Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-10/0-6095-1		

4. Title and Subtitle Potential Use of Longer Combination Vehicles in Texas: First Year Report	5. Report Date October 2009; Revised May 2010 6. Performing Organization Code
7. Author(s) C.M. Walton, Jolanda Prozzi, Alejandra Cruz-Ross, Kara Kockelman, Alison Conway, Daniel Evans, and Robert Harrison of CTR and Jose Weissmann, Thomas Papagiannakis, and Angela Weissmann of UTSA	8. Performing Organization Report No. 0-6095-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 1616 Guadalupe, Suite 4.202 Austin, TX 78701-1255	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-6095
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080	13. Type of Report and Period Covered Technical Report September 2009-October 2009 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract

Trucking remains the only major freight mode not to benefit from increases in size and weight regulations since 1982. The need for more productive trucks—both longer (LTL) and heavier (TL)—is growing with economic activity, rising fuel costs and concerns over environmental impacts from emissions. This study covers the first-year activities of a two-year TxDOT-sponsored study into potential LCV use in Texas. It describes current U.S. LCV operations and regulations, operational characteristics of various LCV types, safety issues, and environmental and energy impacts, together with pavement and bridge consumption associated with LCVs. Methods to measure both pavement and bridge impacts on a route basis are described. A survey of current U.S. LCV operators provides an insight into business characteristics, vehicles, drivers, performance, and safety. The overall study benefited from three sources of direction: an advisory panel from TxDOT, an industry panel comprising heavy truck and LCV operators, and finally an academic team from the University of Michigan Transportation Research Institute. In the second year of the study, a series of routes and LCV types will be evaluated in Texas using methods developed in the first year and approved at a study workshop.

17. Key Words	18. Distribution Statement
Longer combination vehicles, LCVs, road trains	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	142	

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CTR Technical Report:	0-6095-1
Report Date:	October 2009; Revised May 2010
Project:	0-6095
Project Title:	Longer Combination Vehicles & Road Trains for Texas?
Sponsoring Agency:	Texas Department of Transportation
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

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Acknowledgments

The team wishes to recognize the leadership of Dr. Duncan Stewart (RTI) who acted as the Project Director of this study. He was ably assisted by Randy Anderson (ROW), Raymond Hutchinson (MCD), Don Lewis (GSD), Jim Randall P.E. (TPP), and Jeff Tomkins, P.E. (Bridge Division) who formed the advisory panel for this study. The study received significant technical help on desirable LCV types from Ken Allen and Mike Moynahan (HEB), Doug Miller (Fritolay), and Matt Stalter (Pepsi/Quaker Oats), all of whom were willing to offer LCV types for pilot testing in Texas. Finally Drs. Peter Sweatman and John Woodrooffe (University of Michigan Transportation Research Institute) were generous in donating time and direction to the study and ensuring that the workshop was a success. Finally, thanks are due to Tony Furst (FHWA) who provided the Federal Motor Carrier Safety data base on accidents and operator contacts. Sarah Lind patiently put the report together and checked all references.

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Chapter 1. Introduction

A significant portion of economic activity in the United States—1.317 trillion ton miles in 2007—depends on commercial truck operations.[1] As a result, truck size and weight regulations play an important role in the efficiency and productivity of the U.S. economy. Truck productivity is impacted by vehicle technologies, changes in size and weight, fuel costs, and operational regulations like driver hours. Large truck operations are made more complicated and more expensive by different regulations at both national (like NAFTA) and state levels (Mercier, 2007). In Texas, trucks play a critical role in supporting the state economy although trucks on the federal aid system must adhere to vehicle size and weight laws that have changed little since 1982[2].

Size and weight dimensions, however, have changed substantially in the rail[3], vessel[4] and air[5] modes, allowing them to benefit from economies of scale. Texas, like almost all other U.S. states, is facing a highway funding shortfall, which translates to fewer miles of new highway and higher levels of congestion. The trucking sector—or at least that portion representing the largest companies—has recently asked federal and state governments to increase the truck size and weight limits. This issue is not new. In the late 1980s, trucking companies strongly argued for similar increases that were the subject of several research studies, sponsored by the Transportation Research Board, the American Trucking Association, and the Association of American Railroads. The technical debate, at times acrimonious, was finally shelved when Congress decided to "freeze" the federal limits in 1993, effectively passing the debate to individual states and non-federal aid highways. So why has the question re-emerged as a relevant policy issue now?

The answer is a two-fold consequence of reduced highway funding and global competitiveness. There is a full blown current funding crisis in all state Departments of Transportation caused by shortfalls in fuel tax revenues and registration fees, neither of which have changed in Texas in more than 15 years. Strategies to address mobility (congestion) have therefore been cut back, creating the specter of higher passenger and freight delays in the coming decade. Legislation that permits higher truck productivity, in the form of increased size and weight would, it is argued, reduce the *numbers* of trucks, the *fuel consumed* to move the goods, and the *emissions* created by the trucking sector. Many countries, ranging from our NAFTA partners, the European Union, much of Latin America, and Australia permit heavier trucks and appear to keep their highways in good condition. TxDOT decided that it was time to re-visit the issue and sponsored study 0-6095 to evaluate the consequences for the Texas highway infrastructure of allowing heavier vehicles to operate in the state. These vehicles collectively are known as Long Combination Vehicles (LCVs), which actually includes the most prolific heavy vehicle type in the world: a semi-trailer vehicle with a tridem trailer axle that is not a true LCV[6].

1 http://www.bts.gov/publications/national_transportation_statistics/html/table_01_46b.html
2 Paradoxically, higher gross and axle loads are permitted under permit under HB 2060.
3 Union Pacific recently tested an 18,000 ft intermodal train using 7 locomotives from Texas to California
4 Maersk introduced an 11,000 TEU containership in 2006.
5 The Airbus A380 can carry over 600 passengers and a freighter version is being developed
6 The term LCVs typically refers to a tractor pulling at least two trailers, while tractors pulling multiple trailers, like those in Australia, are termed *road trains*.

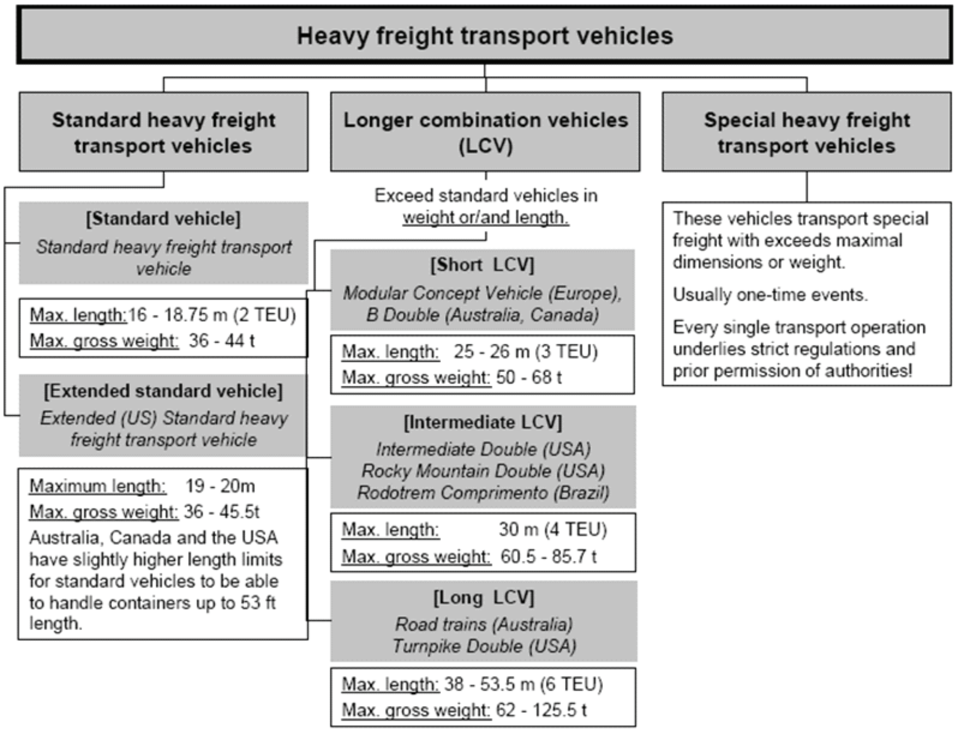
This report details the work completed in the first year of the study and is in four broad areas. First, the background to LCV studies is noted and the wide range of truck regulations governing size and weight in the U.S. is described. Previous studies have balanced the productivity gains from heavy truck use with the incremental consumption of highway infrastructure to balance the costs and benefits and to identify the range of additional fees that LCV users would be required to pay[7]. Bridge strengthening and replacement, together with related user costs arising from traffic disruption, seem to be the greatest obstacles to the adoption of heavier vehicles although the type of truck and the precise route were generally not evaluated in such studies. However, it is clear that pavement and bridge costs are critical in LCV evaluations and these comprise the second group examined in this report. Experiences from those operators currently permitted to operate LCVs in the U.S, together with operational characteristics of LCVs, are the subject of the third focus area. Finally, the recommendations of a project workshop evaluating the first year's work—comprising TxDOT, operators, and research staff—and the proposed evaluation method to be adopted in the second year complete the fourth, and final, area of activities completed in the first year.

1.1 The Regulatory Framework

Commercial vehicles face an array of regulations and Figure 1.1 shows that Long Combination Vehicles[8] (LCV) can be considered as a sub-category of heavy freight transportation vehicles within any federal or state regulatory size and weight framework.

7 Assuming that heavy trucks pay the marginal cost and no cross-subsidization is contemplated.

8 The equivalent terms *Longer Combination Vehicle, a Longer and Heavier Combination Vehicle, or a Longer and Heavier Lorry* are noted in the global literature.



Source: Nagl, 2007

Figure 1.1: Classification of Heavy Freight Vehicles

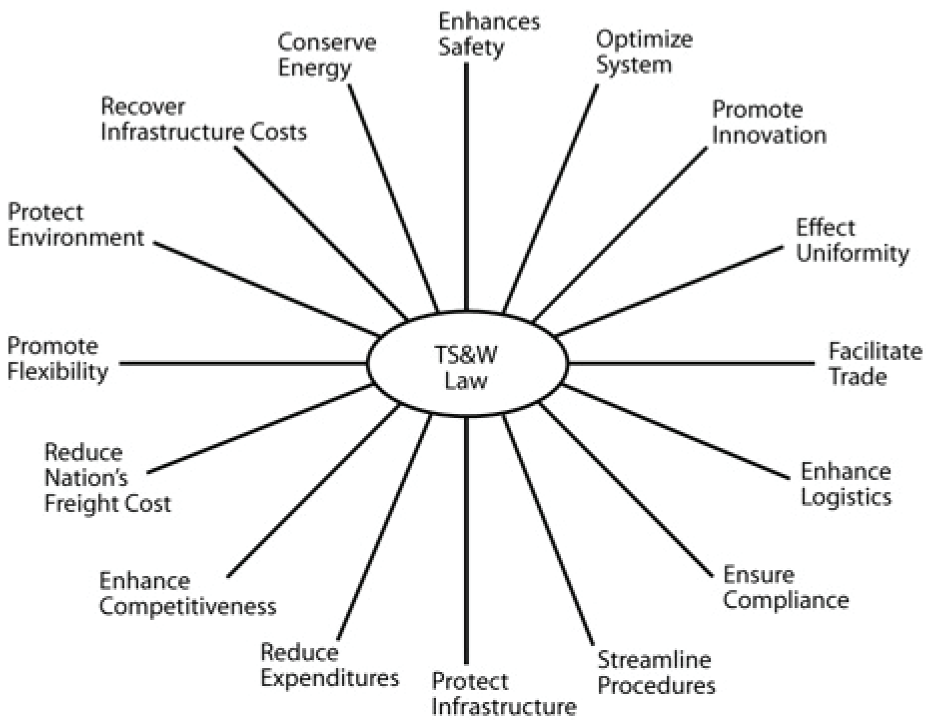
The regulation of these three truck categories differs, sometimes substantially. The standard heavy freight vehicles (such as the large semi-trailer trucks seen on major corridors) operate under a regime that is nationally derived and enforced, for example, over the interstate system. The longer combination vehicles typically have greater restrictions, both on where and how they can operate. The special heavy vehicle category is even more restrictive in route choice and may even be issued permits for single loads only. The U.S. can be considered to operate under a prescriptive system of fixed size and weight standards by vehicle class (Mercier, 2007). However, alternative frameworks include those that allow LCVs to be designed to standards that more precisely meet both desirable operational factors and equitable cost recovery for the highway agency. These include:

- *performance based standards,* which specify the required performance of trucks in certain situations as an alternative to a gross weight limits. Thus, the parameters focus on how well the vehicle performs rather than on how big and heavy it is, through a set of safety and infrastructure standards (NTC, 2006). For example, Canada and Mexico consider the latter in conjunction with other specifications, such as configurations or gross and axle weight limits. Australia has initiated the implementation of performance-based standards reform that cover meeting minimum acceleration, turning and braking characteristics (NTC, 2006).
- *pricing*, which encourages, through price incentives, the selection of types of equipment that results in lower social costs (TRB, 2002).

- *devolution,* which turns regulatory responsibilities to local governments, like U.S. states (TRB, 2002).
- *other* frameworks that include permitting and the improved enforcement of limits and safety regulations, maintenance, and replacement costs.

1.2 Size and Weight

Changes in truck size and weight regulations have historically been driven by improvements to highway infrastructure and from agreements to raise taxation in return for more productive vehicle designs. A range of factors affecting truck size and weight legislation and policy in the U.S. is illustrated in Figure 1.2.



Source: FHWA, 2000

Figure 1.2: Factors Impacting Truck Size and Weight Legislation

The system in Figure 1.2 demonstrates the countervailing nature of the process—one desirable operational benefit is countered by a legitimate consequence, sometimes viewed as undesirable. Accordingly, size and weight limits have changed only slowly since the end of World War II, mostly as a result of highway system improvements and economic pressures to reduce costs and raise efficiency. At some point in the near future, further changes will have to be made on efficiency and competitive grounds and legislators in many states are already under pressure to change long standing regulations[9] and so lower transportation costs and emissions per ton-mile.

State and national governments have maintained current maximum weight limits in part because they have no easy way of funding the cost of highway improvements and maintenance

[9] At the federal level, change comes slowly—U.S. size and weight changes were last made in 1982.

that might follow LCV use[10]. Specific regulations and criteria to meet the public funding associated with large trucks are generally based on a cost allocation formula which fails to capture the full cost associated with the largest truck (TRB, 2002). The LCV freeze has resulted in the U.S lagging behind almost every other developed country in having a highway system that allows longer, heavier, and therefore more productive trucks and for determining an effective method of paying for them.

The current commercial vehicle regulatory framework in the U.S. can be regarded as a "hybrid" and reflects compromises reached in framing and then passing the 1982 truck size and weight regulations. A gross limit of 80,000 pounds (with various axle limits) became the standard interstate truck, thus allowing truckers in many states—including Texas—to raise their total payloads. However, a small number of states—mostly in the western U.S.—allowed higher trucking weight and longer vehicles. A compromise was reached whereby these states were "grandfathered" for LCV operation. Trucking fleets moving freight between jurisdictions that allow LCV operations, and those that do not, must either make additional investments in maintaining equipment or forfeit the efficiencies of heavier and longer trucks (Mercier, 2007). Critics of LCVs are concerned with LCV safety, notwithstanding the likelihood that larger trucks could reduce the numbers of trucks on any highway segment shared with smaller lighter vehicles. The experiences of operators in the grandfathered states provide a survey opportunity to evaluate actual experiences with LCV use.

1.3 Report Outline

The 0-6095 study extends over two years. The first-year report reviews past and current LCV use research, analysis, and operations and recommends a work plan for the second year that will evaluate routes over which a range of LCVs operate in Texas. This report reflects the four elements described at the beginning of the chapter.

Chapter 2 examines the U.S. federal LCV regulations, vehicle dimensions, and LCV operations by state. Chapter 3 examines the LCV impacts on pavements, identifying methods for computing life expectancy and pavement costs with a proposed pavement analysis method. Chapter 4 examines a major issue with LCV operations, namely that of bridge impacts. It reports the design loads and rating system used in bridge design and the proposed method for estimating LCV bridge impacts in this study. It describes several analytical methods used in previous size and weight studies, reports on bridge strengthening and bridge fatigue, and closes with relating the proposed bridge impact method to the second year case studies of Texas LCV routes. Chapter 5 examines LCV operational characteristics, including acceleration, off-tracking, and stability. Chapter 6 examines environmental and energy issues as LCV operations lower both in terms of ton-mile emissions. Chapter 7 examines the safety aspects of LCV operations based on previous studies, available accident databases, and analyses undertaken as part of this study. Chapter 8 reports the findings of a U.S. LCV operator survey conducted as part of this study, capturing views on vehicles, drivers, performance, and safety. Chapter 9 describes a workshop of LCV experts, LCV operators, larger truck users, researchers, and the TxDOT advisory team. The second-year program was developed and approved as part of this workshop.

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[10] Users pay only the costs they face as a result of registering, operating, and depreciating their vehicles. Ideally, all highway users should pay the marginal cost of taking a trip whether the vehicle is an auto or LCV. The costs should cover infrastructure consumption, congestion impacts and social costs for optimal and efficient use of highways (see Walters A.A. "Theory and Measurement of Private and Social Costs of Highway Congestion," Econometrica, Vol 29, No 4, Oct 1961 and "The Economy of Road User Charges," John Hopkins Press, 1968).

Finally, five appendices describe LCV regulations and operations in the European Union (EU) and Australia, NAFTA size and weight harmonization, the proposed project database for pavement and bridge analyses, and the workshop agenda and attendees.

Chapter 2. U.S. Long Combination Vehicle Regulations and Operations

Federal regulations govern the weight and size of commercial vehicles and the number of trailers that a power unit may tow on all federal-aid highways. These regulations have important economic implications because trucking costs and productivity are influenced by truck size and weight regulations. Size and weight also impact highway construction and maintenance costs, as well as highway safety. Finally, regulations affect international commerce, because the U.S. limits are lower than those of Canada and Mexico, which together permit LCV operations at significantly higher weights—though they differ substantially between countries[11].

2.1 Federal LCV Regulations

2.1.1 History of Federal Weight Regulation

Establishing truck size and weight limits has traditionally been the responsibility of states (Maze, 1994). In 1913, Maine, Massachusetts, Pennsylvania, and Washington became the first states to limit truck weights in an effort to protect highway pavements and bridges. By 1933, however, all states had adopted a truck weight limit of some kind. Pennsylvania's axle weight limit of 18,000 lbs was adopted as a basic element for the design of pavements and used as a maximum axle load on all Interstate Highways until 1974 (Maze, 1994). The axle weight limit was derived from rules governing wagon wheels and dirt roads, but ultimately became federal law.

The American Association of State Highway Officials (AASHO)[12] played a key role establishing uniform truck size and weight regulations through its 1932 policy that recommended a single axle weight limit of 16,000 lbs and tandem-axle weight limits as a function of the distance between the two axles. In 1946, AASHO revised its policy to recommend 18,000-lb single-axle limits and 32,000-lb standard tandem-axle limits. The policy also recommended a maximum weight of 73,280 lbs for vehicles having a maximum length of 57 ft between the extremes of the axles. This AASHO policy also introduced the concept that gross vehicle weight (GVW) be based on axle spacing.

Ten years later the federal government imposed truck weight limits for the Interstate Highway System (TRB, 2002). Although it was felt that maximum weight limits for vehicles using the highways were fundamentally a problem of State regulation, the report of the House Committee on Public Works on the Federal Aid Highway Act explained that the Committee felt that if the Federal Government was to pay 90% of the cost of Interstate system improvements, it was entitled to protect the investment against damage caused by heavy loads and that protection could be best ensured by limiting maximum axle loadings. In addition, the 1956 Act required the Secretary of Commerce and the States to develop uniform geometric and construction standards for the development of the Interstate system. Weight limits would facilitate uniform strength standards for pavements and bridges, while width limits were adopted to apparently facilitate uniformity in highway geometric design. The Federal Aid Highway Act of 1956 thus set the maximum gross weight on Interstate Highways at 73,280 lbs. The Act also dramatically changed

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11 Canadian LCV regulations vary by Province; Mexican federal laws limit true LCVs to specific routes.
12 In 1973, AASHO became AASHTO

the federal highway financing program. It created the Federal Highway Trust Fund for the deposit of federal gas taxes, earmarked this revenue for highway purposes, and established a "pay as you go" highway program. It is also pertinent to mention the AASHO "road test," a two-year experiment held at Ottawa, Iowa in the late 1950s. A test track comprising various pavement and bridge designs was built and the U.S. Army provided drivers that drove specially loaded trucks 24 hours a day, 7 days a week for 2 years. The results of this work were fundamental to U.S. highway pavement design for the next half century. A number of key concepts were introduced into pavement design including *load equivalency factors*, *present serviceability index*, and *equivalent standard axles*. The pavement design guide developed from this research was published in 1961, was revised in 1972 and 1993 and is still in use.[13] In 1974, the Federal Aid Highway Amendment increased the gross weight limit to 80,000 lbs—an increase that was viewed as an energy conservation measure—and reduced the speed limit to 55 mph. Both the 1956 and 1974 Highway Acts contained "grandfathered[14]" clauses—i.e., clauses that allowed heavier vehicles than specified in the acts (AASHTO, 1995). In other words, these provisions did not require trucks to comply with federal gross and axle weight limits and the bridge formula provided such vehicles could be lawfully operated at the time federal weight limits were enacted. All vehicles had to comply with posted bridge limits, however.

2.1.2 The Bridge Formula

The federal bridge formula, Formula B, *"was derived from assumptions about the extent to which legal vehicles should be allowed to cause stresses that exceed the stresses assumed in the bridge design (AASHTO, 1995). HS-20 is the minimum design load recommended by AASHTO for bridges on interstate highways"* (AASHTO, 1995). H-15 allows for a lighter design load and applies to many non-Interstate highway bridges. Bridge Formula B essentially prevents the exceeding of design stresses in HS-20 bridges by no more than 5% and HS-15 bridges by no more than 30%. Chapter 4 of this report provides a comprehensive treatment into the subject of bridge formulae and related LCV issues.

