-kg weight increase for the use of a certified C-dolly in a twin-trailer combination."*

Newer designs of truck suspensions offer a range of benefits for both the truck and the highway, at some increased cost. There is a pronounced trend to air suspension on new tractors, but not necessarily on trailers. Táking into account all existing vehicles, the majority of the current truck and trailer population runs on mechanical springs, which lack the performance options possible with air suspensions. Air suspensions have the ability to maintain a constant ride height and a generally constant bounce frequency regardless of load. There are many performance advantages in this feature of air springs; however, maintenance of the shock absorbers is essential to maintain the performance of the air suspension system.

> *"A significant amount of research points to the possibility that air suspensions are more 'road friendly;' that is, less damaging for given loads. If this can be firmly established, it can lead to longer life, rebates to truckers, or increased weights for axles having these features."*

The newer tire designs offer significant benefits for the truck, but may tend to cause problems for the highway. While benefits are sought in increased tire-tread life, reduced weight, reduced rolling resistance, reduced deck height, and enhanced cornering and braking, these tire designs may place higher and more localized vertical and lateral stresses on the pavement surface. There appears to be no easy solutions to the effects of these tires on pavements, although further effort could be made to allow for these effects in pavement design and maintenance strategies. Central tire inflation seems unlikely to have a significant impact.

> *"Radial tires track in ruts, and this needs to be considered in pavement design."*

> *"The interface between the tire and the pavement needs increased attention. The dynamics of this interface may hold a key to better tires, suspensions, and longer pavement life."*

Pavement management systems are being used throughout North America and more emphasis is being placed on the design of rehabilitation and overlay treatments. Structural strength tests such as falling weight deflectometer (FWD) could be used more widely to determine rehabilitation requirements in relation to truck requirements.

Containerized cargo has great potential for intermodal means of transportation, but the size and weight of containers is subject to influences outside the control of the United States. Many of these containers originate in other countries, where they could be subject to other size and weight rules. Current US size and weight rules restrict the movement of containers and may therefore be restricting intermodalism. It is not possible to haul the heavier containers on standard 5-axle tractor-semitrailers and remain within current weight limits. Opportunities exist to develop alternative vehicle configurations that meet defined engineering performance standards for hauling heavier containers.

Truck weight enforcement remains a problem in all North American countries and in Europe, but WIM technology is now maturing to the extent that accuracy and reliability is improved and can be used for screening of overweight vehicles which are then directed to a static weighing device of accredited accuracy. On high-volume truck routes, WIM offers great potential to avoid traffic delays. Improved enforcement is an essential part of fully developed size and weight policy balancing productivity, safety, infrastructure effects, and cost recovery. Compliance with, and enforcement of, weight limits and cost recovery all become more difficult if user fees are not seen to be returned to road funding.

> *"There is great variety in the type and amount of vehicle weight and size enforcement being used in North America. Historically, there appears to have been be no effective weight and size enforcement in Mexico".*
>
> *"Enforcement can be made more effective if shippers are made more responsible and their records are made available through relevant evidence statutes."*

3.3.2 New Technologies

ITS/CVO demonstration projects have been underway for some years, linking electronic license plates, WIM installations, electronic toll collections, AVI and AVC, and vision technology. These projects have shown benefits in reducing delay at toll plazas and border crossings, preventing overweight vehicles, and tracking cargo, though the productivity benefits to truckers have been less clear. Incoming truck technologies such as on-board computers and ITS (including on-board scales) will potentially contribute to improved performance by truckers.

Research is under way to find methods of extending pavement life to extend level of service, including the use of new materials and additives. The influence of pavement construction and maintenance techniques and the profile quality of the pavement on the truck/pavement interaction is not yet completely known, but the development and use of a truck-related pavement roughness index in pavement management would be a major step forward. The concept of "vehicle-friendly" road surfaces could have merit in reducing vehicle life-cycle costs.

It is possible to test and rate bridges for load capacity, and new dynamic techniques are being developed for this purpose. Widespread testing of bridges would contribute to better defining the capacity of the existing bridge stock and the need for upgrading.

Current intermodal containers are built to a variety of standards for dimensions and weight capacity, and this creates difficulties for uniform vehicle size and weight policies. In order to assist with the reform of size and weight policies and limits, it is important to develop intermodal compatibility throughout North America and the world. Innovations in the use of containers, for example in transporting automobiles, also assist intermodalism. Another avenue to improve the efficiency of intermodal transfers is the use of ITS transponders on containers.

Worldwide research is under way to provide scientifically based means of assessing the road-friendliness of trucks. Road-friendly trucks are those that, for a given weight of load, cause less pavement wear. Although the relationship between dynamic loading and pavement wear is not well understood, this is usually brought about by the use of suspensions which distribute the load well among the truck wheels and reduce dynamic loading of the pavement. Independent testing has been carried out in many countries to rank suspensions and has generally confirmed the superior performance of air suspensions, provided they have effective damping. Air suspensions also tend to produce improvements in other important areas of truck performance. There are also some completely new technologies for intelligent suspensions that adapt to road and vehicle conditions.

Automatic load-sensitive lift axles, well-engineered self-steering and steerable axles, and new braking technology such as disc brakes and electronic brakes, have potential for improving vehicle performance.

4. PANEL CONCLUSIONS

The Highway/Commercial Vehicle Scanning Tour has provided valuable information and insights that could make major contributions to improving the efficiency and productivity of our highway transportation system. The Scanning Team has documented information concerning highway (pavement and bridge) design, geometry and wear, heavy vehicle safety, and the engineering performance of heavy vehicles which is currently not being fully utilized to improve productivity and safety of the nation's highway freight operations

4.1 Vehicle Configuration and Road Friendliness

The configurations and components of heavy vehicles are determined by existing constraints. These constraints include regulations (including size and weight), driver operational limitations, safety, and infrastructure design standards. The condition of the infrastructure can also cause changes to vehicle configurations. In every case, the laws of physics play a significant role in the options available to the designers and builders of heavy vehicles. Differences in these constraints (e.g., regulations; infrastructure condition; geometrics on regional, national, and international levels) also have significant potential impact on productivity and efficiency.

A high degree of inventiveness and creativity exists within the heavy vehicle industry seeking to advance the productivity and efficiency of the fleet. In addition to advances in vehicle configuration and components, efforts to optimize productivity address development of intermodal relationships, permitted and special-purpose vehicles, and regulatory exceptions. The result has been a myriad of vehicle configurations serving regional and national markets.

Truck design can contribute to reducing pavement and bridge wear for given weights of load. The use of suspensions that distribute the weight efficiently among axles in multiaxle groups and reduce dynamic loading is expected to reduce pavement wear. Air suspensions generally have superior performance characteristics, not only for reducing dynamic pavement loading but also for truck stability and control performance. However, truck suspensions can only be expected to perform well up to specific tolerable levels of road roughness.

New designs of tires that may improve vehicle handling and economy often cause higher pavement contact stresses. These tires, with smaller diameters, low-profiles, and high inflation pressures, appear to be creating problems for road wear and lateral dynamic stability.

Further research is needed to quantify the effects of dynamic loading and its spatial repeatability on pavement wear, provide reliable means of assessing vehicles for road-friendliness, and better describe the tire/road interface.

While not entirely clear regarding the benefits of certain measures aimed at road friendliness, several countries have introduced such measures/incentives, through weight increases or fee reductions, in order to encourage innovative technological applications.

4.2 Global Competitiveness

Global trade and competitiveness have placed increased pressure on advancing transport efficiency and productivity. Containerized cargo has become particularly significant in intermodal transport, both for improved cargo security as well as opportunities for improved efficiency.

In Europe, vehicles involved in hauling containers in combined transport are permitted an increase in gross weight from 40 tonnes (88,100 lb) to 44 tonnes (96,900 lb). This concession, designed to promote intermodal transport, has been in place since the 1980s and has been retained in the most recent round of European Commission deliberations on size and weight limits.

4.3 Vehicle Performance Standards

A significant body of knowledge exists regarding vehicle performance, design, and configuration. This knowledge is quite advanced in its comprehension of the relevant variables, sciences, and effects and offers significant opportunities to develop performance-based standards for heavy vehicles.

4.4 Enforcement

Levels of regulation and standards enforcement vary significantly among the countries visited. Enforcement or the lack of it significantly influences levels of compliance. While this may be intuitively obvious, it was made clear to the study team in both North America and Europe. ITS developments are likely to provide significant benefits in future heavy-vehicle permitting, monitoring, cost recovery, and enforcement.