2.1.3 The Surface Transportation Assistance Act (1982)

In 1982, the Surface Transportation Assistance Act (STAA-82) extended the federal limits established by the 1956 and 1974 acts. The STAA-82 brought the States into greater uniformity by establishing maximum weight limits on the Interstate Highway System. These limits were the maximum weights established by the 1974 Act (AASHTO, 1995). The role of federal regulation intended in 1956—i.e., to protect the federal investment in roads and bridges and allow uniformity of highway geometric design—was broadened in the 1982 revision. The revision, for example, included the first requirements for states with more restrictive limits to conform to higher federal standards (TRB, 2002). The STAA-82 also designated a national network[15] of Interstate Highways and other major highways (i.e., with 12 ft traffic lanes) on which the wider (102-inch) and longer tractor-semitrailers (i.e., minimum trailer length of 48 ft)

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[13] http://en.wikipedia.org/wiki/AASHO_Road_Test

[14] Grandfather exemptions are applicable to states in which vehicles exceeding a federal limit were in operation before the enactment of the federal limit. Under current regulation, grandfathered vehicles may continue and operate indefinitely. The exemption applies to state permit operations as well as to general state limits (TRB, 2002).

[15] The national network (defined by STAA-82) comprises the Interstate Highway system plus designated portions of the Federal Aid Primary network, which predates the Interstate System (Luskin & Walton, 2001).

and twin trailer[16] (i.e., minimum trailer length of 28 ft) approved by the act could travel without restriction. The STAA-82 thus required States to allow trucks with certain dimensions to operate on the national network. States were prevented from limiting the length of a semitrailer in a semitrailer combination to less than 48 ft. Also, states have to allow trailers of at least 28 feet in a twin-trailer combination. Finally, STAA-82 provided for "reasonable access" of such large vehicles to reach services and facilities from the designated network (AASHTO, 1995).

2.1.4 Intermodal Surface Transportation Efficiency Act (1991)

> Texas is not one of the "grandfathered states" that allow LCV operations. The GVW of trucks is thus limited to the federally established gross limit of 80,000 lbs on the Interstate system.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 allowed certain exemptions (i.e., grandfathered clauses) permitted under previous Acts (AASHTO, 1995). However, ISTEA limited the operation of LCVs—double and triple trailer combinations of greater than 80,000 lbs gross vehicle weight—on the Interstate System to configurations that were authorized by state officials on or before June 1, 1991[17]. The Act therefore limited route expansions for LCV's and prevented the removal of LCV operating restrictions. The act also stipulated that the States shall submit a list of all LCV operations as of June 1st, 1991 to the Secretary of Transportation for publication in the Federal Register. The act specified that the list was to be finalized in 180 days after enactment of the legislation[18] (AASHTO, 1995). Finally, ISTEA included the following exceptions (AASHTO, 1995):

- Wyoming vehicle configurations, which were authorized by state law not later than November 3, 1992 are included, provided that they comply with specified single and tandem axle and bridge formula limits and do not exceed 117,000 lbs,
- Ohio may allow triple combination vehicles (28½ ft) on a one mile Ohio State Route segment that were not in operation on June 1, 1991, and
- Alaska's effective date was July 5, 1991 rather than June 1, 1991.

Regarding vehicle length restrictions, ISTEA Section 4006 provided that States shall not allow by statute, regulation, permit or other means of operation commercial motor vehicle combinations (except non-divisible loads) with 2 or more cargo carrying units on the Interstate and National Defense Highway Systems that (AASHTO, 1995):

- exceed the maximum combination trailer, semitrailer or other type of length limit authorized by state statute or regulation on or before June 1, 1991, or
- exceed the length of the cargo carrying units of specific configurations in lawful operation on a regular or periodic basis on or before June 1, 1991.

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16 A twin trailer combination with two 28 foot trailers is referred to as an STAA double (Luskin & Walton, 2001).

17 ISTEA Section 1023 stipulated that LCVs may continue to operate only if the LCV configuration was authorized by state officials (pursuant to state statute or regulation) and in actual lawful operation on a regular or periodic basis on or before June 1, 1991. In this case, all operations continue to be subject to all state statutes, regulations, limitations and conditions, including routing-specific and configuration specific designations and all other restrictions in force as of June 1, 1991 (AASHTO, 1995).

18 However, a supplemental notice of proposed rule-making was published February 25, 1993 that anticipated the final rule to be published in late summer 1993 (AASHTO, 1995).

The 1991 LCV freeze was the first federal law that prohibited states from allowing vehicles with larger-than-specified dimensions on roads other than Interstates. Also, although vehicle size and weight rules have been imposed on the grounds of concerns about pavement and bridge impacts—as was the case in 1956—the LCV freeze was reportedly the first federal size and weight rule justified in large part because of safety concerns (TRB, 2002).

2.1.5 LCV Driver Regulations

Federal Motor Carrier Safety Administration (FMCSA) Regulation 49CFR established minimum training requirements for LCV operators and for the instructors who train them in a final rule published on March 30, 2004. The effective date for this rule was June 1, 2004. The rule was in response to ISTEA (1991), which directed that training for LCV operators include the certification of an operator's proficiency by an instructor who has met the training requirements established by the Secretary of Transportation (Daniels, 2006). FMCSA Regulation 49CFR (Parts 380 and 381) thus established specific training requirements for LCV drivers and instructors. Before June 1, 2004, a state commercial drivers license with a special endorsement (i.e., double or triple trailer endorsement) was sufficient to operate LCVs. Since then, LCV drivers require:

- *LCV Driver Training Certificate of Grandfathering.* Driver training requirements were waived for LCV drivers who had safe driving records and at least 2 years of LCV driving experience on or before June 1, 2004. These drivers were issued a "*LCV Driver Training Certificate of Grandfathering.*" This certificate had a grace period of a year and issuance stopped on June 1, 2005.
- *LCV Driver Training Certificate.* LCV training entails driving and non-driving classes[19], including route planning and the checking of cargo and weight. Because LCV doubles and triples have different operating characteristics, FMCSA established different training courses for each vehicle configuration. For doubles training, drivers require a valid commercial driver's license and 6 months of driving experience of vehicles with a GVW rating of 26,001 lbs or more. To enroll in the triples training class, drivers require a valid commercial driver's license and six months of truck-tractor/semi-trailer or twin-trailer driver experience. The additional training requirements for LCV drivers aim to alleviate some of the public concerns related to the operation of LCVs.

2.2 Vehicle Dimensions and Regulations

2.2.1 Federal Truck Size and Weight Dimensions

Box 2.1 highlights the truck size and weight dimensions (i.e., weight, width, and length) specified by federal regulations.

[19] FMCSA Regulation 49CFR also established two types of LCV driver instructors: classroom instructors and skills instructors.

Box 2.1: Truck Size and Weight Dimensions per Federal Regulations

Weight

- The maximum allowable weight on a single axle is 20,000 lbs and 34,000 lbs on a tandem axle (i.e., pair of closely spaced axles) for vehicles operating on Interstate highways.
- The Bridge formula determines the maximum weight for each axle group on a vehicle as follows (Luskin and Walton, 2001):

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

in which

W = Maximum weight (lbs) on any group of 2 or more consecutive axles

L = Distance in feet between the extremes of the axle group

N = Number of axles in the axle group

- Federal law specifies the following exceptions to the Bridge formula (Luskin, Walton, 2001):
  (i) the combined weight on the entire set of axles on a vehicle (the "outer bridge") cannot exceed 80,000 lbs—thus, the gross vehicle weight
  (ii) 68,000 lbs may be carried on two sets of tandem axles spaced at least 36 ft apart
  (iii) a single set of tandem axles is limited to 34,000 lbs
- The maximum weight of the entire vehicle is 80,000 lbs on Interstate highways. States cannot impose lower weight limits than the federal limits on Interstate highways.
- States are required to certify that they have effective weight enforcement programs on federal-aid roads as a condition for receiving federal highway funding (TRB, 2002).

Width

- Federal law requires states to allow vehicles 102 in. wide on the National Network for Large Trucks—a federally designated network that includes the Interstates and 160,000 miles of other roads (TRB, 2002)

Length

- Trailer length and numbers: Federal law requires states to allow single trailers at least 48 ft long and tractors pulling two 28 ft. trailers on the National Network.

2.2.2 Special Heavy Freight Transportation Vehicles

As early as 1940, nearly all states had special permit procedures that allow exceptionally heavy and/or oversized loads to be moved on a state highway system. Although these permits typically apply to single trips, there was and continues to be, little uniformity in the permitting procedures applied by states (AASHTO, 1995). The distinction between divisible and non-divisible loads is not necessarily used as the criteria for requiring a special permit (AASHTO, 1995). Often, States grant permits for loads that could be determined divisible, but are included in legal grandfather clauses. Many permits of this type, however, do not exceed the bridge formula. In general though, single and multiple trip permits allow exemption from the bridge formula, vehicle configuration or gross axle weight limits for a single trip or up to a year, respectively. Furthermore, the Transportation Equity Act for the 21st Century (TEA 21, Public Law 105-178[20]) enacted by Congress in June 1998 included special provisions for four states on the issue of special permits and exemptions:

- In Colorado loads of three or more precast concrete panels were defined as non-divisible loads.
- In Louisiana trucks hauling sugar cane during the harvest season are permitted to operate at 100,000 lbs GWV on the Interstate highways.
- In Maine and New Hampshire specific segments of the Interstate highway system were exempted from federal weight limits (TRB, 2002).

The Texas Department of Transportation (TxDOT) may issue a number of single trip or annual specialty type permits to accommodate over-axle and over-gross weight trucks. In the case of indivisible loads, TxDOT can issue a permit that authorizes a truck to operate at up to 120,000 lbs. This annual permit costs approximately $4,000 per truck. Operators can apply online and the processing time is usually less than 5 business days. Permit holders may not use Interstate Highways, such as IH 35, because the vehicle weight exceeds federal regulation. In the case of divisible loads, TxDOT can issue a permit that allows a truck to be operated on state highways at a weight 5% over the legal limit for that specific configuration and 10% over axle limits. For example, if the legal limit of a truck is 80,000 lbs, it can operate with an additional 4,000 lbs. If the legal limit of the truck is 62,000 lbs, it can operate with an additional 3,100 lbs. The cost of this annual permit depends on the number of counties the truck is going to be operated in up to a maximum of $1,100 for all 254 counties[21].

2.2.3 U.S. LCV Configurations

The FMCSA defines an LCV as any combination of a truck-tractor and two or more trailers or semi-trailers that operate on the Interstate Highway System at a GVW greater than 80,000lbs. LCVs in the U.S. thus usually exceed 75 ft in overall length and can operate at a GVW greater than 80,000 lbs[22] (Abdel-Rahim, et al., 2007). However, Figure 2.1 illustrates the three standard LCV configurations most commonly operated in the U.S. The Rocky Mountain Double (RMD) is a semi-trailer combination consisting out of a 48 ft trailer[23] followed by a 28 ft trailer. The Turnpike Double has two 48 ft trailers[24]. In the U.S, the typical triple-trailer operates with three 28.5 ft trailers. It is of interest to note that the initial productivity gains from the grandfathered 1982 legislation have been reduced by changes in federal and state size limits.

[20] Section 1212(d)

[21] ftp://ftp.dot.state.tx.us/pub/txdot-info/mcd/pdf/section2830.pdf

[22] A twin, also called a Western Double, is a tractor followed by two 26 to 28 ft trailers, connected by a converter dolly. Given that the GVW of this combination is less than 80,000 lbs, twins are typically not regarded as a LCV (Daniels, 2006).

[23] In Canada, RMDs operate with a 54 ft long trailer, but the grandfathered length restrictions in most U.S. states do not allow for operation of this combination.

[24] In Canada, the Turnpike Double can be operated with 53 ft trailers, but U.S. grandfathered regulations prohibit the use of longer trailers.

Interstate semi-trailer trucks can operate with a trailer length of 53 ft[25] while grandfathered doubles are fixed at the prevailing length in 1982: 48 ft.

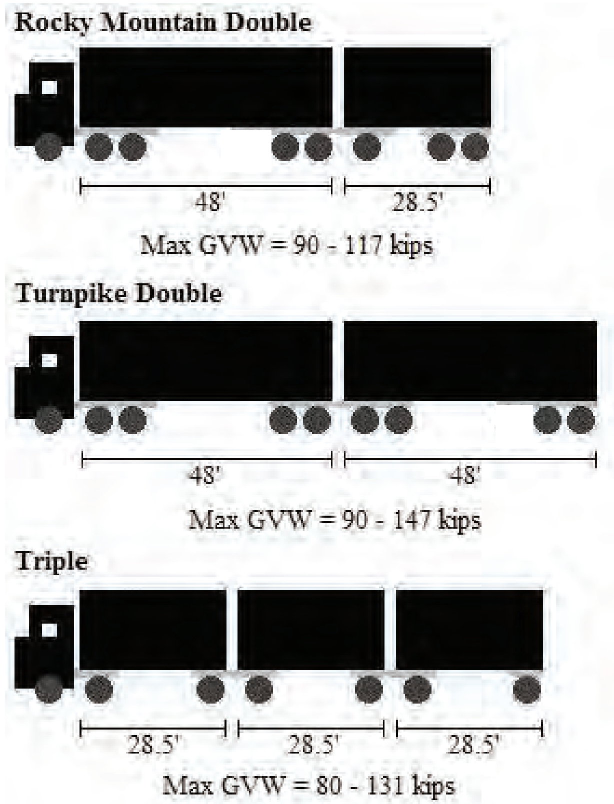


Figure 2.1: U.S. LCV Configurations

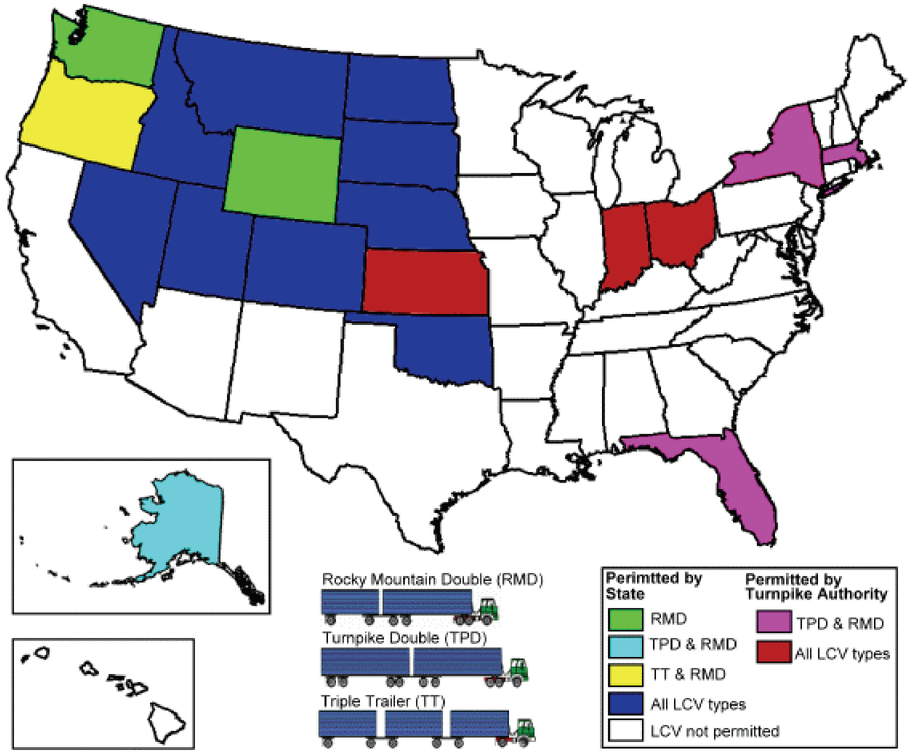
2.3 LCV Operations by State

Federal size and weight regulations have standardized only a portion of the large and heavy truck movements[26] (AASHTO, 1995). In addition to the grandfather exceptions, state and regional regulations vary dramatically from state to state or from one part of the country to another. Figure 2.2 illustrates the LCV configurations permitted by U.S. state and Turnpike Authorities and Table 2.1 illustrates the year in which the specific LCV configuration was first permitted in the individual state or by the Turnpike Authority. The differences in the LCV configurations allowed by states are a concern to some sectors of the trucking industry, which seeks to promote harmonization of vehicle size and weight regulations (AASHTO, 1995).

In 1999, the Western Governors' Association asked in a letter to the Secretary of Transportation that the DOT's "Comprehensive Truck Size and Weight Study" (released in 2000) include the analysis of a regulatory scenario involving the expanded use of LCVs that is consistent with LCV use in the 14 western states (TRB, 2002).

25 Trailers that are 55, 57, and 59 ft are permitted in Texas.

26 Single unit truck length maximums vary from 40 ft to 60 ft; semi-trailer lengths vary from 45 ft to 60 ft or are not restricted; twin combinations vary from not permitted to 88 ft on state designated roads; GVW ranges from 73,280 lb to 143,000 lb for turnpike doubles operating in the New York Thruway (AASHTO, 1995).



Source: U.S. Department of Energy, 2006

Figure 2.2: LCV Configurations Allowed by U.S. State

Table 2.1: Year LCV Configuration was First Permitted by U.S. State

States	Triples	Turnpike doubles	Rocky Mtn. doubles
Alaska	a	1984	1984
Arizona[b]	1976	1976	1976
Colorado	1983	1983	1983
Idaho	1968	1968	1968
Montana	1987	1972	1968
Nebraska[c]	1984	1984	1984
Nevada	1969	1969	1969
North Dakota	1983	1983	1983
Oklahoma	1987	1986	1986
Oregon	1967	a	1982
South Dakota	1988	1984	1981
Utah	1975	1974	1974
Washington	a	a	1983
Wyoming	a	a	1983
State turnpike authorities			
Florida	a	1968	1968
Indiana	1986	1956	1956
Kansas	1960	1960	1960
Massachusetts	a	1959	1959
New York	a	1959	1959
Ohio	1990	1960	1960

Note: Years shown are years in which the LCV type was first permitted.

[a]Not permitted.

[b]Arizona permits LCVs on one interstate crossing the northwest corner of the state.

[c]Nebraska permits LCVs only with empty trailers.

Source: GAO, 1992

Table 2.2 summarizes the types of LCV configurations, dimensions, and the extent of the highway network available to LCV operation by U.S. state and Turnpike Authority.

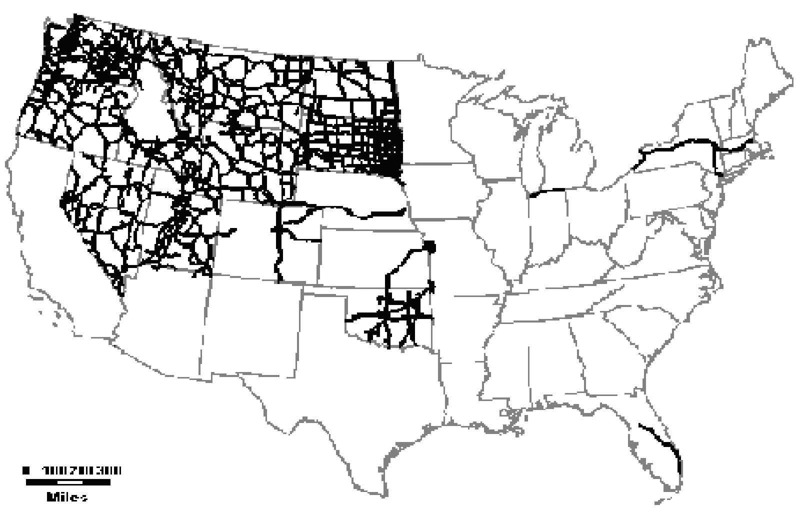
Table 2.2: LCV Configurations, Dimensions, and Routes by U.S. State

State	Maximum Weight ('000 lbs)	Maximum Length (ft)	Route Miles Open for LCVs	Type of LCV Allowed		
				Triples	Turnpike Doubles	Rocky Mountain Doubles (RMD)
Alaska (Summer only)	109	105	50 miles of four-lane roads and 425 miles of two lane roads	✓	✓	✓
Arizona (I-15 only)	111	105	84 miles	✓	✓	✓
Colorado	110	105	650 miles of Interstate	✓	✓	✓
Florida (Turnpike)	138	110	272 miles		✓	
Idaho	105.5	105	612 miles of Interstate open to all LCVs; an additional 2,572 open to LCVs off-tracking less than 6.5 ft on a 165 ft radius curve	✓	✓	✓
Indiana (Toll Road)	127.4	*	157 miles	✓	✓	✓
Kansas (Doubles – Turnpike) (Triples – I-70 only)	120	119	223 miles open to all LCVs; Kansas also allows Triples up to 110,000 lbs on 25 miles of other roads	✓	✓	✓
Massachusetts (Turnpike)	127.4	108	132 miles		✓	
Montana	131	110	State Highway System (11,400 miles) open to RMDs; Interstate open to Triples	✓	✓	✓
Nebraska	95	105	481 miles of Interstate open to Triples traveling empty	✓		
Nevada	129	105	4,872 miles	✓	✓	✓
New York (Turnpike)	143	114	540 miles of New York Thruway		✓	
North Dakota	105.5	110	2,170 miles	✓	✓	✓
Ohio (Turnpike)	127	108	241 miles open to RMDs; 3,500 miles open to Triples	✓	✓	
Oklahoma	90	No limit, although	Interstate highways (929 miles) open to			

State	Maximum Weight (‘000 lbs)	Maximum Length (ft)	Route Miles Open for LCVs	Type of LCV Allowed		
				Triples	Turnpike Doubles	Rocky Mountain Doubles (RMD)
		regularly they measure 105	triples up to 80,000 lbs; 899 miles of other Primaries open to Triples up to 90,000 lbs	✓	✓	✓
Oregon	105.5	105	6,000 miles open to RMDs; 3,500 miles open to Triples	✓		✓
South Dakota	129	110	State Highway System (7,900 miles) open to RMDs, 997 miles open to all LCVs	✓	✓	✓
Utah	129	105	951 miles open to all LCVs; an additional 4,845 miles open to RMDs up to 92 ft	✓	✓	✓
Washington	105.5	75	6,917 miles			✓
Wyoming	117	96	State Highway System (6,378 miles)			✓

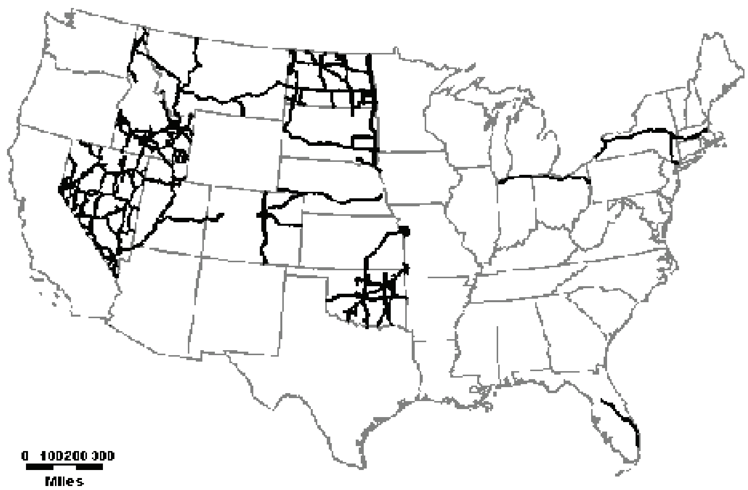
Sources: AASHTO (1995), Daniels (2006) and GAO (1993)

The information in Table 2.2 is graphically illustrated in the Figures 2.3, 2.4 and 2.5 which show the highway networks available to Turnpike Doubles, Rocky Mountain Doubles, and Triple Trailers, respectively.



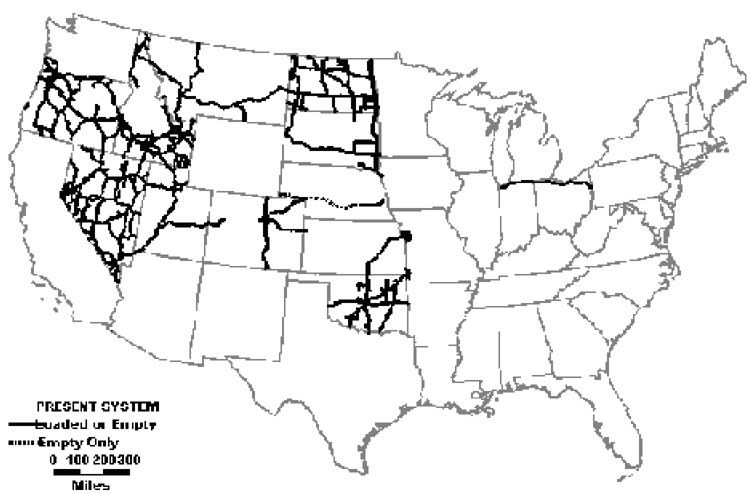
Source: FHWA, 1995

Figure 2.3: Highway Network Available for Turnpike Doubles



Source: FHWA, 1995

Figure 2.4: Highways Available for Rocky Mountain Doubles



Source: FHWA, 1995

Figure 2.5: Highways Available for Triple Trailers

Finally, Table 2.3 presents the estimated vehicle miles traveled (VMT) by selected vehicle configurations in year 2000 and the percentage year 2000 VMT by operating weight (ATRI, 2008).

Table 2.3: Year 2000 VMT by Selected Vehicle Configurations and Operating Weight

Vehicle Configuration[1]	Percentage of Year 2000 VMT by Operating Weight					Year 2000 VMT (million)
	45 - 60,000	65 – 80,000	85 - 100,000	105 - 120,000	125 - 140,000	
5-axle (CS5T)	27%	33%	10%	<1%	0	81,069
Double (DS5)	32%	43%	6%	0	0	5,263
6-axle (CS6)	22%	24%	26%	5%	1%	6,049
RMD (DS7)	23%	21%	28%	14%	3%	632
TRPL (TRPL)	11%	29%	37%	15%	5%	126
TPD (DS8+)	23%	21%	28%	14%	3%	759

1) The configurations listed are included in the categories shown in parenthesis in the HCAS.
Source: 1997 Federal Highway Cost Allocation Study, Appendix C, Table C-8

Source: ATRI, 2008

From Table 2.3, it is evident that the majority of truck VMT (86%) is associated with the 5-axle truck configurations. Furthermore, of the 81.1 billion VMT by 5-axle trucks, 33% of the VMT were at an operating weight that ranged between 65,000 and 80,000 lbs. From Table 2.3 it is also evident that LCVs account for only 1.62% of the total year 2000 truck VMT. Rocky Mountain Doubles accounted for approximately 42% of the LCV VMT in 2000, Triples for approximately 8%, and Turnpike Doubles for approximately 50%. Furthermore, in all three cases, between 40 and 44% of the LCV VMT in 2000 were at operating weights between 45,000 and 80,000 lbs, possibly suggesting the transportation of commodities that "cube out" rather than "weigh out." Similarly, between 17 and 20% of the LCV VMT in 2000 were at operating weights between 105,000 and 140,000 lbs. The latter amounted to 261.67 million VMT or about 0.28% of the total truck VMT in 2000.

2.4 Concluding Remarks

Federal regulation of size and weight standards has been justified on the basis of:

- harmonization of standards to reduce freight costs, which can be attained only through coordinated action. At a minimum, federal regulation thus aims to ensure that interstate or international commerce is not severely impeded by unduly restrictive regulations in a single state or a small number of states, and
- the value of investments in the national highway system may be higher than the value placed by the individual states that would otherwise be responsible for investment decisions. Federal standards will help ensure that the highway will be maintained despite a lack of local interest to invest in improvements that mostly benefit through traffic (TRB, 2002).

However, it has been argued that some of the considerations that influenced setting the size and weight restrictions in the past are questionable. The TRB Truck Weight Limits study (1990)[27] and the U.S. DOT's Comprehensive Truck Size and Weight study (2000)[28] both

27 TRB Special Report 225 Truck Weight Limits: Issues and Options, January 1990

28 http://www.fhwa.dot.gov/reports/tswstudy/index.htm

concluded that imposing nationwide uniform size and weight limits more restrictive than those previously in effect in many U.S. states would increase shipper costs by an amount greater than any compensating savings in highway costs. Uniformity *per se* was argued to be less efficient than regional variability in standards if the variability reflects actual differences in traffic and highway conditions and therefore in the operating costs of trucks of various dimensions. A second questionable goal was an attempt to regulate competition among the freight modes by restricting truck dimensions (TRB, 2002).

To conclude, trucks moved approximately 69% of the total U.S. freight tonnage in 2008 and are estimated to move approximately 71% of the total tonnage by 2020 (Lynch, 2009). Regulations governing the weights and dimensions of heavy trucks thus have major consequences (Schulman, 2003) in terms of transportation costs and ultimately the U.S. economy. Proponents of LCVs have argued that planes have become larger and more fuel efficient, trains longer and heavier, and container vessels substantially larger and more productive, but trucks have only benefited from marginal changes in trailer length and width on the federal highway system. These proponents also typically point to the benefits of more productive trucks in terms of fewer required truck trips, less truck VMT, fuel and emissions savings, and potentially reduced wear and tear on roads and bridges (Lynch, 2009).

The Iowa ASSHO road test, mentioned earlier in this chapter, scientifically proved that impacts from heavy vehicles transmitted through both axle and gross loads are the fundamental determinant of pavement consumption by users. Study 0-6095 recognized this and allocated adequate resources to measuring its impact on Texas highways. This is the subject of the next chapter.

Chapter 3. Pavement Impacts

The objective of this chapter is to develop a method to estimate the pavement infrastructure impacts of proposed LCV combinations. The recommendation includes two separate analyses:

- *Pavement life.* The team analyzed existing methodologies to estimate pavement life expectancy to critically select a method to compute the pavement infrastructure impacts of each LCV combination.
- *Cost Impacts.* The team subsequently analyzed existing methods to translate these impacts into costs.

The selected study methods, after TxDOT approval, will be applied to selected Texas corridors in the second year of the project. Data needed to perform these calculations are discussed in the conclusions and recommendation section of this chapter.

Pavement life expectancy will be calculated by considering aggregate traffic impact in terms of the equivalent single axle loads (ESALs) of the 1993 AASHTO Pavement Design approach (AASHTO, 1993, 1998), as well through the predictions of the M-E Pavement Design Guide developed under NCHRP 1-37A (Asphalt Institute, 1981).

3.1 Methods for Computing Pavement Life Expectancy

There are two widely accepted approaches for the calculation of ESALs: a traditional empirical approach based on the results of the AASHO road test and documented by AASHTO (AASHTO, 1998) and a mechanistic-empirical approach based on stresses and strains and more detailed material properties. Mechanistic-empirical approaches are well documented in references (NCHRP, 2004, Asphalt Institute, 1981). Both approaches apply to flexible and rigid pavements and are described below in detail. A recent report by Karim Chatti et al. (2009) contains extensive documentation on ESAL calculation methodologies for Michigan (NCHRP, 2004).

3.1.1 Empirical ESALs

The empirical ESAL concept dates back to the AASHO road test findings. ESALs capture pavement damage relative to the 18,000 lb dual-tire standard axle (W_{18}), which was the single axle load limit in the 1960s. ESALs were defined as ratios of the number of repetitions to failure of the W_{18} divided by the number of repetitions to failure of the axle in question W_x, as shown in Equation 3.1.

$$ESAL_x = \left(\frac{W_{18}}{W_x} \right) \tag{3.1}$$

This ESAL definition (Equation 3.1) can be used as a means of computing the relative damage of different axle configurations. The number of repetitions to failure can be considered in terms of serviceability failure (e.g., selected p_t of 2.0) as observed at the AASHO Road Test. For flexible pavements, the load equivalency is given by (Huang 2004):

$$\log\left(\frac{W_x}{W_{18}}\right) = 4.79\ \log(18+1) - 4.79\ \log(L_x + L_2) + 4.33\ \log(L_2) + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \tag{3.2}$$

Where:
L_x is the axle load in kips
L_2 is the number of axles per axle group
SN is the structural number.

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \tag{3.3}$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(SN+1)^{5.19}\, L_2^{\ 3.23}} \tag{3.4}$$

For rigid pavements, the load equivalency is given by:

$$\log\left(\frac{W_x}{W_{18}}\right) = 4.62\ \log(18+1) - 4.62\ \log(L_x + L_2) + 3.28\ \log(L_2) + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \tag{3.5}$$

Where:

$$\beta_x = 1.00 + \frac{3.63\ (L_x + L_2)^{5.20}}{(D+1)^{8.46}\, L_2^{\ 3.52}} \tag{3.6}$$

Caution should be exercised in interpreting the results of these equivalencies for triple and quadruple axles, as the performance equations used to derive Equations 3.2 and 3.5 from the data were originally developed for single and tandem axles only (i.e., the type of axles used at the AASHO road test). Another limitation of this approach is that the effect of environment-related deterioration is not considered in these load equivalency computations.

3.1.2 Mechanistic ESALs

ESAL values can be alternatively derived by extending the definition of ESALs (depicted in Equation 3.1) to reflect ratios of pavement life to particular distresses rather than serviceability. Certain traffic-associated distresses (e.g., fatigue cracking/rutting for flexible pavements and cracking for rigid pavements) can be modeled using appropriate damage functions. These are driven by pavement response parameters, which are computed for a specific pavement structure and axle load configuration using mechanistic pavement response models. The mechanistic models proposed for this project are EverStress and EverFE for flexible and rigid pavements, respectively.

For flexible pavement fatigue cracking, the number of repetitions to failure N_f is given by:

$$N_f = 0.0795\ \varepsilon_t^{\ -3.291} E^{-0.854} \tag{3.7}$$

Where:
ε_t is the tensile strain at the bottom of the asphalt concrete layer
E is the layer stiffness (lbs/in^2).

Substituting Equation 3.7 into Equation 3.1, one obtains:

$$ESAL_x = \frac{W_{18}}{W_x} = \left(\frac{\varepsilon_{t\ x}}{\varepsilon_{t\ 18}} \right)^{3.291} \tag{3.8}$$

For flexible pavement rutting, the number of repetitions to failure N_r is given by:

$$N_r = 1.365\,10^{-9}\ \varepsilon_v^{-4.477} \tag{3.9}$$

Where:
ε_v is the compressive strain at the top of the subgrade layer.

Substituting Equation 3.9 into Equation 3.1, one obtains:

$$ESAL_x = \frac{W_{18}}{W_x} = \left(\frac{\varepsilon_{v\ x}}{\varepsilon_{v\ 18}} \right)^{4.477} \tag{3.10}$$

Equations 3.8 and 3.10 can be used to compute the load equivalency of specific axle load configurations for flexible pavement sections.

For rigid pavements, axle load equivalencies can be expressed in terms of fatigue life m, using the following expression:

$$\log\left(N_{i,j,k,l,m,n}\right) = 2.0\left(\frac{MR}{\sigma_{18}} \right)^{1.22} + 0.4371 \tag{3.11}$$

Where:
MR is the modulus of rupture of Portland concrete.

Substituting Equation 3.11 into Equation 3.1, one obtains:

$$ESAL_x = \frac{W_{18}}{W_x} = \frac{10^{2.0\left(\frac{MR}{\sigma_{18}} \right)^{1.22} + 0.4371}}{10^{2.0\left(\frac{MR}{\sigma_x} \right)^{1.22} + 0.4371}} = 10^{2\left[\left(\frac{MR}{\sigma_{18}} \right)^{1.22} - \left(\frac{MR}{\sigma_{1x}} \right)^{1.22} \right]} \tag{3.12}$$

Equation 3.12 can be used to compute the load equivalency of specific axle load configurations and rigid pavement sections.

ESAL Example

A flexible pavement section in one of the Texas corridors, IH 20 in Mitchell County, was analyzed as part of this project. These characteristics, as well as those of the applied loads, are depicted in Figure 3.1. Data were retrieved from the research flexible pavement data base currently maintained by UT Austin under a TxDOT research contract.

The example describes the calculation of the mechanistic ESAL factor for the triple axle of one of the LCV types to be considered (Figure 3.2). The strain predictions obtained with *EverStress* are shown in Table 3.1. This table also shows the ESAL factors computed for this axle configuration in terms of longitudinal fatigue cracking and transverse fatigue cracking (Equation 3.8), as well as rutting (Equation 3.10). Overall, the equivalency of this axle configuration on this corridor ranges from approximately 1.8 to 2.3. The impact of this axle load configuration on a rigid pavement structure can be computed in a similar fashion, using *EverFE* for the pavement response predictions and Equation 3.12 for the load equivalencies.

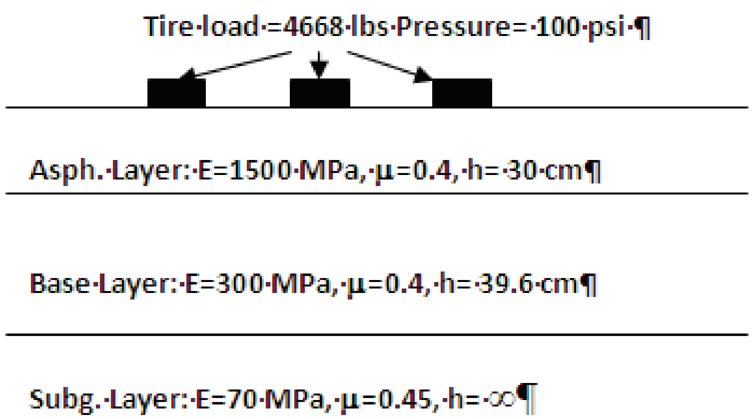


Figure 3.1: Layer Elastic Analysis of the Impact of the Triple Axle of the Vehicle Shown in Figure 3.2 on the IH 20 Corridor (Section in Mitchell County)

Table 3.1: Results of Mechanistic ESAL Computation Example

18,000 lbs Ref. Axle			**56,000 lbs on Triple Axle**			**Mechanistic ESALs**		
Strain 10^{-6}						**With respect to:**		
ε_{xx}	ε_{yy}	ε_{zz}	ε_{xx}	ε_{yy}	ε_{zz}	ε_{xx}	ε_{yy}	ε_{zz}
84.62	113.94	-123.55	100.89	103.54	-148.04	1.78	0.73	2.25

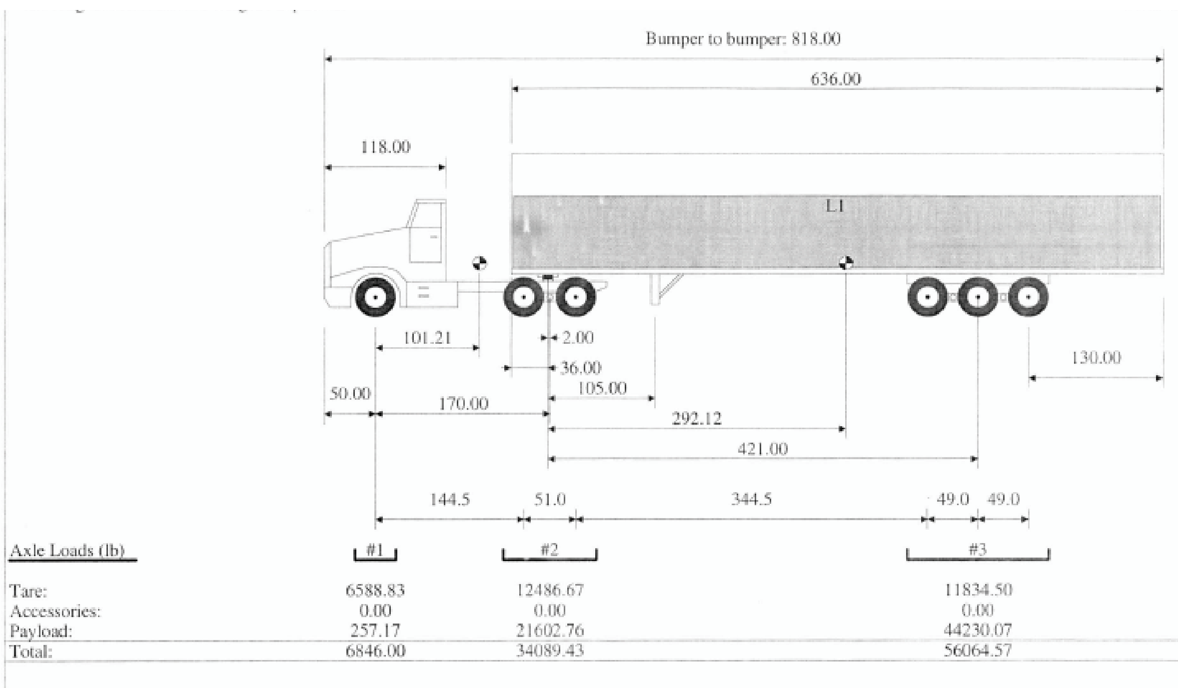


Figure 3.2: One of the Proposed LCV types

3.1.3 Mechanistic-Empirical PDG (MEPDG) Performance Approach

The MEPDG uses a combination of mechanistic principles and empirical relationships to predict site-specific pavement deterioration by distress type, as well as overall pavement performance versus time. The MEPDG program was developed by industry and university teaming partners for adoption and distribution by the American Association of State Highway and Transportation Officials (AASHTO) under a series of National Cooperative Highway Research Program (NCHRP) studies (ARA, 2009). The program accepts as inputs load spectra synthesized from data on truck count, classification, number of axles by truck class, and load distribution by axle type (Harrigan, 2006).

Using this method to estimate the impact of alternative LCV types involves the estimation of the resulting changes in the traffic load elements highlighted above for a selected pavement site and roadway corridor. Inputting these varying traffic data elements into the M-E PDG software will produce changes in the distress and performance predictions of the particular pavement site. Distresses reaching selected critical values (Table 3.2) define pavement failure and hence useful life. The difference in pavement useful lives between the current traffic loading and the modified loading caused by the introduction of the LCV type can readily be translated into a differential cost attributed to the latter. Repeating this process for alternative LCV types and axle load levels generates a table of infrastructure cost responsibility for these LCV types. An advantage of this approach is that the environmental conditions at a particular site and their effect on pavement deterioration are taken into consideration in predicting pavement performance.

Table 3.2: Critical Pavement Distress Levels

Pavement Type	Failure Mode	Limit
AC	Rutting	0.50 inches (or 12.5 mm)
	Longitudinal Cracking	20% (or 1028 feet per mile)
JPRC	Slabs Cracked	50% of total slabs
CRC	Punchouts	30 per mile

MEPDG Example

An example illustrating the MEPDG design approach is given here for the same flexible pavement section described in Figure 3.1 and used in the previous example. In this case, the impact of the FHWA Class 10 vehicle shown in Figure 3.2 is computed by estimating the length of time it takes for this vehicle alone to cause terminal distress to the pavement. This is compared to the length of time it takes for a conventional Class 9 vehicle to cause the same terminal pavement distress. In this comparison, the cargo being carried by these two vehicle configurations is taken into account. Because the proposed Class 10 truck carries 50% more cargo than the conventional Class 9 vehicle, 33% fewer trips would be required in this corridor if this LCV type was allowed in this corridor. Pavement rutting was identified as the critical distress parameter for this pavement (i.e., the other pavement distresses and the roughness did not reach critical values within the 20-year analysis period). The main assumptions for this analysis were:

1. The benchmark truck traffic volume (Class 9 trucks only) in the design lane is 950 trucks/day, hence the modified (i.e., Class 10 trucks only) is 633 trucks/day.
2. The axle load distribution of single, tandem and triple axles follows national default values (i.e., did not simulate all trucks loaded to the maximum axle load limit).
3. Traffic growth rate is 4% per year compounded.

The results of this analysis are plotted on Figure 3.3. This example shows that the introduction of the proposed Class 10 vehicle (i.e., the truck in Figure 3.2) will result in a reduction in pavement rutting life of about 11 months at a 95% reliability level. Pavement managers usually set a limiting value for distress development to denote failure. In this particular example, let us assume that this limit for rutting was set at 0.4 inches. By drawing an horizontal line at rutting 0.4 inches in Figure 3.3, one may estimate that the reduction in pavement life would be about 11 months by comparing the Class 9 and Class 10 curves for 95% reliability. Similar analysis can be carried out for each proposed LCV type.