4.5 Safety

Heavy vehicle safety continues to be a significant issue in every country visited. The need to quantify safety effects and causes continues to elude researchers and regulators. Accident-reporting systems do not contain sufficiently detailed, vehicle-specific information to isolate causes or to develop recommendations to prevent future occurrences. Additionally, the statistical infrequency of heavy vehicle accidents complicates this issue. In response to this problem, several countries are developing performance standards based upon engineering standards to increase vehicular and infrastructure safety.

Size and weight limits have a profound effect on vehicle configuration and, hence, engineering performance. Vehicle engineering performance, exposure, and size have a pervasive but indirect influence on safety. Because this effect is interactive, it is difficult to isolate it with accident data. Determination of this effect is also made more difficult by drivers' efforts to compensate for poor vehicle performance.

While larger and heavier vehicles are not necessarily less safe, it is vital that appropriate engineering performance standards continue to be met and that the better-performing vehicle configurations are encouraged.

Research is needed to achieve the following results:

- Determine clearer correlations between engineering performance of heavy vehicles and accident risks.

- Determine appropriate performance standards to apply to various classes of heavy vehicles.

- Develop improved accident databases to the identify the engineering characteristics of trucks involved in crashes.

- Develop and implement innovative means of improving safety through truck design, including measures to improve both active and passive safety.

4.6 Comprehensive Freight Policy

A comprehensive national freight policy was recognized by the panel as essential to the development of integrated multi/intermodal transport efficiency. It was recognized there was a general lack of national freight policy direction in nearly every country visited. Effective truck size and weight policy cannot be developed outside the context of national freight policy.

4.7 Infrastructure Investment and Cost Recovery

Improved highway design and maintenance standards can contribute to reducing truck user costs and to improving productivity. Pavements designed and maintained to interface with the new generation of vehicle technology developments would allow the potential economic and performance benefits to be realized. Stronger, smoother pavements can lead to improved highway/commercial vehicle interaction.

Across the spectrum of the countries visited, a need for significant additional investment in highway infrastructure was identified. These investments were projected to meet the need to preserve and restore existing facilities as well as to expand facilities to provide access to intermodal and other key links. In every case the resources needed exceeded the revenue streams currently available. The economic and financial benefits of increased transport productivity can be substantial; however, it is necessary to formulate fair and equitable cost-recovery mechanisms to sustained infrastructure service.

5. PANEL RECOMMENDATIONS

The panel developed and prioritized recommendations based on findings and conclusions from both the North American and European scanning tours. The recommendations are presented in three categories: high-priority items to immediately advance toward implementation; medium-priority recommendations that should be further pursued in the intermediate term; lower priority, but important, recommendations that deserve further study or research.

The following are high priority recommendations of the Highway/Commercial Vehicle Interaction Panel:

5.1 Technologies for Transfer to The United States

The following selected technologies are recommended for evaluation for transfer to the United States and for consideration for future implementation.

Distill conclusions on the viability of "road-friendly" truck components for implementation in US size and weight regulations with particular focus on the following components:

- Review suspension systems (particularly air or its equivalent) for truck and infrastructure friendliness. Evaluate benefits and limitations for US application and appropriate implementation mechanisms.
- Evaluate the advantages and disadvantages of wide, single-based tires for heavy trucks.
- Consider implementation of load sensitive, automatically deploying lift axles to replace existing manual lift axles (consider phaseout of existing lift axles).

5.2 Expanded Leadership

FHWA and AASHTO (American Association of State Highway Transportation Officials), as regulators and operators of highway infrastructure should provide the national leadership necessary to make the freight transport system more efficient, including the development of a continuing, cooperative working relationship with public and private stakeholders to address inefficiencies in the nation's freight transportation system and promote appropriate solutions.

5.3 Comprehensive Freight Policy

Develop a comprehensive national freight policy that includes the following factors:

- Safety.
- Infrastructure.
- Modal efficiency.
- Truck size and weight policy.

- Taxation.
- Intermodal movement (especially containers).
- International competitiveness.
- Environment.