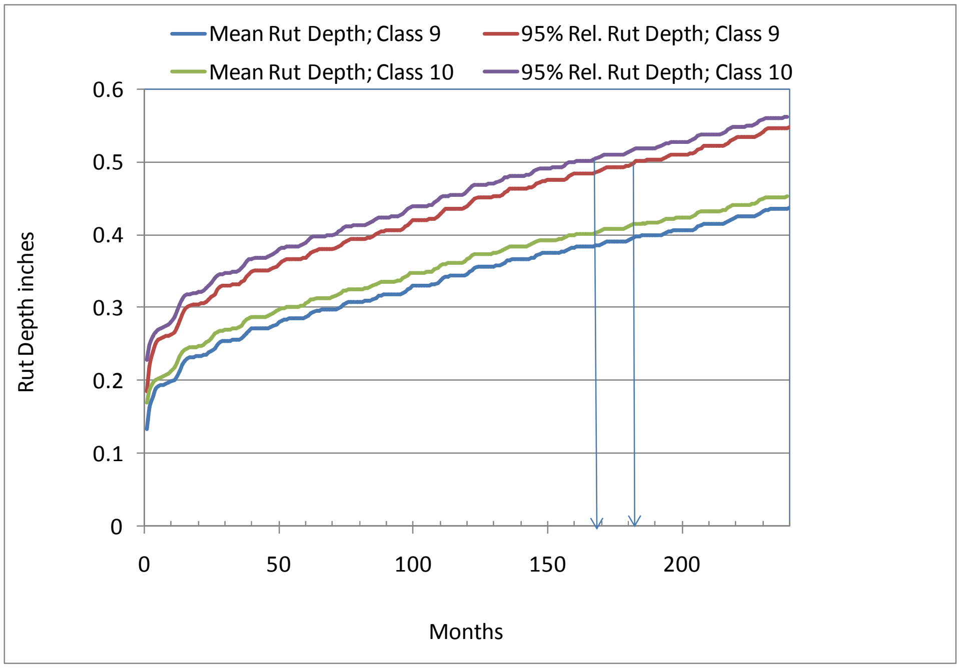


Figure 3.3: Pavement Impact Comparison between the Proposed LCV (Figure 3.2) and a Conventional Class 9 Truck; IH 20 Corridor in Mitchell County.

It is important to note that accurate traffic-related inputs are essential for accurate results, because MEPDG results are very sensitive to variations in traffic inputs. A recent Arizona study performed a sensitivity analysis of MEPDG input traffic parameters and the pavement performance predictions. This study examined the differences in input traffic data from different sources and their impact on the pavement distresses at the end of a design year. Moreover, the national default load distribution factors were compared with the site-specific distribution factors measured as part of the Long Term Pavement Performance (LTPP) program by evaluating the errors associated with predicting various pavement distresses. Findings showed that average daily truck traffic (ADTT) varied significantly between two data sources (LTPP and Arizona Department of Transportation), resulting in large differences in predicted longitudinal and alligator cracking. A further sensitivity analysis revealed that the longitudinal and alligator cracking increased by a larger factor with respect to increases in ADTT. The use of national default load distribution factors revealed a similar result, such that the errors associated with predicting cracking were large (Ahn, et al., 2009).

This discussion places great responsibility in the estimation of changes in load spectra and traffic due to the introduction of larger, heavier and more productive trucks.

3.2 Methods for Estimating Pavement Cost Impacts

3.2.1 Introduction

A recent NCHRP-sponsored study examined the history and evolution of highway cost allocation practices and reported on the current state of the art (NCHRP, 2008). This study addressed numerous issues, including the conceptual basis of highway cost allocation methods, methods used to allocate the costs associated with many highway program elements, methods for revenue attribution, and emerging highway cost allocation issues (NCHRP, 2008). This section relies extensively on this reference, and presents an executive summary of the findings that are relevant to this project.

3.2.2 Conceptual Cost Allocation Approaches

Incremental Method. The most common approach to determine pavement cost responsibilities for different vehicle classes uses an incremental approach, where pavement construction and rehabilitation costs are essentially allocated in the same way (USDOT, 2001, Li and Sinha, 2000). The Incremental Method assigns responsibility for highway costs by first determining the costs of constructing and maintaining facilities for the lightest vehicle class and then building the facility up to account for the costs attributed to each increment of larger and heavier vehicles. All vehicles are allocated the costs of the base highway system in proportion to their usage of the highway system, as if they all had the same size and weight. The additional costs of accommodating heavier and larger vehicles are defined as their occasioned incremental costs, which could be avoided if those additional classes were excluded from the highway system (NCHRP, 2008).

National Pavement Cost Model (NAPCOM). NAPCOM applies a set of pavement deterioration analyses to a large sample of pavement sections to determine what types of deterioration will occur and which vehicles are responsible for each type of deterioration. Heavy axles cause more damage per passage than light axles. For some types of pavement deterioration, doubling the axle load causes 15 to 20 times more damage; for other types of deterioration, doubling the load only doubles the damage. NAPCOM was developed because traditional approaches using simplistic ESALs did not mesh well with empirical data on pavement wear (NCHRP, 2008).

An important study on LCV impacts utilized the National Pavement Cost Model (NAPCOM) to estimate potential pavement impacts resulting from changes in vehicle size and weight limits in the western region (USDOT, 2004). NAPCOM is a complex simulation model initially developed in 1992 and subsequently improved for use in the 1997 Highway Cost Allocation Study. The key output of NAPCOM for truck size and weight analysis is the change in overall pavement improvement needs under alternative size and weight policy scenarios. The model is sensitive to different weight policies, depending on truck configuration, including the number of axles. Changes in pavement rehabilitation cost between successive runs of NAPCOM with changed assumptions about the distribution of freight among truck configurations and operating weights are attributed to specific groups of vehicles (USDOT, 2004).

3.3 Conclusions and Recommendations

Available pavement data at TxDOT are still being investigated through meetings with former and current TxDOT personnel as the pavement consumption related task in the project is still ongoing. ESAL calculations are a key aspect of the development of this research project and will consume a fair amount of resources. The project staff plans to concentrate on mechanistic-empirical approaches that may be constrained by the limitations on available network level pavement data at TxDOT.

3.3.1 LCV Impacts Traffic Mix, Load Spectrum, and Horizontal Loads

When apportioning loads to the LCVs, it seems reasonable to assume that the amount of freight being carried along each corridor will remain unchanged. Its redistribution between different truck types will affect the truck count, classification distribution and axle load spectra distribution on a particular corridor. Is not known at this point exactly how the load will be redistributed. The team will develop reasonable assumptions to calculate the new truck mix, if necessary in concert with TxDOT.

During a July 2009 international transportation conference there was an interesting discussion on LCV impacts on pavements (CONINFRA, 2009). Participants practicing in countries where LCVs are allowed reported pavement damages that appear to be due to horizontal loads. This damage occurs primarily when the heavy vehicles have only one powered axle. Because there are no models to calculate pavement distress due to horizontal loads, the issue is still under initial scrutiny. Nevertheless, its suspected existence is worth reporting to the study sponsor (TxDOT).

3.3.2 Proposed Pavement Analysis Methodology

The following sequence of steps for the analysis of the pavement impacts for a specific route is proposed by the pavement researchers at this point:

1. Identify the most critical segment(s) of the corridor in terms of heavy truck traffic (if any).
2. Retrieve pavement cross sectional data.
3. Determine existing traffic volumes, mix, and load spectrum without LCV operations.
4. Forecast traffic without LCV based on economic inputs (volumes, classification and axle weights).
5. Calculate pavement performance for the existing and forecasted mix without LCV.
6. Calculate the decrease in other trucks after LCV operations are allowed.
7. Estimate existing and forecasted traffic volumes, mix, and load spectrum with LCV operations for the critical areas of the corridor.
8. Calculate pavement performance for the existing and forecasted mix with LCV.
9. Estimate annualized pavement costs without LCV.
10. Estimate annualized pavement costs with LCV.
11. Compare and allocate costs based on Cost Allocation methodologies discussed in this chapter.
12. Estimate LCV pavement cost responsibility.

The pavement analysis group expects a strong interaction with Task 8, Policy Implications of LCV Operations, to obtain inputs of the impact of LCV operations on traffic volumes and classification (step 3 of the pavement analysis).

Two factors were paramount in convincing policy makers to “freeze” the LCV debate in the early 1990s. The first was based on the public objections—measured in letters and telephone calls to Congressional members and staff—to the prospect of automobiles sharing the highway with longer and heavier trucks. This perception was largely based on television and newspaper advertisements sharply focused on safety "risks" that were sponsored by the Association of American Railroads, who represented the transport sector most likely to lose market share if LCVs were widely adopted by the trucking industry. The second factor was the cost—to both highway agency and users—of strengthening or replacing the highway bridges over which LCVs would operate. Alliances between large trucking companies and Class 1 railroads in the late 1990s lessened the objections to LCV operations from the railroad industry. Bridge costs still remain a critical issue to be addressed in the study and are the subject of the next chapter.

Chapter 4. Bridge Impacts

Over the past two decades, all major studies examining the potential impacts of truck size and weight (TS&W) increases, including those sponsored by the Federal Highway Administration (FHWA) in its TS&W studies (USDOT, 2004, USDOT, 2000), the Transportation Research Board (TRB) (TRB, 1990, TRB, 1990), and several other researchers (Weissmann and Harrison, 1992, Weissmann et al., 1992), all found that the estimated damage to bridges would be the greatest single infrastructure cost caused by larger, heavier trucks.

In general, bridges must accommodate two forms of traffic stresses: bending stresses and shear stresses. There is also the issue related to the repetitive nature of highway loads that limit the amount of load cycles for a given material and are generally referred to as fatigue effects. If a load were to be placed at the center of a beam that is supported at each end, the beam would bend, or deflect. The beam material would stretch at the bottom and compress at the top. Truck loads produce a bending moment, which causes these types of stresses. There is a direct one-to-one relationship between bending moment and bending stress.

Shear stresses can be thought of as those stresses caused by a force that cuts (i.e., shears) rather than bends the beam. For example, if a very large load were applied very close to the support of a beam, there would be no significant bending action (because the distance to the support is very small). However, the beam would resist the "cutting" action, that is, the shear stresses. Although bridge engineers consider and design for all stresses, in most cases the bending moment stresses are usually a controlling factor in the design and operation of a bridge. They were used in several of the completed TS&W studies as a indicator to be used to screen bridge deficiencies.

4.1 Design Loads and Rating Loads

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

4.1.1 Design Vehicles

Bridge engineers developed the concept of design vehicles prior to World War II. Design vehicles are hypothetical vehicles intended to represent the entire truck fleet in the vehicle stream. Use of the design vehicle allows the engineer to design bridges to safely withstand live load stresses caused by a single envelope vehicle rather than having to estimate stresses for each of the many different types of trucks forecasted to use that bridge.

Most States use one type of design vehicle, the HS vehicle. The HS vehicle is a three-axle vehicle with the load on the steering axle of X tons, a load on the second axle of 4X tons 14 feet behind the steering axle, and a load on the third axle also of 4X tons spaced 14 to 30 feet from the other non-steering axle. The engineer, during the design process, models several axle spacings for the distance between the second and third axles to determine which axle spacing produces the maximum stresses. In most cases, the HS vehicle with the short 28-foot wheelbase is the most critical. An HS vehicle is denoted with a number (e.g., HS20) that indicates the total weight of the vehicle in tons divided by 1.8. Consequently, the HS vehicle weighing 72,000 pounds would be the HS20 vehicle, because 36 tons (72,000 pounds) divided by 1.8 is 20. This vehicle would have a 4-ton load on the steering axle and loads of 16 tons on each of the other two other axles. Figure 4.1 illustrates the HS vehicle axle layout.

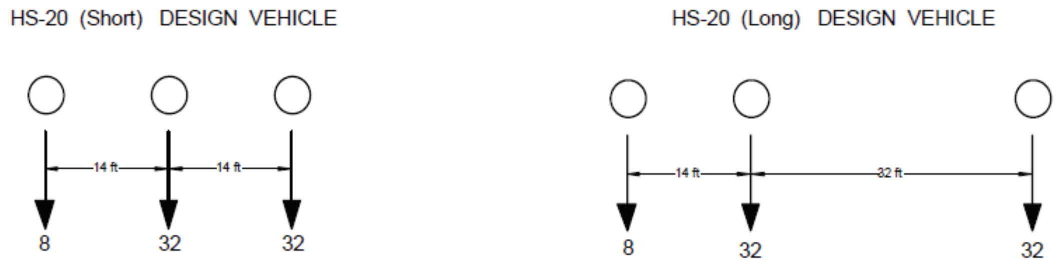


Figure 4.1: HS Design Vehicle

4.1.2 Bridge Ratings

Two bridge ratings are reported by the States to the FHWA for inclusion in the National Bridge Inventory (NBI), the inventory rating and the operating rating. The inventory rating is determined, in the case of steel bridges, by limiting the stresses to 55% of the yield stress. The operating rating is determined by limiting the stresses to 75% of the yield stress.

The design stress level for new bridges is effectively the same as the inventory rating, 55% of the yield stress. However, as the bridge ages and deteriorates, the inventory rating could be effectively lower than the design load. The FHWA requires that states report these ratings in terms of the hypothetical HS vehicle through well documented procedures (AASHTO, 1994). To determine the inventory rating of a bridge, the bridge engineer computes the heaviest HS vehicle that can traverse the bridge such that the weakest structural member is effectively at 55% of its yield stress. In a well-designed bridge, once loaded, all the designed members will be at or near 55% of their yield stress. Generally, that produces a safety factor of 1.8 (1÷0.55). Most States allow full and legal operation of trucks that produce bending moments on a particular bridge less than or equal to the moment caused by this Inventory Rating Vehicle.

The operating rating is computed in a fashion similar to the inventory rating, except that the maximum stress is set at 75% of the yield stress of the weakest structural bridge member. Generally, this produces a safety factor of 1.33 (1÷0.75). Most States do not allow vehicles with or without a permit to travel on bridges that would be stressed beyond their operating rating. The only exception may be for special non-divisible loads for which a detailed engineering analysis of the bridge confirms that a single passage will not cause measurable harm to the bridge. Previous research confirms this approach to permitting by the States nationwide (Harrison, et al., 1991).

The FHWA requires States to use a consistent analysis methodology to compute the operation rating and to report this rating in the HS rating system. This provides consistency across all States. For example, if the heaviest HS design vehicle that can traverse a bridge without exceeding the bridge inventory rating weighs 62,000 pounds, the bridge is rated at HS17.2, because 62,000 pounds is 31 tons, and 31 divided by 1.8 yields 17.2. Inventory rating load levels are accepted by bridge managers and designers as a load level where fatigue effects are minimized or irrelevant. Operating rating load levels are recognized by the same group as a cause of concern in terms of bridge fatigue life.

4.1.3 Impacts of Rating and Design Vehicle Choices

Significant cost differences result from the choice of rating. Any analytical process such as the one required by the case studies for this research project need to test the sensitivity of bridge investment needs to assumptions about the level of stress at which bridge improvements would be needed. The project staff plans to provide estimates of bridge needs for several stress levels between the inventory and operating ratings. As expected, use of the lower stress level (inventory rating) results in many more bridges being identified as needing to be upgraded to accommodate increased weights. This outcome is expected because the design rating is effectively the same as the inventory rating on a new bridge. Bridge designers have used the HS20 vehicle as the design standard for most bridges built in the last 50 years, although some States have started to use the HS25 design vehicle so that the new bridges better accommodate heavier trucks. Texas used the HS25 design vehicle for a brief time and then moved to HL-93 design live load.

Use of the HS20 design vehicle resulted in bridges being overdesigned for the truck fleet of 50 years ago. However, over time, as trucks were allowed to become heavier, this extra factor of safety has been eroded. Today, while the HS20 vehicle still envelops most of the current truck fleet (except for LCVs and a few other very heavy trucks in States with “grandfather” rights), it does so with little margin of safety. Consequently, in most bridges, small increases in truck weight will result in stresses greater than those caused by the HS20 design vehicle. However, because the operating rating stresses are 36% greater than the inventory rating stresses, only large increases in truck weight and length will overstress bridges when the operating rating is used as the threshold in defining “overstress.”

The term “overstress” is figurative and does not necessarily mean that a bridge is in danger of failure. The NBI and the Texas-specific bridge inventory (BRINSAP) contains an inventory rating for each bridge that represents a stress effectively equivalent to 55% of the lowest yield stress of the primary bridge members. The rating is expressed in terms of a standardized vehicle, e.g., the HS20 vehicle. If a bridge has an HS20 inventory rating as reported in the NBI, it means that an HS20 vehicle on each lane produces an acceptable stress for the bridge. Any vehicle that creates a greater moment than the HS20 vehicle “overstresses” the bridge. States regularly allow small overstresses, but large overstresses could cause premature deterioration or, if truly excessive, failure of key bridge members. There are several factors that allow some bridge overstress without compromising safety. Using the inventory rating as the basis for determining the level of overstress provides a large measure of safety because it represents stresses of only 55% of the yield stress a bridge can withstand. In addition, bridges have some redundancy in their structural systems, and this is not usually captured in the design process. Finally, the rating methodology considers a truck with a moment equivalent to the rating vehicle in each lane of the bridge. This rarely occurs, especially on low volume roads, and thereby contributes to a considerable factor of safety. Except in unusual cases, the dead load and the truck live load (multiplied by a factor to account for dynamic stresses) are the prevailing factors in the design of the bridge, and also in decisions associated with TS&W that would lead to bridge replacement or strengthening.

4.2 Proposed Methodology

4.2.1 Rationale

The analysis proposed for the case studies of this research project concentrates on bending moment stresses for several reasons. Generally, a highway bridge designed to accommodate the bending moment stresses caused by the live, dead, and dynamic loads, will also accommodate the fatigue effects and shear stresses. If the bending stress is excessive, the other stresses usually are excessive as well. This is one reason that bridge replacement often is the best solution for a bending moment overstressed bridge. Another important reason is that highway agencies often must improve safety features like alignment, lighting, utilities, and other level of service characteristics if they strengthen a bridge. When costs of these other improvements are added to the cost of strengthening, total bridge replacement often is found to be more cost effective.

Strengthening is possible only for some bridge types. Steel girder, some trusses, and even some prestressed concrete beam bridges can be economically strengthened if they meet all other stress and level of service criteria, but reinforced concrete slab and several other bridge types cannot be easily strengthened.

Bridge analysis for policy studies must rely on readily available bridge data. The FHWA's National Bridge Inventory (NBI), known as BRINSAP in Texas, is the only dataset that meets this objective. Unfortunately, BRINSAP does not contain any detailed data describing the bridge geometry, location of details, and other detailed information. This effectively rules out the analysis of fatigue, shear or other stresses that require this level of detailed data on the individual bridge design elements. However, the NBI/BRINSAP does contain sufficient data describing the bridge length, support type, design type, and material that permits the accurate estimation and computation of the live load and total bending moments. This is an additional reason why previous studies of national TS&W policy issues have either ignored fatigue effects and other less critical stresses or handled them in a very simplified manner. But, as discussed before, little is gained by considering fatigue or other stresses, because the bending stress is a defensible surrogate for all stresses. In the Texas case, the fatigue issue is further minimized by the nature of bridge construction and the existing bridge inventory. Most bridges in the main routes of Texas are pre-stressed concrete bridges that are less prone to fatigue effects when compared to steel bridges.

4.2.2 Bending Moment Analysis

The data available in the NBI/BRINSAP allows the application of simplified methodologies to screen deficient bridges for proposed traffic configurations at the policy level. This process has been implemented by several authors for evaluating bridges along a given route or for a given highway system for specific truck configurations (Weissmann and Harrison, 1992, Weissmann et al., 1992, Imbsen and Schomber, 1987, Moses, 1989). The essence of all these methods is summarized by the following formula:

$$OR = \frac{MLLIO + MDL}{MLLIR + MDL} \tag{4.1}$$

Where:

OR is the overstress ratio,

MLLIO is the maximum moment due to live load plus impact for the proposed vehicle,

MDL is the maximum moment due to the dead load, and

MLLIR is the maximum moment due to live load plus impact for the rating load (operating or inventory levels as recorded in the NBI (AASHTO, 1994))

An overstress ratio equal to or less than one means that the bridge is within the stress limit selected (operating or inventory). An overstress ratio greater than one, means that the overweight vehicle causes stresses above the selected stress limit.

None of the size and weight studies available in the literature carries out an analysis incorporating the dead loads due to the unavailability of this information in the NBI. The Moment Analysis of Structures (MOANSTR) (Weissmann et al., 2002) computerized routine incorporates the dead loads in the analysis, and was used in all the recent FHWA TS&W studies (USDOT, 2004, USDOT, 2000). These studies takes advantage of live load to dead load moment ratios developed in previous research (Weissmann, et al.,1993, Weissmann, et al.,1994) to support a full moment analysis (live + dead load moments). This issue will be further discussed in the analytical tools section of this report.

4.3 Analytical Tools for Bridge TS&W Studies

4.3.1 Bridge Analysis and Structural Improvement Costs (BASIC)

BASIC is a fully functional system for evaluating the impacts of changes on vehicle size and weight on bridges. This system was developed as specific deliverable for FHWA Study DTFH61-92-C-00099 (Weissmann et al., 2002), Harrison, et al.,1996) entitled “Impacts of Heavy Trucks on Bridge Investment” and had an important role as a policy-making tool for use by FHWA in the last Federal Comprehensive TS&W study and other cost allocation studies performed by the FHWA (USDOT, 2004, USDOT, 2000).

BASIC integrates the operations of evaluating the impacts of changes in truck size and weight legislation on bridges along a specified route or a given network. For example, the analyst can begin with the complete NBI/BRINSAP database and retrieve the interstate bridges for the State of Texas. Then, the analyst would be able to compare moments for the NBI rating vehicle and the proposed truck configurations for all the bridges in the Texas Interstate set using the routine Moment Analysis of Structures (MOANSTR). Next, the analyst would use the Bridge Improvement Traffic Impacts (BITI) routine to estimate the work zone impacts of rehabilitating or replacing all the bridges identified as deficient by BASIC (using the MOANSTR results). Finally, with the BASIC environment, the analyst can generate combined reports of bridge reconstruction and user costs for those bridges that are deficient to carry the proposed truck configurations. The flowchart depicted in Figure 4.2 shows the flow of information within the BASIC environment.

The reports generated by BASIC and its supporting routines, MOANSTR and BITI, can be viewed and processed by spreadsheet applications, because the output files are all comma delimited. The BASIC system components are discussed next.

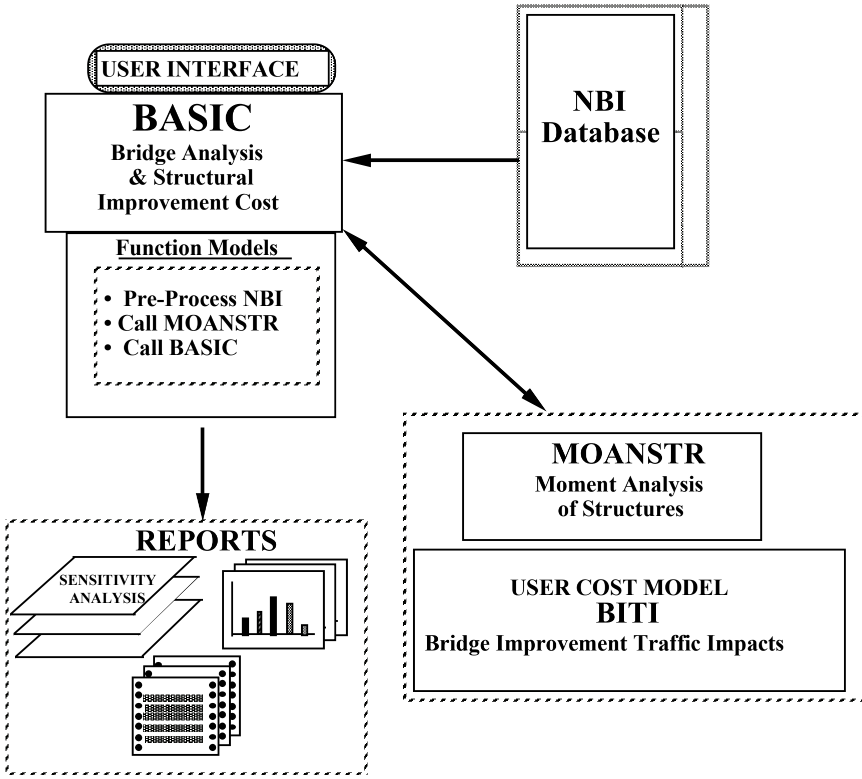


Figure 4.2: BASIC System Architecture

4.3.2 Moment Analysis of Structures (MOANSTR)

The core of the MOANSTR program is a finite differences routine used to calculate the moment envelopes generated by the proposed truck configurations and the NBI/BRINSAP rating loads. MOANSTR is controlled by user friendly menus, illustrated by Figure 4.4. The MOANSTR routine incorporates previous research work developed by Matlock (Matlock and Taylor, 1968).

MOANSTR calculates moment envelopes as depicted in Figure 4.3 and identifies the maximum live load bending moments (positive and negative) induced by the proposed configuration and the rating load. In addition, it estimates dead load moments from built-in moment ratios calculated in previous research (Weissmann, et al., 1993, Weissmann, et al., 1994), and calculates the overstress ratio based on Equation 4.1. Table 4.1 presents an example of the tabulations for these live to dead load moment ratios (Weissmann, et al., 1993).

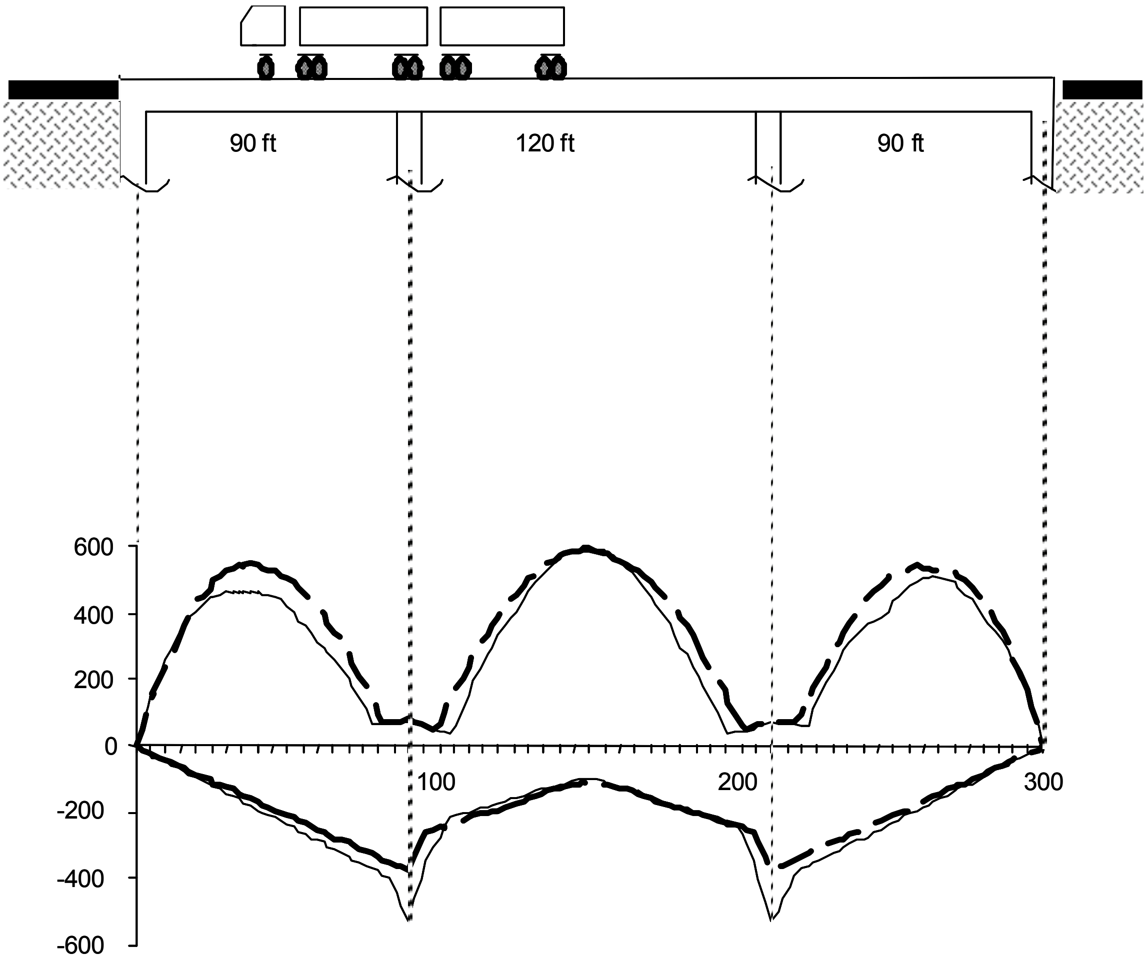


Figure 4.3: Moment Envelopes

```
                         M O A N S T R
                  Moment Analysis of Structures

                            Main Menu

          (1)  NBI Data File Pre-Processor.

          (2)  Enter or Edit Future Traffic Loads.

          (3)  Include Dead Load Moments?: NO

          (4)  Rating Type for Analysis?: INVENTORY

          (5)  Perform Batch Moment Analysis.

          (6)  Save or Load Future Traffic Loads.

          (7)  Moment Analysis Interrupt Criteria (% Overload): 50

          (8)  Enter Inventory Rating Multipliers.

               Select a Number (1-8)  or  <ESC> to Exit
```

Figure 4.4: MOANSTR Menu

Table 4.3: Prestressed Concrete Beams (Precast) Moment Ratios

LOAD	**Span 30’**			**Span 40'**			**Span 50’**		
	Moment (kip*ft)		**Ratio**	**Moment (kip*ft)**		**Ratio**	**Moment (kip*ft)**		**Ratio**
	Dead	Live	Live/Total	Dead	Live	Live/Total	Dead	Live	Live/Total
HS 25	117	365	0.757	208	583	0.737	353	818	0.699
HS 15	117	230	0.663	208	370	0.640	353	523	0.597
H 20	117	263	0.692	314	379	0.547	500	500	0.500
H 2.5	117	54	0.316	207	89	0.301	129	129	0.500

LOAD	**Span 60'**			**Span 70'**			**Span 80'**		
	Moment (kip*ft)		**Ratio**	**Moment (kip*ft)**		**Ratio**	**Moment (kip*ft)**		**Ratio**
	Dead	Live	Live/Total	Dead	Live	Live/Total	Dead	Live	Live/Total
HS 25	506	1048	0.674	776	1288	0.624	1257	1522	0.548
HS 15	506	676	0.572	776	836	0.519	1013	996	0.496
H 20	506	632	0.555	689	807	0.539	1013	994	0.495
H 2.5	467	182	0.280	689	240	0.258	900	306	0.254

LOAD	**Span 90'**			**Span 100'**			**Span 120'**		
	Moment (kip*ft)		**Ratio**	**Moment (kip*ft)**		**Ratio**	**Moment (kip*ft)**		**Ratio**
	Dead	Live	Live/Total	Dead	Live	Live/Total	Dead	Live	Live/Total
HS 25	1591	1577	0.498	2163	2015	0.482	3114	2523	0.448
HS 15	1591	1165	0.423	1964	1339	0.405	3114	1701	0.353
H 20	1591	1203	0.431	2162	1434	0.399	3114	1945	0.384
H 2.5	1282	380	0.229	1964	464	0.191	3114	765	0.197

4.3.3 Bridge Investment Traffic Impacts (BITI)

The subroutines included in the Bridge Investment Traffic Impacts (BITI), another BASIC module, calculate user costs, emissions, and vehicle operating costs and take into consideration a significant number of cost items. These include time delay, fuel, oil, tire wear, maintenance and depreciation, and vehicle rates of emission production. BITI was developed based on QUEWZE, developed at the University of Texas at Austin's Center for Transportation Research (CTR) (Seshadri, et al., 1993). Several improvements were made to facilitate the usage of the model and the following modifications led to the development of BITI:

- Diversion routine to model vehicles diverting from a queue
- Capability to enter traffic volumes by default distribution by choosing a functional classification and entering an ADT
- Capability to enter vehicle operating costs directly instead of using a consumer price index to adjust costs in 1985 dollars
- Development of a batch processor to perform several analyses at once using standard NBI computer records
- User interface that provides the user with menu choices instead of a command line
- Graphic plot of results displayed by hour of work zone activity
- Capability of saving and loading work zone configurations to disk

BITI was written specifically to address federal and state policy analysis issues as they relate to the impacts that bridge work zones impose on the traveling public. Typically, such policy analysis is directed to sets of bridges, such as all structures on the interstate network, or in the case of this research project along a given route. The applicability of such a model lies in its ability to predict user costs and emissions for a set of bridges rendered deficient by the introduction of heavier truck configurations. The batch processor for NBI/BRINSAP data, combined with a moment analysis routine such as MOANSTR, provides a powerful combination for reporting bridge user cost impacts and emissions due to bridge improvement work zones in policy evaluation of increases in truck size and weight.

The lane closure strategy is selected for each bridge and the user cost impacts are calculated, considering the direction of traffic on the facility, the number of lanes in each direction, the number of lanes that are possible to sustain by the facility in a work zone, and the availability of a nearby detour. The subroutines embedded in the computer code for BITI calculate the user costs, emissions, and queue lengths under the selected lane closure strategy and the existing conditions based on information extracted from the NBI/BRINSAP database. This results in a user cost and an emissions estimate for each bridge screened in a selected route. The results can then be reported on an aggregated basis or on a bridge by bridge basis. Again, all the results of the batch analysis performed by BITI are stored in comma delimited files that can be easily manipulated using electronic spreadsheet applications.

4.3.4 Stepwise Methodology for Using BASIC

The steps and intrinsic capabilities involved in running BASIC are summarized as follows:

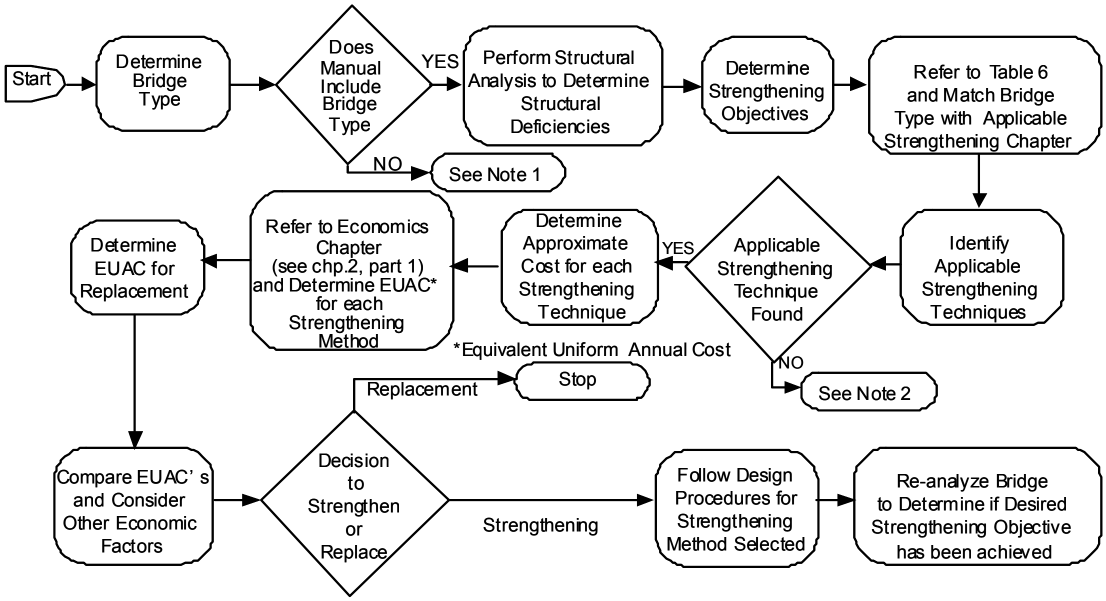
1. Retrieve the NBI/BRINSAP records pertinent to the desired analysis based on several screening variables and prepare input files for MOANSTR and BITI, a process that will be more accurately and expeditious using the GIS data mining system described in a subsequent chapter. After this step is accomplished, all the files generated by BASIC are comma delimited, allowing easy viewing and manipulation using spreadsheet programs.
2. Compare moments for the NBI/BRINSAP rating vehicle and the proposed truck configurations for all the bridges in the previously retrieved set using the routine MOANSTR. MOANSTR can perform a live load or a live load + dead load moment comparisons. The total moment comparison using the live and dead load moments incorporates the moment ratio results developed in associated research (Harrison et al, 1991; Imbsen and Schomber, 1987). Output files for MOANSTR are also comma delimited, allowing easy viewing and manipulation with spreadsheet programs.
3. Estimate work zone impacts in terms of user costs and emissions for rehabilitation or replacement for all the bridges identified by MOANSTR in step 1 using BITI. Output files for BITI are also comma delimited, allowing easy viewing and manipulation using spreadsheet programs.
4. Finally, using the BASIC environment, the user can generate combined reports of bridge reconstruction and user costs for the bridges screened as deficient along a given route to carry the proposed truck configurations. The bridge agency and user costs file summaries for the bridges screened as deficient to carry the proposed truck configurations generated by the BASIC environment are also comma delimited allowing easy viewing and manipulation using spreadsheet programs.

4.4 Bridge Strengthening

NCHRP Report 293 (Klaiber, et al., 1987) is a key reference in the subject of bridge strengthening, and comprises four chapters. Chapter 1 of the report outlines the research objectives and the research approach. Chapter 2 reports on the results of the questionnaire survey, which summarizes the responses on the subject of bridge strengthening from respondents nationwide, and summarizes the most common strengthening methods for each bridge type found in a comprehensive literature survey. Chapter 3 includes a bridge strengthening manual with costs and recommendations for the different bridge types. It also includes a Life-Cycle Cost (LCC) model to evaluate and compare the alternatives of strengthening or replacing a given load deficient bridge. Chapter 4 includes the summary and conclusions for the NCHRP report.

The most relevant information for this project is contained in Chapter 3, and could be used in the development of the case studies once the bridges deficient for LCV operations are identified by the analytical processes discussed in this chapter.

NCHRP Report 293, Chapter 3 provides a methodology, based on life-cycle costs and Equivalent Uniform Annual Costs (EUAC), which could be used at the project level to support the decision of either replacing or strengthening a given bridge. The methodology is summarized as follows in Figure 4.5. As depicted in Figure 4.5, the procedure involves detailed information and analysis that makes the procedure almost unfeasible for implementation for LCV policy network level decisions in Texas without additional data gathering and analysis that are beyond the scope of this project. Most of the information required to implement the procedure is currently unavailable in network level databases, and is unlikely to be included in the foreseeable future.



NOTE 1: The bridge types emphasized in the Strengthening Manual are those most commonly found in the United States. Many of these Strengthening Techniques, however , could be applied to other types of bridges. It is recommended that the manual user review each Strengthening Technique and evaluate its potential effectiveness.

NOTE 2: Additional information on each particular bridge Strengthening problem can be found in the literature review and the bibliography .

Figure 4.5: NCHRP 293 Strengthening Evaluation Flowchart

NCHRP 293 discusses the concept of level-of-service as a means of quantifying user benefits following the construction of a new bridge. This is a concept currently used by Bridge Management Systems (BMS) in establishing priorities for bridge improvement. Existing bridges, particularly those with obsolete geometry, or inadequate traffic flow capacity, are not able to provide the same level of service as a new bridge, causing congestion problems and additional accidents. New bridges will have reduced accident rates, reduced traffic delays and other social savings, sometimes termed *externalities*. Reduced level-of-service in BMS applications is typically accounted for as an additional annual cost of keeping an existing bridge open, and basically translates into additional user costs. These costs are difficult to quantify, and it will be assumed for the case study analysis for this research project that if an existing bridge is deficient in either capacity or geometry, it will automatically be rejected as a candidate for strengthening. This decision will be made by using widely accepted levels of service suggested for BMS applications nationwide. The attainment of specified levels of service is an important issue for bridge engineers across the nation when faced with the decision of strengthening or replacing a load deficient bridge. These concepts lie behind the numbers obtained from the questionnaire reported in NCHRP 293 when bridge engineers were asked, "At what maximum percentage of replacement cost would you chose strengthening over replacement?" A weighted average of the results indicated a 35% to 44% range of the replacement cost for the cost of strengthening (a rather low value) indicating that, nationwide, the engineers are aware that the decision to strengthen or replace is not a first cost decision, and that other life-cycle-costs, such as the user costs and the rather short gains in bridge life through strengthening due to functional obsolescence of the bridge, are important issues in the decision process of replacement versus strengthening.

NCHRP 293 documents a number of available strengthening techniques for bridges. Over 375 publications were reviewed to identify and describe available methods for strengthening bridges. Both laboratory-documented innovative procedures as well as established field techniques were considered. A detailed questionnaire was sent to many bridge engineers across the United States and around the world.

Methods of increasing the live-load carrying capacity include (1) reducing dead load, (2) providing composite action, (3) increasing transverse stiffness, (4) increasing cross section, (5) adding or replacing members, (6) applying external post-tensioning, (7) strengthening critical connections, and (8) providing continuity and/or adding supports. Each of these methods was described in detail and examples of their use were provided (17).

However, for determining the impacts of LCVs on Texas corridors at the project level, the procedures detailed by NCHRP 293 are of limited value, as the major concern of this research project is a policy corridor analysis compatible with network level analysis of the impacts of heavier and longer trucks. The detailed project level information required by the NCHRP 293 procedures is currently unavailable in databases such as the NBI/BRINSAP.

If decisions to permit longer and heavier trucks are to be a recurring feature at state and federal policy levels, then the NBI/BRINSAP could include a field with the cost to increase the capacity of the bridge to a higher load capacity, particularly if strengthening is considered a competitive option for that specific bridge. The calculation of this single strengthening cost estimate, however, would involve extensive calculations as documented herein, and raise the cost to the state departments of transportation responsible for NBI input collection.

4.5 Bridge Fatigue

DOTs routinely receive requests to raise the load limits on highway bridges. To evaluate these requests and effectively use financial and personnel resources, DOTs need dependable, straightforward tools to help in establishing permitting policies, a strong motivation for this research project.

Research conducted by the Minnesota Department of Transportation (MnDOT), "Effects of Increasing Truck Weight on Steel and Prestressed Bridges" (2003-16), found that fatigue of the details of steel bridges, steel strands, and bridge decks in concrete bridges is the primary mechanism for deterioration and needs to be considered in the TS&W evaluation process (Altry, et al., 2003).

In the MnDOT report, three-dimensional beam grillage models of the bridges were used to assess the effect of truck weights on bridges, which were then verified through field measurements. The MnDOT project found that the governing deterioration mechanism for steel bridges is fatigue. Fatigue is insensitive to loading that occurs less frequently than 0.01% of all load cycles—such as special permit loads. However, annual permits are issued in Minnesota for an unlimited number of trips with almost twice the present legal Gross Vehicle Weight (GVW). An increase in the allowable weight of these annual permit vehicles could become significant for steel bridges if they exceed 0.01% of the truck traffic at a particular bridge. This would be specially relevant for steel girders designed before improved fatigue design specifications in the 1970s and 1980s, which often feature poor fatigue details such as welded cover plates. Many of these bridges in Minnesota are already experiencing fatigue cracking according to this report. The cost impact of an increase in legal GVW on bridges that are already experiencing fatigue cracking significantly depends on the action taken, e.g. replacement or repair. Fortunately, most of the bridges on the Texas On-System are not steel bridges, as indicated in Figure 4.6 frequency distribution. In fact, about 86% of the bridges are concrete bridges (prestressed being the majority) and the reminder 14% steel. Figure 4.6 presents the summaries based on Item 43 3rd and 4th digits in the BRINSAP coding guide.

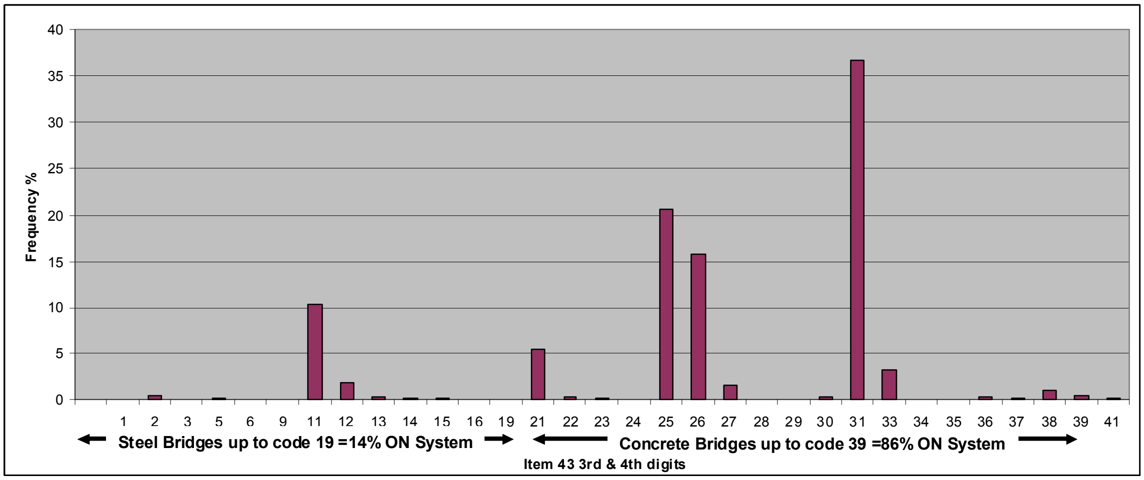


Figure 4.6: Distribution of Texas Bridges by Material Type

According to the Minnesota report, if repair is the approach taken, it can be estimated that the frequency of the repairs will increase 33% if the legal GVW increased by 10%; and the frequency of the repairs will increase 73% if the legal GVW increased by 20%. The present costs for maintenance and repairs of bridges already experiencing fatigue cracking would be expected to increase because the repair frequency will increase (Altry, et al., 2003).).