As part of current Federal efforts and in cooperation with customers and stakeholders, any size and weight changes should be accompanied by provisions for the following:

- Bridge stress, pavement, and capacity consumption.
- Vehicle performance (including tire parameters).
- Safety enhancements.
- Cost recovery by permit to agencies incurring costs.
- Elimination of ratcheting.
- Access control by States.
- Interstate/international compatibility (including better longer combination vehicles (LCVs).
- Rationalization of fee structures, including permit fees reflecting intensity and extent of use.
- Controlled rail diversion.

The following medium-priority recommendations are supported for consideration in the intermediate term:

5.4 Performance Standards

A performance-standards approach to size and weight regulations should be seriously considered. Performance standards should address acceptable vehicle operations and include consideration of safety and infrastructure impacts. Highway performance standards related to pavement design and rehabilitation should consider a truck-related pavement condition index and tire parameters. Implementation feasibility should be reviewed including institutional factors.

5.5 Cost Recovery

Existing cost allocation procedures for trucks should be benchmarked, and a rational procedure for cost recovery under any revised size and weight limits should be established. Appropriate charges for the operation of high-productivity vehicles should be established. States should have a size and weight permit review process to assess impacts on pavements and bridges and should assure appropriate cost recovery to the agencies incurring the costs.

5.6 Possible Short-Term Changes to Accommodate Intermodal Containers

In the interest of international compatibility of intermodal containers, consideration should be given to a specific change of US size and weight regulations for containers on tridem axle semi-trailers, at appropriate gross vehicle weight (GVW) above 80,000 lbs.

5.7 Re-assessment of Bridge Formula

Existing Bridge Formula "B" should be reassessed with the intention of providing a more appropriate control on bridge stress, if possible. Any proposed change in truck size and weight limits should be screened to ensure compatibility with an appropriate bridge formula, the ratings of existing bridges, and bridge design standards.

5.8 Envelope of Allowable Vehicle Configurations

If performance standards appear feasible, policymakers should consider development of envelopes of allowable vehicle configurations for designated systems and subsystems, based on engineering and safety performance of both vehicles and infrastructure.

5.9 Enhanced Truck Accident Data

A national system should be developed to identify and evaluate all accidents involving large trucks. Such a system should include an improved accident/VMT (vehicle miles traveled) recording system sensitive to vehicle type, configuration, and design.

The following lower-priority but important recommendations are also supported for further study and research:

5.10 Researching "Road-Friendly" Vehicles

Truck and infrastructure research should be expanded to resolve questions concerning the extent of potential benefits to pavements and bridges of "road-friendly" vehicles.

The possibility of differential weight limits or fee schedules for "road-friendly" suspensions should be further explored. The issue of the maintenance of "road-friendly" suspensions should be further explored, especially the means of ensuring the maintenance of damping characteristics over time.

5.11 More Effective Enforcement

More effective deterrence from overloading should be provided in enforcement programs. The programs should include the factors listed below.

- An escalating fine structure with stiffer penalties for greater degrees of overload and repeat offenders.
- Education of judicial branches at all levels concerning the consequences of overloading for the infrastructure.
- Effective judicial enforcement.

- Application of ITS technology.

5.12 Standards for International Containers

More effective means of establishing and maintaining standards for the size and weight of international containers should be explored.

5.13 Public Education

A public education program should be developed to address heavy vehicle size and weight issues, particularly with respect to safety, intermodalism, and environmental issues.

ACKNOWLEDGMENTS

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Particular acknowledgment is due the Transportation Technology Evaluation Center (TTEC) at Loyola College in Maryland for its coordination of the team and editing of this report.

Finally, special thanks are given to TTEC's liaison personnel, James L. Brown (North America) and American Trade Initiatives, Inc. (Europe), for arranging the meetings, planning the travel, and escorting the team.

APPENDIX A: Scanning Team Questionnaire

Pavements

1. What pavement design theory and methods do you use? Why do you use them? Do you use life-cycle cost methods to evaluate pavement design alternatives? How do you estimate loads for designing your pavements? Do you consider static or dynamic loads? Are you considering any new design theory or methods?

2. How do you monitor pavement performance? How does the observed performance of your pavements compare to their design lives in years or in loads? If different, have you been able to identify the factors, especially such vehicle factors as weight, tires, axles and suspensions, that contribute to the differences? What do you think are the major problems in pavement performance?

3. What distress types do your pavements exhibit? At what point of pavement deterioration do you rehabilitate a pavement or perform maintenance of various types? Do you have a formal pavement management system?