For bridges with some remaining life before fatigue cracking begins to occur, the remaining life can be reliably calculated if the fatigue life is due to cracking from primary loads on poor fatigue details such as cover plates. For these bridges, an increase in legal GVW of 10% would lead to a reduction in the remaining fatigue life of 25%; whereas an increase in GVW of 20% would lead to a reduction in the remaining fatigue life of 42%. The impact of the decrease in life will be accelerated costs for inspection and repair, and possibly even replacement.

If the fatigue life is limited by distortion-induced cracking such as at web-gap details, the remaining life is not presently quantifiable. However, the treatment for this deficiency is typically repair, and therefore the increase in the frequency of the repairs are the same as stated above for a 10% and 20% increase in legal GVW. Therefore, the present rate of spending on repairs for distortion-induced cracking can be expected to increase 33% or 73% if the legal GVW increased by 10% or 20%, respectively. Steel girders designed since 1985 are typically not susceptible to fatigue at present truck weights and should be able to tolerate a 20% increase in truck weight without reducing the expected fatigue life to less than 75 years.

Typical Minnesota prestressed concrete girders and concrete decks were found to be not susceptible to fatigue for present or even 20% increased truck weights. If the loads were increased on the prestressed-concrete girders, the first deterioration mechanism to occur that is significantly affected by increasing loads would be shear cracking. Shear cracking is a serviceability problem and there is significant additional capacity in shear before failure could occur. However, shear cracking could increase the rate at which water can penetrate the girders and increase the rate of corrosion of the prestressing strands and other reinforcement. Unlike fatigue, cracking of concrete is a single event due to a single load, and therefore could be caused by increases in permit loads as well as increases in legal load limits.

Various truck configurations were investigated for typical Minnesota prestressed concrete I-girders. In all cases, the particular truck configuration that gave the worst-case shear would have to increase weight by more than 20% before shear cracking and associated reduction in service life would occur. Flexural cracking and fatigue of the prestressing strands and other reinforcement and fatigue of the concrete were also investigated but these phenomena would require even greater increases in truck weight before they would occur. Bridge decks are affected by axle weights rather than overall truck weights. The first adverse phenomenon to occur in bridge decks due to increasing axle weights would be longitudinal flexural cracking. As in prestressed concrete girders, cracking of bridge decks will increase the potential for corrosion. Transverse cracks are more common than longitudinal cracks in bridge decks. However, transverse cracks are primarily caused by shrinkage during or soon after construction and are not affected by increasing truck weight. However, the spacing of transverse cracks may influence the potential for longitudinal cracking. Typically, standard 9-inch-thick (225 mm) decks with girder spacing less than 10 feet (3 m) should not be affected by an increase of up to 20% in axle weights. However, more flexible decks (thinner and/or wider girder spacing) with pre-existing transverse cracks spaced less than 5 feet (1.5 m) apart may be susceptible to longitudinal flexural cracks even from present truck traffic. Texas common deck thicknesses are 8 inches, with a recommendation of 8.5 inches in the regions of Texas where the use of deicing compounds is common.

Several other studies have been conducted as well. Frangopol and Das (1999) studied management of bridge stocks based on future reliability and maintenance costs, in which entire history of the bridge reliability deterioration has been considered. Maes et al. (2001) also studied fatigue reliability of deteriorating prestressed concrete bridge due to stress corrosion cracking. Klowak et al. (2007) researched static and fatigue investigation of innovative second-generation steel-free bridge decks. Yokoyama et al. (2006) developed a bridge management system for expressway bridges in Japan considering deck fatigue deterioration. However, all of these results are not tied to TS&W analysis and did not associate the fatigue deterioration with the specific load rating components and have intensive data requirements for their use.

4.5.2 Fatigue Concepts

Fatigue is a cumulative process in which repetitive stress cycles accumulate damage until failure occurs. The basic concept of the fatigue design and assessment for bridges relates to the fact that each cycle of truck passage causes some damage. The damage due to a population of trucks accumulates until failure (usually cracking) occurs. The damage caused by each truck depends on the vehicle weight, the bridge span length, and member section dimensions considering that weight and span are directly used to calculate bending moments and member section and bending moment are used in calculating stresses. In other words, stresses are directly proportional to live load bending moments.

Based on experimental data and fracture mechanics principles, it is observed that fatigue damage is proportional to:

$$(\text{Stress range amplitude})^3 \tag{4.2}$$

The stress range is the difference between the maximum and minimum stress caused by a vehicle passage at the location of concern. The exponent of 3.0 in Equation 4.2 for the welded steel attachments is an important parameter in comparing influences of variable stress amplitudes. It means that if the stress amplitude is doubled, the fatigue damage will increase by a factor of eight. To account for different stress ranges due to various truck weights, a linear damage accumulation law is usually assumed. The damage of one stress cycle is inversely proportional to the life that would exist if that stress of constant amplitude were cyclically repeated. The life for constant stress amplitude is predicted using the stress-life (S-N) curve for that type of attachment based on physical testing. Thus, in a non-dimensional form, failure (cracking) occurs when a damage sum D equals 1.0 (Miner's rule):

$$D = \Sigma \frac{n_i}{N_i} \tag{4.3}$$

Where:

n_i is the number of stress cycles due to vehicle weight and class i.

Ni is the number of cycles to failure from the S-N curve if only the stress corresponding to vehicle weight and class i were applied.

Using the data developed from tests and the exponent of 3.0 mentioned above, a constant amplitude fatigue life leads to:

$$N_i\, S_i^{\,3} = b \tag{4.4}$$

Where:

Si is the constant stress range leading to the number of cycles to failure, Ni.

b is a constant depending on the fatigue strength of the detail, and it is explicitly considered and tabulated in the design and evaluation procedures (AASHTO 1990, 1998).

4.5.3 Steel Bridges

AASHTO's 1990 publication, "Guide Specifications for Fatigue Evaluation of Existing Steel Bridges," includes fatigue curves for several steel bridge details as shown in Figure 4.7.

For different bridges, the challenge to implement this analysis to specific routes in Texas will be to determine the details (A, E, etc.) to be analyzed and carry out a structural analysis to determine moment envelopes as described by the MOANSTR routine.

With a given maximum moment envelope for a proposed vehicle, the stress variation generated on a typical cross section due to increased weight can be determined through Equation 4.5:

$$\Delta\sigma = \frac{\Delta M_{env}\, y}{I} \tag{4.5}$$

Where:

y are the locations of the steel details, such as cover plates;

I is the moment of inertia

ΔM_{env} is the increase of the maximum moment envelope value due to TS&W increase.

Through the calculated stress range, the decrease in fatigue life due to an increase of truck weight can be determined.

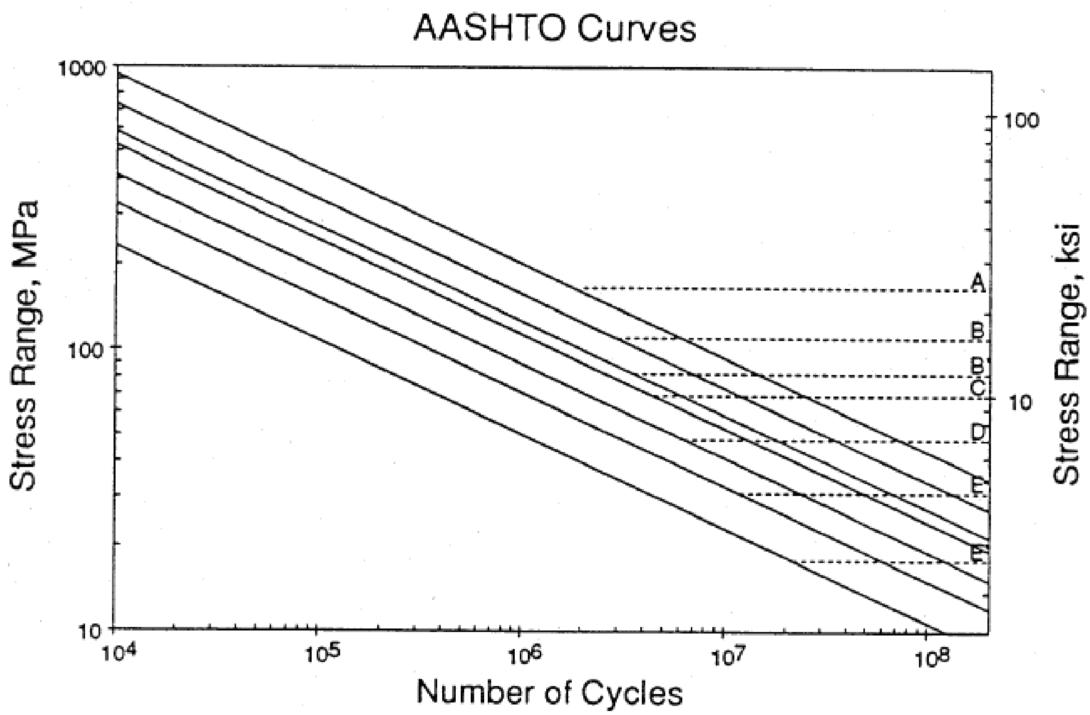


Figure 4.7: Fatigue life for different steel bridge details

Example: A hypothetical single-span bridge that is loaded by a Permit Vehicle would lead to a maximum bending moment that may be calculated by a program like MOANSTR. If the cross section of this steel bridge is an I section with fatigue detail type E, subject to the moving truck, the fatigue life due to over weight can be estimated. If the proposed weight change is estimated to be a 20% increase in GVW, the maximum moment will be increased by 20% due to the linear relationship between them. If a type E detail is used for the I section, the number of cycles that can be sustained by the bridge will be 7×106 (assuming initial stress range right at the endurance limit). Using the Figure 4.7 chart and log properties, the fatigue life would be shortened about 30% compared to the infinite number of cycles of the initial endurance limit.

4.5.4 Prestressed Concrete Bridges

For concrete bridges, the most important components subjected to fatigue are bridge decks and prestress steel strands. Because shear cracking is a dominant factor in affecting the deterioration behavior of prestressed concrete bridges, we would need to revise the stress range calculation from bending moment based to shear force based which would require a modification of MOANSTR for implementation in the current research project. Given a maximum shear force envelop through a typical line girder analysis, its stress variation generated through a typical section due to increased weight can be determined through Equation 4.6:

$$\Delta\tau = \frac{\Delta V_{env} Q}{It} \tag{4.6}$$

Where:

Q is the maximum first static moment of area of the section at the Neutral Axis location;
I is the moment of inertia,
t is the thickness of cross section
ΔV_{env} is the increase of the maximum shear force envelope value due to increased weight.

The decrease in fatigue life due to weight increase can be theoretically determined using the calculated stress range.

Equation 4.1 proposed by Overman et al. (1984) was used to predict the number of cycles to fatigue failure for prestressed concrete I-girders. Equation 4.7 relates the strand stress range S to the number of cycles to fatigue failure for prestressed concrete girders.

$$\text{Log } N = 11.0 - 3.5 \text{ Log } S_r \tag{4.7}$$

where:

N is the fatigue life in number of cycles
S_r is the strand shear stress range, which is equal to maximum stress – minimum stress (ksi).

Example: A single-span simply supported bridge with an I prestressed concrete section with the prestress strands, subject to the same moving truck as described in the steel bridge example above.

If the section is an I-section and the proposed TS&W scenario calls for a truck weight estimated increase of 20% GVW, the maximum shear will also be increased by 20% due to the linear relationship between them. Based on Equation 4.7, we calculate that the number of cycles that could be sustained by the prestressed I-girder is reduced by about 50%.

4.5.5 Concrete Decks

The equation yielding the conservative fatigue life for reinforced concrete decks proposed by MnDOT's report 2003-16 can be used and is discussed below.

$$\text{Log}(P/Pu) = 1.022\text{-}0.243 \text{ Log}(Npf) \tag{4.8}$$

Where:
Pu: Ultimate strength of the deck (kips or kN)
P: Applied shear load range

Npf: Number of cycles to failure

4.5.6 Summary

The fatigue concepts discussed in this section could be used to estimate fatigue-associated costs of bridges for different TS&W scenarios along a route. The authors envision a methodology where deficient bridges would be screened into two categories. The first category would involve bridges that reach an overstress level that is unacceptable to bridge engineers at TxDOT and need to be replaced. The second category would involve bridges that are overstressed at a level that would lead to increased maintenance costs that would be apportioned proportionally to the fatigue effects discussed before and may be candidates, in the future, for strengthening procedures as discussed by NCHRP 293.

4.6 Proposed Bridge Analysis Framework for Case Studies

4.6.1 Identify Candidate Vehicle, Route and Planning Horizon

In concert with the project advisory panel and the industry, specific routes will be indentified for the bridge analysis of the case studies to be reported in a subsequent report. Other inputs such as candidate vehicle configurations and a planning horizon will be defined.

4.6.2 Retrieve bridge and other supporting data with GIS.

Utilizing the GIS system described in another chapter of this report, specific bridge data for the selected routes will be retrieved. Data will include NBI/BRINSAP and traffic data from TxDOT's RHINO file. Data sets will be prepared for input in the BASIC system.

4.6.3 Analysis of the bridges along the route for overstress ratios using MOANSTR

An initial step of analysis will consist on running the retrieved bridge route data through MOANSTR to screen bridges in the categories discussed previously. The first category would involve bridges that reach an overstress level that is unacceptable to bridge engineers at TxDOT and need to be replaced. The second category would involve bridges that are overstressed at a level that would lead to increased maintenance costs. These would be apportioned proportionally to the fatigue effects discussed before and may be candidates, in the future, for strengthening procedures as discussed by NCHRP 293. Based on this preliminary analysis, an additional step could be warranted that would involve more detailed traffic characterization such as detailed vehicle load spectra in order to employ the fatigue modeling discussed previously. This would require this project's economics research team to provide the entire vehicle load spectra with the proposed configurations.

4.6.4 Forecast traffic based on economic inputs (volumes, classification and axle weights).

If level of overstress caused by the proposed configuration on several bridges along the selected route is low enough to justify the fatigue approach to cost estimation, then detailed traffic forecasts including vehicle classification and spectra will be needed and will involve strong interaction with the economics team assigned to this research project in order to estimate these vehicle load spectra as affected by the penetration of the proposed vehicle configurations.

4.6.5 Forecast bridge costs for route over planning horizon for LCV and no LCV operations

An incremental cost approach is recommended for the case studies to be developed in the second year of this research project. This approach will involve calculating all the bridge associated costs resulting from two scenarios over the established planning horizon: with and without the introduction of the heavier and or longer vehicle configurations. The cost differential between these two scenarios will be assigned to the proposed truck configurations and combined with the other infrastructure cost components associated with the introduction of longer and heavier trucks such as required highway geometrics requirements.

This and the previous chapter have addressed the requirements to adequately calculate the impacts of LCVs on highway sections. The analysis of both requires substantial data mining and storage and for that a specific database is proposed for this LCV study and is described in Appendix D. LCV operations impact the geometric design of highways. The characteristics most likely to impact both design and traffic flow are described in the next chapter.

Chapter 5. LCV Operational Characteristics

Table 5.1 highlights the relevant heavy vehicle characteristics that impact geometric design and traffic operations as identified in FHWA's Comprehensive Truck Size and Weight Study (FHWA, 2000). This chapter discusses a number of the identified issues in detail.

Table 5.1: Operational Impacts of Truck Size and Weight Limits

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

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

Source: FHWA, 2000

5.1 Traffic Congestion

It has been argued that congestion could be reduced by allowing LCV operations. LCVs could result in fewer truck trips, possibly reducing traffic congestion with associated energy consumption and emissions benefits. However, it has also been argued that these congestion benefits will only be realized if LCVs are allowed to travel at the same speed as other trucks (TRL, 2008). Reduced allowable speed limits would be undesirable and reduce many of the economic advantages of using LCVs. In Belgium, LCVs proved a viable alternative for serving ports, which were hampered in their development by increasing congestion on their access roads (Debauche, 2007).

5.1 Vehicle Offtracking

Offtracking results in truck encroachment on adjacent lanes, creating safety hazards, and encroachment on shoulders and curbs, resulting in infrastructure damage. According to the FHWA (2000), three different types of offtracking can be measured:

- *low-speed offtracking*—Low-speed offtracking occurs when a truck is operating at a very low speed, so that the impacts of weight, weight distribution, and vehicle dynamic characteristics are negligible. Two different measures of low-speed offtracking are defined: the offtracking amount and the swept path width (TRB 2003). The offtracking amount is the radial offset between the path of the centerline of the front axle and the path of the centerline of a following axle. The swept path width, which is used more often in highway design, is defined as the difference in paths between the outside front tractor tire and the inside rear trailer tire. Low-speed offtracking is considered the *"principle measure of a vehicle's ability to negotiate turns"* (FHWA 2000). The primary vehicle characteristic that determines low-speed offtracking is the wheelbase, or the distance from the kingpin connection to the center of the trailer's rear axle group (FHWA 2000). In general, the longer this distance, the more a vehicle will offtrack.
- *high-speed offtracking*—High-speed offtracking occurs when a truck *"negotiates a gentle curve"* at highway speeds and dynamic effects must be considered (FHWA 2000).
- *dynamic high-speed offtracking*—Dynamic high-speed offtracking occurs when rapid steering inputs are required, such as an evasive-lane change maneuver, resulting in the swinging back and forth of the vehicle. For Rocky Mountain Doubles, Turnpike Doubles, and Triple Trailers, high-speed offtracking can be avoided on curves of radius 600 feet (183 m) using a lane width of 11 feet (3.4 m) at average speeds of 55 mph—as long as the vehicles are aligned along the center of the roadway section (Harkey, et al., 1996). To prevent high-speed offtracking, AASHTO recommends a minimum lane width of 12 feet (3.7 m).

LCVs with short trailers and multiple articulation points offtrack less than vehicles with long single trailers. Table 5.2 illustrates the maximum offtracking and the maximum swept path for both standard vehicles and a number of LCV configurations on a 90 degree turn (TRB 2003).

Table 5.2: Maximum Offtracking Values of Selected Vehicle Configurations for a Low-Speed 90 Degree Turn

	Maximum Offtracking (ft)		**Maximum Swept Path Width (ft)**	
Turn Radius (ft)	100	150	100	150
Vehicle Type				
5 Axle Tractor—48 ft Semi-Trailer	10.1	6.9	18.4	15.1
5 Axle Tractor—53 ft Semi-Trailer	12.1	8.3	20.3	16.6
STAA Double	6.3	4.2	14.6	12.5
Rocky Mountain Double	12.7	8.7	21.0	17.0
Turnpike Double—48 ft Trailers	17.1	12.0	25.3	19.2
Turnpike Double—53 ft Trailers	17.9	12.6	26.1	20.8

Source: TRB, 2003

From Table 5.2 it is evident that an STAA double (i.e., tractor with two 28.5 foot trailers) offtracks considerably less than a 48 foot five-axle semi-trailer. Similarly, a triple-trailer combination also offtracks less than a standard five axle semi-trailer (FHWA 2000). This is because STAA doubles and triple-trailers have short wheelbases and multiple articulation points.

The Turnpike Double has the worst offtracking performance as it requires several feet of additional maximum offtracking and swept path width to safely complete a turn, resulting in increased lane width and turning radii requirements. To prevent lane encroachment due to low-speed offtracking, AASHTO recommends a minimum lane width of 16 feet (4.9 m) (Harkey, et al., 1996).

5.2 Traffic Operations

5.2.1 Passing

The primary operational characteristic of LCVs that impacts traffic operations is the inability of these vehicles to accelerate at the speed of lighter vehicles. This leads to both capacity and safety concerns for performing basic traffic maneuvers. Increased acceleration time also impacts LCVs attempting a passing maneuver, potentially increasing the vehicle's exposure to a potential collision when performed on a two-lane highway. Additionally, lighter vehicles passing an LCV require large sight distances. The Comprehensive Truck Size and Weight Study (2000) reported that cars passing a LCV on a two-lane road may require as much as an 8% longer passing sight distance compared to passing a car. Also, longer vehicles making a lane change maneuver require larger gaps between vehicles.

5.2.2 Acceleration (Merging and Hill Climbing)

The inability of heavier vehicles to accelerate at the speed of lighter vehicles, especially on grades, can be mitigated through the use of bigger engines with higher horsepower (although this may reduce the energy and environmental improvements resulting from LCV operation) and aerodynamic truck designs (FHWA, 2000). Other potential mitigation methods include specifying minimum acceptable speeds on grades and posting minimum acceptable acceleration times from stop or 30 mph to 50 mph.

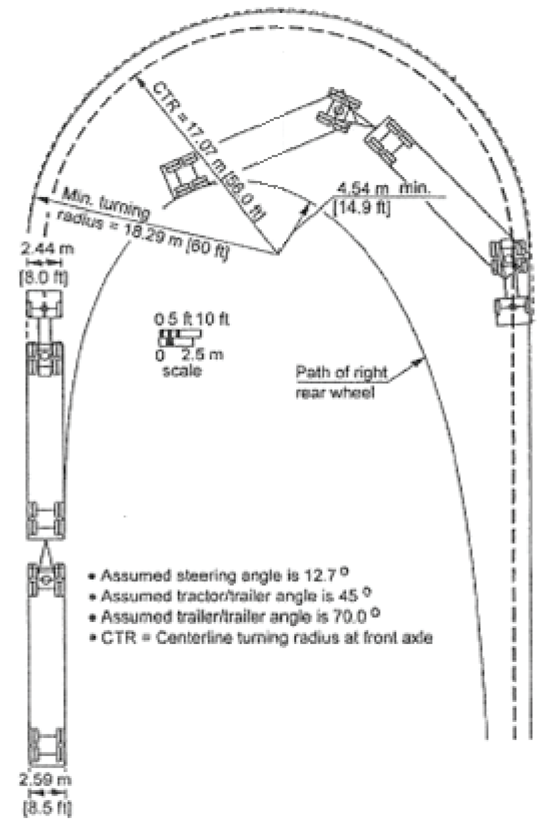
Braking and traction may also be performance characteristics of concern when implementing LCV operations. However, LCV braking performance should not be any different from that of other truck configurations because of the additional axles (USDOT, 2004). The only breaking-related concern should be the maintenance of the additional brakes. On the other hand, heavier trucks operating on grades may experience traction problems in slippery road conditions (USDOT, 2004). Specifically, single drive axles pulling combination vehicles may be unable to generate sufficient traction to pull the combination up the hill. This concern can be mitigated through the use of a tandem- axle tractor or a tractor equipped with automatic traction control.