4. What data and other information do you have available on truck traffic and pavement performance? How have they been used in evaluating pavement design and management practices? Do you have any recent reports to share?

5. Please describe recent pavement research activity and results, ongoing research and research programmed for the future. Have you identified additional research that is needed? How do you identify what research is needed? How are your pavement research results being used?

   Specifically, have you investigated the impacts of spatial repeatability, tire pressures and diameters, tread widths, super-single versus dual tires, and single versus tandem and tridem axles at various spreads between or among axles in these groups on pavements? Have you investigated the rate of pavement deterioration with respect to pavement load and condition in terms such as present serviceability index (PSI)?

6. Do you have any mechanisms through which public and private interests cooperate with the goal of improving pavement performance in terms of condition and vehicle performance in terms of maintenance costs and ride quality?

7. Who are the major players in pavements? These would be organizations and individuals, not only in your firm or agency but others you know about, including those in other countries?

Bridges

1. What bridge design theory and methods do you use? Why do you use them? How do you estimate live bridge loads? Do you consider dynamic loads? Do you consider life-cycle costs for evaluating alternative bridge designs? Are you considering any new design theory or methods?

2. What bridge conditions do you monitor? How do you monitor them? What types of distress or failure are your bridges exhibiting? How do the observed conditions compare to your expectations? If different, have you been able to identify the factors, especially vehicle factors such as weight, length and axle configuration, that contribute to the differences? What type of distress or failure are your bridges exhibiting? Do you have a formal bridge management system?

3. What data and other information do you have available on truck traffic and bridge performance? How have they been used in evaluating bridge design and management practices? What do you think are the major problems in bridge performance? Do you have any recent reports to share?

4. Please describe recent bridge research activity and results, ongoing research and research programmed for the future. Have you identified additional research that is needed? How are your bridge research results being used? Do you have any recent study reports to share?

5. Do you have any mechanisms through which public and private interests cooperate with the goal of improving bridge performance and vehicle performance in terms of economic productivity?

6. Who are the major players in bridges? These would be organizations and individuals, not only in your firm or agency but others you know about, including those in other countries.

Commercial Motor Vehicles

1. How are vehicle weight and dimension limits and related requirements used in vehicle design? Do you have ideas on how vehicle design and performance can be improved through a better informed regulatory process without negative impacts on highway pavements, bridges and safety? Do you have any ideas on new designs or technologies to improve highway/commercial vehicle interactions?

2. What vehicle research have you done in the following areas?

   - Truck/pavement interaction
   - Bridge considerations

- Handling and stability: offtracking, rearward amplification (response of last trailer to driver steering inputs), rollover.
- Braking
- Fuel efficiency
- Air pollutant emissions
- Other vehicle and vehicle component research.

What were the results? What research are you doing now? What research is planned for the near future? What other research would you like to do? How are your vehicle research results being used? Do you have any recent study reports to share?

3. What data and other information do you have available on vehicle performance? How have they been used in evaluating truck and truck component design? Do you have any recent reports to share? What are the major problems to be overcome to improve highway/commercial vehicle interactions?

4. Do you have any mechanisms through which public and private interests cooperate with the goal of improving vehicle performance in terms of productivity and safety while enhancing pavement and bridge performance?

5. Who are the major players in highway/commercial vehicle interactions? These would be organizations and individuals, not only in your firm or agency but others you know about, including those in other countries.

Truck Size and Weight Policy

1. What are your vehicle weight and dimension limits and related requirements such as equipment requirements and operational restrictions (routes, access, weather conditions and time of day)? Do you have a bridge formula and, if so, what is it? If not, what controls do you use to prevent bridge damage from heavy vehicles? What factors, such as the following, were considered in setting the limits?

    - economic productivity
    - vehicle configuration performance characteristics
    - vehicle component performance characteristics
    - bridge life consumption
    - bridge damage and fatigue life consumption
    - highway safety
    - impact on other transportation modes
    - fuel consumption
    - environmental quality

Do you have any special requirements for trucks that exceed the US Federal truck size and weight limits? What factors, such as traffic conditions and highway geometrics, were considered in determining what these requirements should be? Do you have special provisions for containers used in international trade? What are the major areas of controversy regarding truck size and weight policy?

2. Do you have vehicle, pavement or other performance standards that you maintain or set as goals to be achieved through vehicle weight and dimension requirements? Are you looking into such areas?