5.2.3 Intersection Requirements

In general, longer and heavier vehicles require more space for turning and maneuvering, resulting in intersection and ramp attributes, lane widths, grades, and curve geometry all being key to LCV performance.

A heavier truck crossing an unsignalized at-grade intersection requires additional time to accelerate, potentially reducing the capacity of the intersection, as well as increasing the potential exposure of crossing vehicles to collisions with the truck (USDOT 2004). Furthermore, the turning radius required by different LCV configurations depends primarily on two vehicle characteristics: the number of articulation points and the length of the wheelbase for individual trailers. Vehicles with shorter trailers generally require a smaller turning radius. For combination trailers, additional articulation points may reduce the need for a larger turning radius.

The AASHTO Green Book (2004) defines three different design turning radii for different vehicle types: (a) the minimum turning radius, (b) the center-line turning radius, and (c) the minimum inside radius. Figure 5.1 illustrates the minimum turning radii for a Turnpike Double.



Source: AASHTO, 2004

Figure 5.1: Minimum Turning Radii for a Standard Turnpike Double

Table 5.3 provides the design values for the turning radii of a 53 foot five-axle semitrailer, a Turnpike Double, and a Triple Trailer, respectively. While the Turnpike Double requires a larger radius for all three different design turning radii compared to the five-axle semi-trailer, the Triple Trailer only requires a larger minimum inside radius compared to the five-axle semi-trailer (see Table 5.3).

Table 5.3: Minimum Turning Radii, Selected Vehicle Types

	5 Axle Semi-Trailer	Turnpike Double	Triple Trailer
Minimum Turning Radius (ft)	45	60	45
Center-line Turning Radius (ft)	41	56	41
Minimum Inside Radius (ft)	4.4	19.3	9.9

Source: AASHTO, 2004

5.3 Vehicle Features

5.3.1 Vehicle Stability

The stability of LCVs, specifically their tendency to roll over, also poses concerns. In general, there are two types of rollover that may occur (USDOT, 2004): steady state-induced and evasive maneuver-induced.

Steady state-induced rollover occurs when a truck exceeds an acceptable speed threshold when attempting to make a turn (usually on a highway off-ramp). The centrifugal force created by the maneuver exceeds the vehicle's ability to counteract the force, resulting in rollover. The primary truck characteristics that impact its susceptibility to steady state-induced rollover are the height of the cargo center of gravity, the track width of the vehicle, and suspension and tire properties. High travel speeds and tight curve radii also increase the likelihood of steady state-induced rollover. The relevant measure to determine a vehicle's likelihood to experience steady state-induced rollover is its static roll stability, defined as the minimum amount of lateral acceleration needed to result in wheel lift-off from ground. LCVs do not necessarily exhibit a higher tendency for steady state-induced rollover relative to other trucks. As long as the additional weight is distributed to maintain a low center of gravity, the likelihood of rollover should not increase significantly.

Evasive maneuver-induced rollover occurs when trucks traveling faster than 50 mph need to abruptly steer from side to side to avoid an obstruction (USDOT, 2004). When this event occurs, lateral acceleration at the tractor is amplified at each succeeding trailer. As a result, for combination trucks, the rearmost trailer can experience lateral acceleration two to three times as high as the tractor, resulting in trailer encroachment into adjacent lanes or roll over. The primary truck characteristics that impact its susceptibility to evasive maneuver-induced rollover are its number of articulation points, wheelbase lengths, and the static roll stability of individual trailers. In general, vehicles with more articulation points are more likely to roll over. Trailers with shorter wheelbases and low static roll stability are also more likely to experience evasive maneuver-induced rollover. There are two relevant measures to determine the likelihood of a vehicle to experience evasive maneuver-induced rollover (USDOT 2004): rearward amplification and the load transfer ratio. Rearward amplification is defined as the ratio of the lateral acceleration experienced at the rearmost trailer in a combination to that of the tractor when a lane change evasive maneuver is executed. Values of two or less are generally acceptable. For example, interstate semi-trailers usually perform with a rearward amplification value around 1.0, while STAA doubles have a value around 1.7. Reducing a vehicle's number of articulation points from three to two improves performance by 80%, while doubling the length of trailers improves performance by 100%. Rearward amplification is a problem for triple-trailers, which usually have five articulation points (Harkey, et al., 2006). Load transfer ratio is the proportion of a total axle load carried on one side of the truck relative to the other side (USDOT, 2004). Load transfer ratio is considered the primary measure of a truck's dynamic roll stability. In this case, the load shifts to one side of the truck when the truck performs an evasive maneuver traveling above 50 mph. A vehicle experiencing a load transfer ratio above 0.7 is susceptible to rollover, and a truck with a load transfer ratio of 1.0 is almost certain to roll over.

5.3.2 Vehicle Connection Types

The type of connection used to connect double and triple trailer trucks can influence vehicle performance in offtracking and stability. In general, three types of connections are used: A-dollies, B-trains, and C-dollies.

In an A connection, a single or tandem axle dolly is connected to a preceding semi-trailer using a single drawbar (FHWA, 2009). The drawbar is equipped with a pintle "eye" that connects to a pintle "hook" at the rear of the semi-trailer. The eye is allowed to rotate about a longitudinal axis to *"avoid failure if the second trailer rolls over."* The drawbar can *"pivot on a transverse horizontal axis at the dolly"* allowing for a tighter turning radius. The dolly is equipped with a "fifth wheel" mount that allows for connection of an additional semi-trailer. This connection is the most common connection type used in the U.S. (UNB, 2009).

In a B-train, the first semi-trailer is directly equipped with a "fifth wheel" mount. B-train connections are used to reduce a vehicle's number of articulation points, and as a result, to reduce the likelihood of rollover (USDOT, 2004). B-trains allow for better dynamic roll stability and higher payload for a given length (FHWA, 2009). In Canada, B-trains are permitted to carry higher loads compared to vehicles with other connection types.

A C-connection provides higher roll and coupling stiffness relative to an A connection through use of second drawbar (USDOT, 2004). A C-dolly is connected to the preceding semi-trailer by two drawbars, which prevents rotation about a vertical axis at the hitch point (FHWA, 2009). In Canada, C-trains are permitted to carry higher loads than A trains. B and C connections are particularly effective in improving stability during an evasive lane-change maneuver when trailers are rolling in opposite directions (USDOT, 2004).

5.4 Concluding Remarks

The vehicle and operational characteristics of LCVs are important as they potentially impact traffic congestion, vehicle offtracking, and traffic operations. For example, the stability and acceleration speed of different LCV configurations may impact both traffic operations and safety, while vehicle weights, dimensions, and connection types may influence a vehicle's ability to perform basic traffic maneuvers. It is, however, important to consider all of the potential operational impacts of allowing changes in truck configurations, as often changes that produce improvement in one area can lead to a worsening situation in another. For example, combination trucks with short trailer wheelbases and multiple articulation points, such as Triple Trailers, offtrack less than vehicles with longer trailers and fewer articulation points, such as Turnpike Doubles, but these vehicles are considerably more likely to roll over.

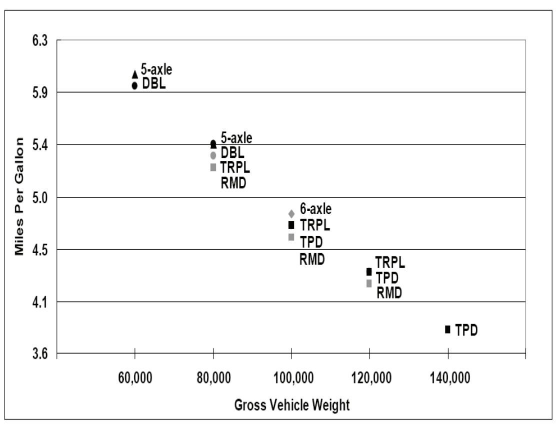
One important benefit from LCVs is the ability to lower ton-mile fuel consumption and so lower operating costs in a vital area of expense. This is the subject of the next chapter.

Chapter 6. Environmental and Energy Issues

This chapter highlights the results of a number of studies that considered the fuel economy, energy efficiency, and emissions impacts associated with operating LCVs. Fuel economy for freight modes carries a desirable mix of private and social benefits. Less fuel is burned (thus lowering operating costs) and fewer emissions are released—thus benefitting those living or working near freight corridors and larger issues such as global warming. LCVs clearly lower fuel consumption in terms of ton-mile units. Woodrooffe (2005) reported a 32% reduction in fuel and greenhouse gas emissions associated with LCV operations in the Province of Alberta, Canada. LCVs are thus sometimes referred to as Energy Efficient Motor Vehicles (EEMVs) or, in Quebec, as Special Road Trains (Schulman, 2003).

6.1 Fuel Economy

Fuel costs are typically the second largest expenditure item for heavy-duty vehicle operators (Greene & Schafer, 2003). At first glance, LCVs have higher fuel economy than the standard 5 axle truck operating at 60,000 and 80,000 lbs (44 tons or less) GVW (see Figure 6.1 below). An ATRI study (2008) reported that the standard 5-axle truck and double trailer combination (non LCV) typically achieves an average round trip fuel economy of 5.4 miles per gallon when operating at 80,000 lbs GVW over a modeled route. An LCV, on the other hand, operating at 100,000 lbs GVW achieved on average an 11 to 15% lower fuel economy than the 5 axle truck operating at 80,000 lbs GVW. Similarly, a Turnpike Double operating at 140,000 lbs GVW will achieve an estimated 30% reduction in average fuel economy compared to the 5 axle truck. LCVs require more powerful engines to move the additional trailers, axles, wheels, and cargo weight and thus consume more fuel, resulting in a lower miles-per-gallon-fuel economy (ATRI, 2008).



Source: ATRI, 2008

Figure 6.1: Fuel Economy by Gross Vehicle Weight

When accounting for the payload, LCV fuel consumption compares more favorably when compared to the total fuel consumed by the equivalent number of vehicles required to carry the same load (Umwelt Bundes Amt, 2007). A Canadian study (LP Tardiff & Associates, 2006) collected fuel consumption data from a number of trucking fleets operating Turnpike Doubles and traditional tractor-trailers. The data is summarized in Table 6.1.

Table 6.1: Fuel Economy Data: Turnpike Doubles and Tractor-Trailers

Company	Turnpike Double Fuel Consumption		Tractor-Trailer Fuel Consumption		Fuel Savings per Turnpike Double Movement **	
	L/100 km	mpg	L/100 km	mpg	L/100 km	mpg
A	53.3	5.4	41.5	6.8	29.7	2.0
B	56.0	5.0	41.6	6.7	27.2	1.65
C	47.8	5.9	39.7	7.1	31.6	2.35
D	57.3	4.9	41.6	6.7	25.9	1.55
E	56.3	5.0	n/a	n/a	n/a	n/a
F	50.2	5.6	n/a	n/a	n/a	n/a
G	45.6	6.2	37.2	7.6	28.8	2.4
H*	51.4	5.5	40.4	7.0	29.4	2.0
				Average Saving	**28.8**	**2.0**

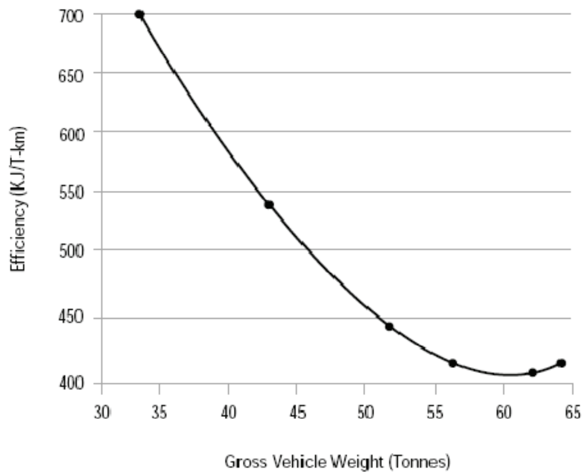
*Provided average fuel economy for this vehicle type in this fleet, but not individual trip data.
**One Turnpike Double contains twice the space of a standard tractor-trailer. Therefore, when comparing for fuel efficiently, one Turnpike Double movement equals two tractor-trailer movements.

Source: LP Tardiff & Associates, 2006

From Table 6.1, it is evident that on average, the use of Turnpike Doubles results in an estimated fuel saving of 28.8 liters/100 km (7.61 gallons/ 62 miles)—a 55% saving when compared to the single-trailer configurations necessary to move the same load.

6.2 Energy Efficiency

Energy efficiency for freight transportation is measured as the energy consumed per ton-kilometer (ton-km) (De Ceuster, et al., 2008). The Canadian Air Pollution Prevention Directorate (2001) reported that a truck's efficiency measured in kilojoules per ton-km improves as the GWV increases (see Figure 6.2).

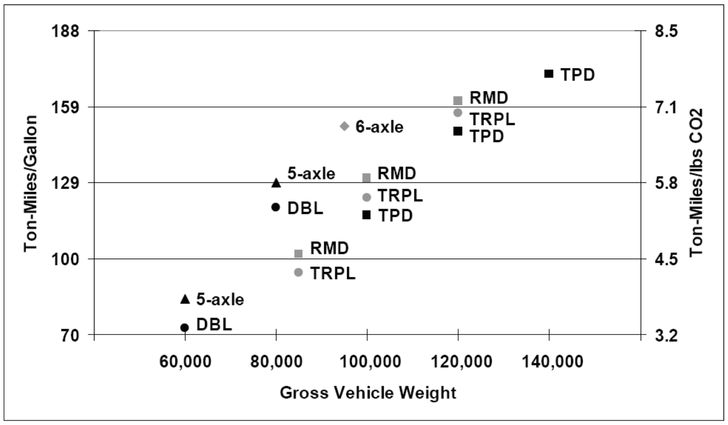


Source: Air Pollution Prevention Directorate, 2001

Figure 6.2: Efficiency by Gross Vehicle Weight

Energy efficiency can also be measured in ton-miles/gallon. ATRI's (2008) approach enabled efficiency comparisons among different vehicle configurations operating over a common route at different payload weights.

Figure 6.3 shows that at a 80,000 lbs GWV limit, the standard 5 axle truck achieved 129 ton-miles/gallon and was more energy efficient than the Rocky Mountain Double and the Triple at a slightly higher than 80,000 lbs GVW (ATRI, 2008). At 97,000 lbs GVW limit, the 6 axle configuration achieved a 17% increase in ton-miles/gallon and at 120,000 lbs GVW limit, the Rocky Mountain Double, the Triple, and the Turnpike Double achieved a substantial increase in ton-miles/gallon compared to the 80,000 lbs GVW standard 5-axle truck—for example, 25% higher in the case of the Rocky Mountain Double. At 140,000 lbs GVW, the Turnpike Double achieved a 33% increase in ton-miles/ gallon compared to the 80,000 lbs GVW 5 axle truck.



Source: ATRI 2008

Figure 6.3: Ton-Miles/Gallon by Gross Vehicle Weight[29]

These efficiency gains can, however, be realized only if the loading capacity of the LCV is utilized. If not, the fuel efficiency of LCVs may be lower than that of a standard 5 axle truck that is well utilized (Umwelt Bundes Amt, 2007). However, because trucking is competitive, it safe to assume that rationality is a key to survival. If there are no gains from LCV adoption, then few will be used.

6.3 Emissions

The 2008 ATRI study also used a simple algorithm to estimate emissions from six different vehicle configurations operating at different GVWs. The analysis was conducted with trucks cruising at highway speeds ranging between 55 and 65 mph. Emissions emitted was estimated by multiplying the total fuel consumed on the route with an emissions factor (ATRI, 2008). Figure 6.4 illustrates the ton-miles/gram of nitrogen oxide[30] (NOx) and particulate matter[31] (PM) emitted by the different vehicle configurations tested.

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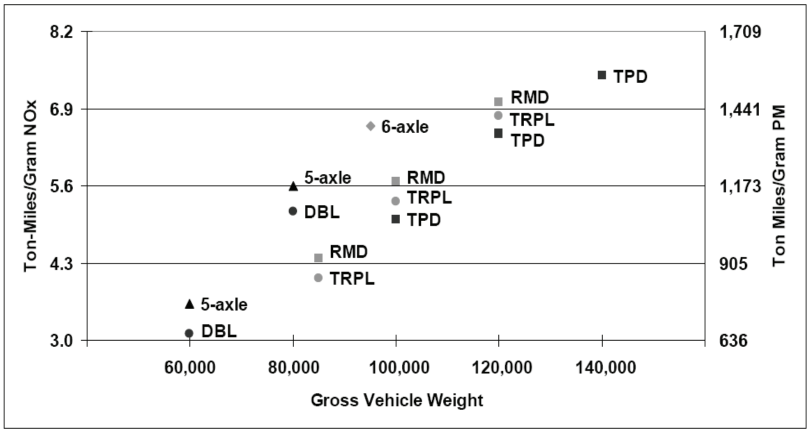
29 ATRI (2008) also calculated the ton-miles/ lbs of CO_2 emitted to allow for a consistent comparison among the vehicle configurations and operating weights analyzed in the study. This metric mirrors fuel consumption on a ton-mile basis (ATRI, 2008) and can be explained by the fact that the amount of CO_2 emissions is directly related to fuel consumption. For each quart of diesel fuel consumed, approximately 4.85 lbs of CO_2 is emitted into the air (De Ceuster, et al., 2008).

30 NOx is a generic term for mono-nitrogen oxides (NO and NO2). Ground-level (tropospheric) ozone (smog) is formed when NOx and volatile organic compounds (VOCs) react in the presence of sunlight. Children, people with lung disease, and people who work or exercise outside are susceptible to the adverse effects of this pollutant, including damage to lung tissue and reduction in lung function. Other potential adverse impacts include damaged vegetation and reduced crop yields (De Ceuster, *et al.*, 2008).

31 Particulate matter (PM) comprises tiny particles of solid or liquid suspended in a gas. PM is generally classified in terms of its diameter, ranging from 10 µm to smaller than 0.1µm. Inhalation of the bigger particles (i.e., ranging from 2.5 µm to 10 µm) can cause pulmonary disease, such as asthma or lung cancer. Vehicle exhaust PM is typically smaller than 2.5 µm. Inhalation of the latter can lead to cardiovascular problems. The road transportation sector contributes to PM in the form of vehicle exhaust particles and suspension of road dust (De Ceuster, *et al.*, 2008).



Source: ATRI, 2008

Figure 6.4: Emissions by Gross Vehicle Weight

From Figure 6.4, it is evident that the 5 axle truck achieved 5.6 ton-miles/gram of NOx and 1,172 ton-miles/gram of PM at 80,000 lbs GVW. In comparison, the Rocky Mountain Double, Triple, and Turnpike Double achieved superior emissions performance operating at 120,000 lbs GVW than the 5 axle truck at 80,000 lbs. For example, the Rocky Mountain Double achieved approximately 6.9 ton-miles/ gram of NOx and 1,441 ton-miles/gram of PM at a 120,000 lbs GVW (ATRI, 2008).

Similarly, LP Tardiff & Associates (2008) compared emissions from LCVs with the equivalent number of single trailer configurations required to move the same payload. The estimated reduction in emissions per ton-mile of freight moved were approximately 27% for an LCV operating at 140,000 lbs GVW when compared against two single-trailer configurations of 80,000 lbs GVW each.

6.4 Potential Scenarios

The ATRI study (2008) also presented a hypothetical scenario that quantified the energy and emissions impacts of using a Rocky Mountain Double and a conventional 5 axle truck to move a 1,000 ton shipment to a destination 500 miles away. Table 6.2 illustrates the following savings associated with the use of the Rocky Mountain Double: 674 gallons of fuel, 7.5 tons of CO_2 emissions, 34 lbs of PM, and 16 lbs of NOx emissions.

Table 6.2: Energy and Emissions Benefits Resulting from Rocky Mountain Double

Type of Vehicle	GVW (lbs)	Number of Trips	Fuel Economy (mpg)	Fuel Required (Gallons)	CO_2 Emissions (tons)	PM Emissions (lbs)	NOx Emissions (lbs)
5 Axle	80,000	42	5.4	3,889	--		
Rocky Mountain Double	120,000	27	4.2	3,215	- 7.5	- 34	- 0.16

Source: ATRI, 2008

Anheuser-Busch performed a similar analysis for their Texas operations to illustrate the potential benefits of using a 97,000 lbs GVW 6 axle truck in its operations instead of the 5 axle 80,000 lbs GVW truck. The results are illustrated in Table 6.3.

Table 6.3: Benefits from Operating the 6 Axle Truck Configuration

Route	Trucks per week (80,000 lbs GVW)	Trucks per week (97,000 lbs GVW)	Change in cargo per truck (lbs)	Reduction in diesel fuel/ week (gallons)	Reduction in CO_2 emissions/ week (lbs)
Houston to San Antonio (198 miles)	128	96	15,000	807	17,996
Houston to Waco* (219 miles)	1,126	845	15,000	7,824	174,475

** For distribution in Texas*
Source: Jacoby, 2008

From Table 6.3, it is evident that Anheuser-Bush expects to make 281 fewer truck trips/ week on its Houston to Waco route alone, translating into a savings of 7,824 gallons of fuel and 174,475 lbs of CO_2 emissions per week.

6.5 Concluding Remarks

Proposals to amend truck size and weight limits have, however, always been met with concerns about a significant and lucrative share of the freight market being diverted from rail to truck (Picher, 1995; Maze, 1994). This has resulted in consistent lobbying by the railroad industry against allowing the widespread use of LCVs. Such a diversion of freight, and the resulting loss of revenue, would, according to the rail industry cause irrevocable damage to the industry and the abandonment of rail lines and diminished rail services. It is thus claimed that the introduction of LCVs would result in more rather than fewer trucks on the road (Umwelt Bundes Amt, 2007). The latter would result in increased emissions, energy use, and pavement and bridge consumption. At a national level, the Association of American Railroads estimated that LCV use would result in an 11% diversion of current rail ton-miles to truck (ICF, 2001). Trucking associations have, however, argued that the impact on the railroad industry would be much less (Maze 1994), but agree that there would potentially be some diversion if a nationwide network is available for LCV use.