3. What data and other information do you have available on truck accidents and pavement, bridge and vehicle performance? Regarding truck accident statistics, have you been able to determine how factors such as driver experience, highway type, weather, amount of traffic or vehicle weight, length and configuration (especially double and triple trailer combinations) affect truck accidents? How has this data and information been used in evaluating truck size and weight policy options? Do you have any recent reports to share?

4. Are you presently conducting any evaluations of options for revising your current limits and related requirements? What interests are driving your consideration of revisions? What factors are being considered? Do you have any recent study reports to share? Do you have any ideas on new policies to improve highway/commercial vehicle interactions?

   Specifically, have you evaluated such policy options as allowing additional weight for trucks that have special safety features, like C-dollies, or pavement friendly components, like more dynamically quiet axle suspensions? Does your highway user tax structure encourage the use of trucks with desirable safety features and pavement friendly components?

5. What are your policies for issuing overweight and overdimensional permits? What vehicle equipment do you require? What information is required? What issuing procedures, such as route reviews, do you use? Do you have any copies of your policies to share?

6. Who are the major players in truck size and weight policy? These would be organizations and individuals, not only in your firm or agency but others you know about, including those in other countries.

Truck Size and Weight Compliance and Enforcement

1. How do you enforce your vehicle weight and dimension limits and related requirements, such as equipment requirements and operational restrictions? What types of equipment: static scales, portable scales, weigh-in-motion (WIM), or other do you use to weigh trucks? What are the maintenance requirements and reliability of each type.

Do you employ special strategies for weight enforcement, such as use of portable scales, weigh-in-motion or other electronic equipment, and review of carrier or shipper records? What do you think are the major problems in truck size and weight enforcement?

2. Do you have an estimate of the degree of compliance with your weight limits? If so, how did you derive it?

3. Are you conducting research on ways to improve compliance and/or enforcement? Do you have any studies that relate level of enforcement to compliance and/or pavement life consumption? What research would you like to do? Do you have any recent study reports to share. Do you have any ideas on new enforcement strategies or equipment to improve compliance?

4. Do you have mechanisms through which the public and private interests cooperate with the goal of improving truck size and weight compliance and enforcement?

5. Who are the major players in truck size and weight enforcement? These would be organizations and individuals, not only in your firm or agency but others you know about, including those in other countries.

APPENDIX B: Participants in North American Meetings

September 24, 1994 — Turner-Fairbank Highway Research Center, McLean VA

Susan Binder	FHWA, Policy (HPP-11)
Alan Clayton	University of Manitoba/FHWA Policy
Michael Ryan	Pennsylvania Department of Transportation
Jim Sherwood	FHWA, Pavements Division
Otto Sonefeld	American Association of State Highway & Transportation Officials

September 26, 1994 — National Research Council of Canada, Ottawa, Ontario

John R. Billing	Ontario Ministry of Transportation
Moustafa El-Gindy	NRC
Edward Fekpe	NRC
Pierre LeBlanç	NRC
Gordon Mutch	ORTECH Corporation
Laverne Palmer	NRC
Jon Preston-Thomas	NRC
Fergus Savage	ICBC
John Woodrooffe	NRC

September 28, 1994 — University of Michigan Transport Research Institute (UMTRI), Ann Arbor, MI

Susan Binton	Michigan Department of Transportation
Ken Campbell	UMTRI
Leo Defrain	Michigan Department of Transportation
Paul Fancher	UMTRI
Tom Gillespie	UMTRI
Steve Karamihas	UMTRI
James Roach	UMTRI
David Smiley	Michigan Department of Transportation (Pavement Research)
Chris Winkler	UMTRI

September 29, 1994

Edward C Levy Co, Dearborn, MI

Edward C Levy Jr.	President/CEO
Evan Weiner	Executive Vice President/COO

Thomas Barton	Manager of Technical Services
Jim Broderick	Vice President Sales & Marketing
Edward J. Connelly	Chairman of Program
Paul Deller	Special Assistant to the President
Joe McCall	General Manager Transportation Division
John Perry	Sales
Gale Reninger	General Manager Michigan Steel Mill Operations
Stephen B. Ryan	Manager Customer Services

Michigan Trucking Association

Walt Heinritzi	Executive Director
Patrick Turner	Director Government Affairs

September 30, 1994 **Navistar Technical Center, Fort Wayne, IN**

Dave Andrewski	Indiana Department of Transportation, Materials & Tests
Dave Belford	INDOT Technical Services Division
Dave Harrold	NTC Road Simulator
Scott Herrin	INDOT Technical Services Division
Rebecca S. McDaniel	INDOT Research
Charlie Powell	Navistar
Bill Rieck	Specialty Carriers & Rigging Association.
Ted Scott	American Trucking Associations
John Weaver	INDOT Roadway Management
Jack White	INDOT Design Division
Bob Woods	IDDOT Roadway Management Division

October 3, 1994 **University of Washington, Seattle, WA**

Al Aderichin	British Columbia, Ministry of Transportation & Highways
Keith W. Anderson	Washington State Department of Transportation
Karim Chattie	Michigan State University
Ron Copstead	PNW Research Station, USDA Forest Service
Barry Diseth	WADOT
Garrick Hu	Consultant
Colin Hughes	Trimac Transportation Services
Steve Krammer	University of Washington
Samual Lam	British Columbia Motor Vehicle Branch
Joe Mahoney	University of Washington
Tom Moran	PACCAR
Robyn Moore	WADOT
Cathy Nicholas	FHWA - WA Div.

Linda Pierce	WADOT
Tom Papagiannakis	Washington State University
Margaret Sullivan	PACCAR

October 4, 1994	**PACCAR Technical Center, Mt. Vernon, WA**
Jim Bechtold	PACCAR
Rich Bishel	PACCAR
Dave Menmuir	PACCAR
Joe Mahoney	University of Washington
Tom Moran	PACCAR
Christopher Nern	PACCAR
Larry Orr	PACCAR
Roger Penzotti	PACCAR
Linda Pierce	Washington State Department of Transportation
Margaret Sullivan	PACCAR

October 5, 1994	**Freightliner Facility, Portland, OR**
Chris Bell	Oregon State University
Dan Fuchs	Freightliner
Gary Gaussoin	Silver Eagle Manufacturing Co.
Ross Gaussoin	Silver Eagle Manufacturing Co.
Jeff Gower	Oregon Department of Transportation, Pavements Engineer
Lloyd Henion	Oregon Department of Transportation
Jim Lundy	Oregon State University
Bjorn Klingenberg	Freightliner
Gary Rossow	Freightliner
Dick Younts	Independent Trailer Inc.

October 7, 1994	**Mexican Department of Transportation, Mexico City, DF**
Carlos Mendez Bueno	Mexican Association of Private Toll Roads
Oscar de Buen	SCT
Roberto Courtade	Chamber of Heavy Duty Transport
Amilcar Galindo	SCT
Alejandro Lozano	IMT
Carlos Fisher Marmolejo	Truck Manufacturers Association
Arturo Massutier	Asoc. Fab. Vehiculos
Luis Orcacitas M.	Road Construction Company
Juan M. Orozco	Consultant

Raul Vincente Orozco	Consultant
Jose A. Romero	IMT
Jorge Antonio Tapic	SCT
Francisco Ruz Villamil	SCT

APPENDIX C: Participants in European Meetings

April 26, 1995	**Michelin, Clermont Ferrand, France**
Nicolas Beaumont	Michelin
M. Chalencon	Michelin
Mme. Dalle	Michelin
M. Deleuze	Michelin
M. Favre	Michelin
M. Fevrier	Michelin
Marc Laferriere	Michelin US
April 26, 1995	**Multi Transport, Clermont Ferrand, France**
Yves Jamon	President
April 27, 1995	**European Conference of Ministers of Transport (ECMT), Paris, France**
Sophie Fouvez	ECMT, Policy Director/Principal Administrator
Bernard Marmontoff	LCPC, Staff of Direction
Georges Pilot	LCPC, Assistant Director International/Chief Engineer
Jack Short	ECMT, Deputy Secretary General
Alexandra Spernol	SCETAUROUTE, Pavement Department
Michel Violland	ECMT, Research Director/Administrator
April 28, 1995	**Eurotunnel, Calais, France**
Bill Coleman	Eurotunnel Public Relations
May 1, 1995	**University of Cambridge, Cambridge, United Kingdom**
David Cebon	Lecturer, Engineering Department
C. Y. Cheung	Research Associate
David Cole	Research Associate
Andrew Collop	Research Associate
V. S. Deshpande	Research Associate
Richard Dorling	Research Student
Kevin Kitching	Research Student
T. E. C. Potter	Research Associate
Ron Rider	Freight Transport Association
Tseng-Ti Fu	Research Student

May 2, 1995	**Commission of the European Union, DG VII, Brussels, Belgium**
John Berry	European Commission
Robert Missen	European Commission
Luc Werring	European Commission
May 3, 1995	**Port of Rotterdam, The Netherlands**
Muan Roermund	Delta Port, ECT Home Terminal
H. Sutherland	Port of Rotterdam
May 4, 1995	**University of Hannover, Hannover, Germany**
Wolf Hahn	University of Hannover
Michael Stanzel	University of Hannover
Gerhard Voss	University of Hannover
Hilke Willeke	University of Hannover
Jens Willius	University of Hannover
May 5, 1995	**BPW Bergische Achsen, Wiehl, Germany**
Manfred Adolfs	Manager, Air Suspension Design
Uwe Kotz	Managing Director
Karl-Rainer Lang	Manager, Axle Design
Reinhold Pittius	R & D Manager
Peter Rostock	Finance Director
May 8, 1995	**Volvo Truck Corporation, Gothenberg, Sweden**
John Aurell	Volvo Truck Corporation
Lars Eriksson	VWB, S. Akeri AB
Stefan Larsson	Volvo Truck Corporation
Anders Lundguist	Sweden National Road Administration
Georg Magnusson	Swedish Road and Transport Research Institute (VTI)
Wilio Rosenquist	Volvo Truck Corporation
Lennart Svenson	Volvo Truck Corporation
Thomas Wadman	Volvo Truck Corporation

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Rotterdam Port Statistics. Port of Rotterdam

GLOSSARY OF ACRONYMS and ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-lock Braking System
ATA	American Trucking Association
AVC	Advanced Vehicle Control
AVI	Advanced Vehicle Identification
CTI	Central Tire Inflation
CVO	Commercial Vehicle Operation(s)
D	damping ratio
DG	Directorate General
DOT	Department of Transportation
EC	European Commission
ECMT	European Council of Ministers of Transport
EEC	European Economic Community
EPA	Environmental Protection Agency
ESAL	Equivalent Single-Axle Load
EU	European Union
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Statndards
ft	feet
FWD	Falling Weight Deflectometer
GCVW	Gross Commercial Vehicle Weight
GVW	Gross Vehicle Weight
hp	horsepower
Hz	Hertz
IMT	Instituto Mexicano del Transporte
IN	Indiana
IRU	International Road Union
ISO	International Standards Organization
ISTEA	Intermodal Surface Transportation Efficiency Act
ITRI	International Technology Research Institute
ITS	Intelligent Trasnportation Systems
k	kilometers
kg	kilogram(s)
km/h	kilometers per hour
kPa	kilo-Pascal(s)
lb(s)	pound(s)
LCPC	Laboratoire Central des Ponts et Chaussées
LCV	Longer Combination Vehicle
LTPP	Long-Term Pavement Performance
m	meter(s)
MI	Michigan

mm	millimeters
mph	miles per hour
NAFTA	North American Free Trade Agreement
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
NHTSA	National Highway Transportation Safety Administration
NRC	National Research Council
NRC-CSTT	National Research Council, Center for Surface Transportation Technology
OECD	Organization for Economic Co-peration and Development
OR	Oregon
PSI	Present Serviceability Index
psi	pounds per square inch
R&D	Research and Development
RTAC	Royal Transportation Association of Canada
SAE	Society of Automotive Engineers
SCT	Servicios Tecnicos y Concesiones
t	tons
TAC	Transportation Association of Canada
TIFA	Trucks Involved in Fatal Accidents
TRL	Transportation Research Laboratory
TS&W	Truck Size and Weight
TTEC	Transportation Technology Evaluation Center
TTI	Texas Transportation Institute
UK	United Kingdom
UMTRI	University of Michigan Transportation Research Institute
USDA	United States Department of Agriculture
VA	Virginia
VMT	Vehicle Miles Traveled
VTI	Swedish Road and Traffic Research Institute
WA	Washington
WIM	weigh in motion