This does not alter the fact that LCV use—mainly on corridors where there is no rail alternatives—offers substantial reductions in both fuel consumption and tail pipe emissions. A major concern to the travelling public remains—that of safety—and this is the subject of the next chapter.

Chapter 7. Safety Issues

The safety of LCVs is prominent in the debate over allowing LCV operations (Mercier, 2007). Media reports and public perceptions of truck safety have led many to conclude that more and larger trucks pose increased safety concerns (Daniels, 2006). In addition, advocacy groups have argued that larger trucks pose increased safety hazards (Mercier, 2007) and as a consequence LCV operations have been constrained to certain weather conditions, allowable speeds, and seasons.

In the U.S., LCVs are substantially less crash-involved than passenger vehicles and generally less crash-involved than regular combination trucks. It is thus difficult to disentangle the reasons for such differences, which include professional driver assignments to vehicles, assignment of vehicles to different routes and driving conditions, cargo variations, and the like. Many studies have explored the reasons behind crash involvement, as well as the severity of the outcomes. Those examining the safety of LCVs tend to focus on either LCV operations (in relation to infrastructure geometry and driver abilities) or accident analyses using existing crash data.

7.1 Operational Studies

A number of studies examining the safety impacts of LCV operational characteristics have been completed. These studies tend to focus on arterials and highways, where the great majority of LCV use takes place. Harkey et al. (1996) concluded that, in terms of braking and stopping sight distances, there is no strong evidence to suggest that LCVs pose increased safety hazards, as compared to traditional tractor trailers. Stopping distances and braking characteristics were found to vary widely depending on the load, roadway design, and drivers' skill levels. However, due to LCVs' distinctive speed and acceleration characteristics, they can induce speed differentials and traffic flow disruptions which may compromise the safety of other vehicles. This problem is compounded when highway grades are moderate or severe (Harkey et al., 1996).

Hanley et al. (2005) conducted a simulation-based analysis of a four-mile two-lane highway to study passing maneuvers made by different vehicle classes in the presence of an LCV. The study concluded that passing maneuvers are more likely to fail in the presence of an LCV than a more common heavy duty truck. For example, the chances of failure to overtake a 120 feet LCV when compared to a 15 feet vehicle were 2-6 times higher than the chances of failure to overtake a 65 feet truck when compared to a 15 feet vehicle. While attempting to overtake an LCV the passing vehicle is exposed to opposing traffic direction for a longer period of time, thus reducing roadway safety. Similar observations were made in the Caltrans' operational tests in 1983 (Caltrans 1983).

Glaeser et al. (2006) studied LCVs ability to use existing roadway infrastructure in Germany based on the operational characteristics of the LCVs and geometry of the roadway sections and concluded that using longer trailer combinations on motorways did not result in added risk and recommended adopting reliable braking systems on grades. Glaeser et al. (2006) do not recommend LCV use on routes with multiple at-grade intersections, railway crossings or single lanes (in each direction), due to decreased safety levels and disturbance of traffic flow.

Debauche et al. (2007) conducted a simulation based analysis of Longer and Heavier Goods Vehicles (LHVs) maneuvers in Belgium, and concluded that LHVs do not exhibit any additional maneuverability issues when compared to HGVs on entry and exit ramps or at gradeseparated interchanges. However, LHVs may have problems on intersections and roundabouts on lower category roads which are typically designed for lower speeds and smaller vehicle operations.

Renshaw (2007), conducting preliminary trial studies on partially loaded LHVs in Germany, concludes that LHVs cause considerably more damage when involved in accidents than HGVs and the researchers recommended LHV use for transporting high-volume, low-weight cargos. They also recommend restriction of LHVs to motorways and strict enforcement of speed limits and load distribution rules.

Knight et al. (2008) studied the safety impacts of LHV maneuverability, field of view, braking, stability, and collision outcomes. From the point of view of maneuverability, longer LHVs equipped with steering axles complied with European Union swept-path requirements (a measure of low-speed offtracking) and out-swing limits (a measure of lateral sway). Shorter LHVs, which use a 58 ft-long articulated vehicle combination, do not require steering axles to comply with the EU requirements. LHVs enjoy a similar field of view to an HGV while travelling along a straight segment or during lane change operations. However, depending on LHV length and configuration, additional blind spots may be present while taking relatively tight turns. These blind spots in the field of view need to be addressed using mirror configurations or camera technology. The braking system in place must avoid locking of all wheels. Use of modern technology, such as antilock braking systems (ABS) and electronically-controlled braking systems (EBS) help prevent wheel locking and the resulting safety issues. Knight et al. (2008) also surveyed various measures of LHV stability as related to both directional instability (where different trailers follow different paths) and rollover instability (where trailers overturn). They identified the following as important operational attributes: (i) static rollover threshold acceleration levels (at which rollover occurs), (ii) rearward amplification (the lateral acceleration of the rear end trailer), (iii) dynamic load transfer ratio (a measure of lateral balance in vehicle load distribution), (iv) lateral displacement caused by high-speed offtracking, and (v) yaw damping ratio (a measure of the time taken to dampen the rear-end oscillations caused by sudden maneuvers). Most of the stability risks can be reduced using steered axles and electronic stability controls, which selectively brake the wheels depending on the nature and extent of instability.

Almost all European and U.S. studies recommend LCV operations on freeways. However, they also recommend inspection and enhancement of existing highway design attributes, strict enforcement of speed limits, and rapid deployment of modern technologies to aid LCV braking and stability. In general, such studies do not recommend use of LCVs on roadways with multiple at-grade intersections and smaller lane widths.

7.2 Crash Outcome Studies

In addition to studies examining the safety impacts related to LCV operational characteristics, a second type of LCV safety study falls into the category of crash outcomes. In general, analysis of LCV crashes and comparisons to other heavy and combination trucks have been difficult due to a lack of data involving LCVs (US GAO 1992; US DOT, 2000).

USDOT's 2000 study, based on the crash histories of multiple-trailer trucks, concluded that trucks pulling more than two trailers are likely to be involved in 11% more crashes per mile than single trailer trucks when both trucks operate under similar conditions. However, LCVs carry more cargo, so their crash-rate per ton-mile can be significantly lower. Crash-severity differences can go either way, as discussed later.

Vierth et al. (2008) conducted an analysis of 2003 to 2005 accident data in Sweden to check if the presence of longer trucks results in more overtaking-related crashes and concluded that the increase in accident risk is not statistically significant and is offset by truck-mile reductions (thanks to bigger cargos). No statistically significant correlations where found between overtaking-related crashes and vehicle length and axle numbers. However, the analysis did suggest that longer trucks resulted in higher casualty ratios: with 13 people outside the heavy truck being killed for every person killed inside the heavy truck. The corresponding ratio for light duty trucks was just 1.6.

Zaloshnja et al. (2000) findings estimated 1.118 casualties for multiple combination vehicles versus 1.109 for single trailer crashes. Zaloshnja et al. (2004) extended this work by conducting a more detailed analysis of NHTSA's Fatality Analysis Reporting System (FARS) and General Estimation Systems (GES) databases. They concluded that multiple combination trucks have higher crash costs per incident when compared to single-unit-truck incidents, and single-combination trucks have the lowest crash costs per truck-mile.

Wang et al. (1999), using GES data for the years 1989-1993, showed that combination-unit-trucks are involved in significantly fewer crashes as compared to passenger vehicles and single-unit trucks (at rates of 226 combination-unit crashes per 100 million miles traveled, versus 556 for passenger cars, 416 for light-duty trucks, and 289 for single-unit trucks), but they have a very high lifetime crash cost due to their longer travel distances, longer operational lives, and greater involvement in severe crashes. They estimated the associated lifetime costs of combination-unit-trucks (CUT) to be at least four times greater than those of any other vehicle type.

Forkenbrock et al. (2003) used multiple classification analysis and automatic interaction detectors on the Trucks Involved in Fatal Accidents (TIFA) data file for the years 1995-1998, as maintained by the University of Michigan Transportation Research Institute (UMTRI). They concluded that multiple trailer trucks have a higher likelihood of crash involvement when compared to a single trailer trucks under difficult driving conditions. Such conditions include darkness, snow on the road, and moderate traffic volumes on reasonably high-speed facilities. While their analyses did not distinguish LCVs from multiple combination trucks, LCV safety levels are not generally expected to be higher than those of multiple combination trucks.

Campbell et al. (1989) conducted one of the earliest U.S. studies on LCV crashes. They surveyed 12 western states where LCV operations were permitted and identified around 550 police-reported crashes involving LCVs. The accident rates were found to be lower than what was expected for combination vehicles, either due to under-reporting or the presence of operational restrictions on LCVs. Rocky Mountain Doubles were found to be involved in a significant majority of reported accidents as compared to turnpike doubles and triples. Campbell et al. (1989) recommended a detailed study for measurement of crash rates (per vehicle-mile) and related factors such as road classification, surface condition, grades, curvature, existing traffic volumes, and driver characteristics in the state of Washington.

Abdel-Rahim et al. (2006) recently reviewed LCV crash data in eight western U.S. states (in a report commissioned by the American Trucking Association) and concluded that only Idaho, Montana, Oregon, and Utah have sufficient data for detailed crash analyses. Furthermore, only data from Utah allow for distinctions across all truck types. In all four states, triple combination trucks were found to have the lowest crash rates among all LCVs; such combinations accounted for less than 3.5% of all crash-involved LCVs. In Montana and Oregon, triple combination trucks were involved in a higher number of crashes than double combination trucks under adverse weather conditions, such as snow and ice. In Idaho and Montana nearly 50% of the triple combination crashes occurred in darkness. In all four states, triple combination trucks were involved in the highest number of property damage only crashes. Overall, they estimated Utah's average LCV crash rates for the years 1999-2004 to be as follows: 104 per 100 million miles traveled for Rocky Mountain doubles, 135 per 100 million miles traveled for Turnpike doubles, and 90 per 100 million miles traveled for triple trailers (10% less than Alberta's crash rate). In the first two cases, these numbers are significantly higher than Alberta's crash rates, but about 10% less in the case of the triple trailers. In all three cases, they are significantly (roughly 50%) lower than the U.S. average across all multi-unit trucks in the early 1990s (Wang et al. 1999), as noted earlier. While crash rate trends have long been downward over time, the trends have been gentle. These significantly lower rates suggest that LCVs enjoy lower crash rates. In general, Abdel-Rahim et al. (2006) observed that no consistent trends were observed among vehicle types with respect to crash types and crash severity in the four states.

Craft (1999) analyzed the truck combinations involved in fatal U.S. crashes between 1991 and 1996 and noted that LCVs were involved in only 1.3% of such crashes. He concluded that, due to the paucity of data on LCV crashes, no solid conclusions could be made on their relative safety. Woodrooffe (2001) compared LCV safety to that of other vehicle classes using data from 1995 to 1998 in Alberta, Canada. He determined that the LCVs enjoy the lowest collision rates (per mile-traveled) among all vehicle classes in that region, with fewer than 14 crashes involving LCVs per year. The number of LCV collisions that occurred in rural areas was roughly twice the number of such incidents in Alberta's urban areas.

Woodrooffe (2001), in contrast to Campbell et al.'s (1989) earlier study, found Rocky Mountain doubles to exhibit the fewest collisions per mile traveled among the various LCV classes, and experiencing zero fatalities observed over the four-year period. Turnpike doubles had the highest collision rates among LCV classes.

Montufar et al. (2007) conducted a similar study in the Alberta region from 1999 to 2005 to compare and contrast LCV safety performance over the study periods. Their work revealed LCVs to be the safest among all vehicle types, with just 40 collisions for every 100 million miles traveled and the lowest injury and fatality rates. In contrast to Woodrooffe's (2001) results, turnpike doubles were found to have the lowest collision rates (just 26 per 100 million miles traveled) followed by Rocky Mountain doubles, at twice the rate of turnpike doubles. Triple trailer combinations had the highest collision rate at 99 per 100 million miles—still well under the 226 value estimated by Wang et al. (1990) for all U.S. combination trucks in the early 1990s. Driving actions such as improper turning and lane change maneuvers and unsafe roadway conditions such as presence of snow, ice, slush or rain were the major causes of LCV-involved incidents.

Debauche et al.'s (2007) safety survey of roughly 100 LHVs for the Dutch Ministry of Transport estimated LHVs to have similar levels of safety when compared to heavy goods vehicles (HGVs) but slightly lower fatal injury crash counts (totaling just 4 to 25 such crashes a year in the Netherlands). Motorists also did not report any decrease in perceived safety level in the presence of a LHV on road as opposed to a regular HGV. Based on these results, Debauche et al. (2007) recommended LHV operations be permitted in Belgium, as long as trials are conducted to identify and rectify various geometric design issues (including roundabouts and entry and exit ramps) and operational issues (such as braking and load distribution).

Knight et al. (2008) found that in the UK, around 18.3% of traffic fatalities involved one HGV, even though they accounted for less than 6% of the total distance travelled. The three main factors affecting the likelihood of a fatal outcome were found to be collision speed, mass of the two vehicles and type of impact. Of course, the higher the collision speed, the more severe the crash. Interestingly as the ratio of vehicle masses increases beyond 50:1 (as is generally the case with LHVs) there is no significant change in incident severity for the passenger vehicle occupants assuming there are no secondary incidents. The likelihood of death for an HGVs occupant is low, as long as the truck can absorb some of the crash impact (as is the case with most HGV automobile accidents). Knight et al. (2008) noted that the presence of Collision Mitigating Braking Systems (CMBS) has the potential to reduce heavy vehicle crash frequencies by up to 75%, and an even greater percentage for LHVs (Grover et al., 2007; Knight et al., 2008). By extrapolating the UK casualty rate data over more number of axles, Knight et al. (2008) concluded that casualty risks increase with the number of axles. However, they acknowledge that the methodology adopted significantly overestimates the risks associated with LHV use. No trends were observed when fatality rates were extrapolated over gross vehicle weights. The analysis also concluded that LHVs are more likely to be involved (around 5 to 10%) in severe accidents when compared to standard trucks, assuming that no additional safety measures are employed in LHV usage.

Finally, Knipling et al. (2008) used the U.S.'s Large Truck Crash Causation Study (LTCCS) containing information about 963 crashes involving 1,241 trucks between 2001 and 2003 to compare crashes involving combination trucks to single-unit trucks. The study examined 44 variables related to crash types, driver characteristics, driving environment, and vehicle types. The percentage of crashes in dark conditions was found to be three times higher for combination trucks when compared to single-unit trucks. Higher numbers of combination truck crashes were found to occur on divided roads and on roadway sections with curvature. Driver decision error and recognition failure due to distraction appear to be the top two reported causes of combination truck crashes, accounting for 69% of such crashes. A key result of this analysis is that there are far greater differences in crash characteristics across crash types (single vehicle, multiple vehicles) than across different vehicle types. Different crash types should thus be analyzed separately, as opposed to crashes involving different vehicle types.

7.3 Concluding Remarks

Given the relatively few LCVs in the vehicle fleet, and distinctions in driver and shipment assignments to LCVs, a lack of data and subtle differences in travel contexts has made it difficult to conduct a rigorous crash analysis and identify clear trends. In general, there has been no strong evidence to indicate that LCVs are less safe than regular multi-combination vehicles. Furthermore, it has been shown that modern braking systems can allow heavier vehicles to stop in the same distance as vehicles operating at present weights. Finally, a TRB study (1990) concluded that the most important factor contributing to truck-car accidents is the presence of the truck; its size, weight, or configuration plays only a limited role. The study therefore recommended that heavier and longer trucks be allowed to reduce the number of trucks on the nation's highways in an effort to reduce highway accidents.

LCV safety can also be examined by surveying those companies operating LCVs, presumably some since 1982. It was therefore decided to survey a sample of LCVs and capture a range of experiences associated with LCV use. The results are reported in the next chapter.

Chapter 8. U.S. LCV Operations: An Operator Perspective

A critical element in the first year activities was to get feedback from operators who actually operate LCVs under the 1982 "grandfather" regulations. This group has now over two decades of experience which plays a vital role in measuring LCV operational characteristics in the U.S. The objective of this chapter, therefore, is to document insights obtained through telephone surveys with LCV operators into several aspects of LCV. This chapter summarizes the responses by LCV operators and carriers to a survey concerning LCV use. The questions focused on four specific areas of concern: operations and management, performance and safety, vehicle characteristics, and drivers.

8.1 Survey Methodology

The objective of the performed surveys was to contact LCV operators and carriers to obtain each individual's perspective concerning various aspects of LCV operations. Four primary areas within LCV usage were targeted:

1. LCV operations from a management perspective,
2. Vehicle specifics,
3. LCV driver specifics, and
4. LCV performance and safety.

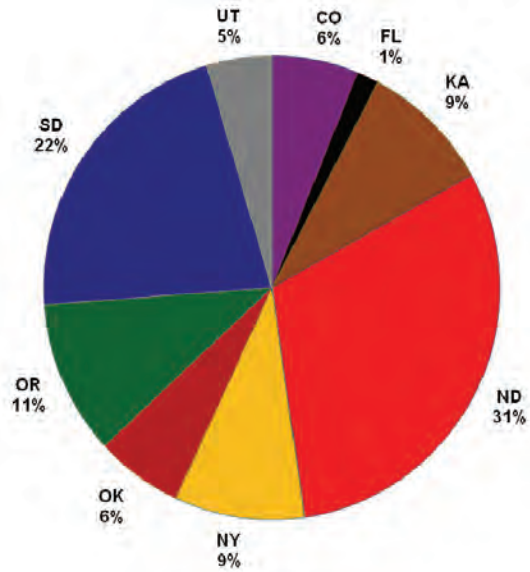
Specifically within LCV operations, survey questions focused on benefits, costs, commodities, and challenges associated with LCVs. This particular section concentrated on the LCV investment and realized benefits and costs experienced by companies. Other questions examined cost savings for LCVs in relation to standard heavy duty trucks, LCV trip distances and travel times, and states in which respondents would like to operate LCVs currently but could not due to regulation

The vehicle question section examined differences between LCVs and standard trucks in terms of tractors, tractor life, maintenance, vehicle expense, and fleet size. LCV drivers were contrasted against standard truck drivers in terms of experience, training, compensation, operating constraints, and assignments. Questions examined differences in driver experience and training, as well as LCV driver compensation relative to standard truck drivers. Respondents also answered questions relating to how drivers were assigned to vehicles and to driving routes.

Performance and safety were investigated by questioning respondents about operational and geometric design concerns pertaining to LCVs, as well as any past LCV accidents that may have occurred and the nature/cause of such accidents.

The conducted surveys utilized the FMCSA database of registered vehicle owners and operators. The variety of contacts included large and small trucking companies, owner-operators, harvesters, concrete companies, and heavy-haulers. Many of the contacts used only standard trucks in their operations while some companies performed specialized truck operations that did not fall into the category of LCVs being evaluated in this study. The following survey results and data summarize responses. In some instances a respondent could not or did not provide an answer to a particular question or instead provided multiple answers to a question. Therefore each question has a unique number of responses or responders that affects the survey size for any one question.

One limitation to the survey is that only 9 states are represented out of 19 possible LCV-operating states, although various geographic regions are represented, including the Northeast, Northwest, Midwest, and Southeast. Uncertainty exists as to the meaning of the proportions of respondents that represent each state, yet the survey population may be somewhat indicative of the extent of LCV use in states. For example, North Dakota and South Dakota represent a very large portion of the survey possibly because LCV use has been ongoing and extensive for many years, so respondents are comfortable sharing information concerning their LCV operations. Likewise, only one respondent represented Florida, indicating a limited use of LCVs and a limited LCV infrastructure within the state. Figure 8.1 illustrates the survey population by state.



Number of Respondents: 65

Figure 8.1: Survey Respondents by State

8.2 Survey Results

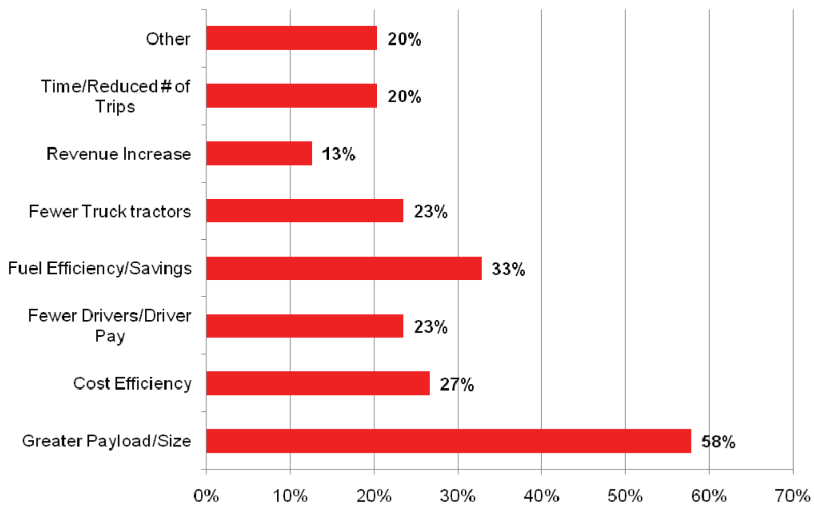
8.2.1 Operations from a Management Perspective

Respondents were asked what their company viewed as the most significant benefits to LCV operations. From Figure 8.2 it is evident that over half of the respondents stated that a major benefit was the ability to move more freight because of an increased payload capacity. Some respondents noted the greater weight capacity due to LCVs while other operators commented that LCVs provided more space to carry more cargo. Thus, LCV operations can aid companies that generally either cube or gross out. Revenue increase was also cited as a benefit and is closely associated with a greater payload because several companies receive payment for a load based on the amount of freight moved. An increase in payload due to LCV use typically corresponds to increased revenue for the freight carrier.

After increased payload capacity, the next most-cited LCV benefits related to efficiencies. Respondents continually mentioned cost efficiency both as an over-arching term and in the context of specific examples including fuel efficiency, time savings, and a reduction in the number of tractors and drivers. One-third of respondents noted fuel savings because of LCV use. This confirms the results of researchers noted in earlier chapters of this report—namely that

LCVs have greater fuel efficiency than standard trucks on a ton-mile basis. Twenty-three percent of respondents cited a reduction in the number of drivers as a primary benefit. Likewise, 23% of respondents also specified a reduction in the number of tractors as a major priority. Driver pay and capital investment in truck-tractors are primary costs to freight companies, so any reduction in either element corresponds to a possibly substantial cost-savings benefit for the company.

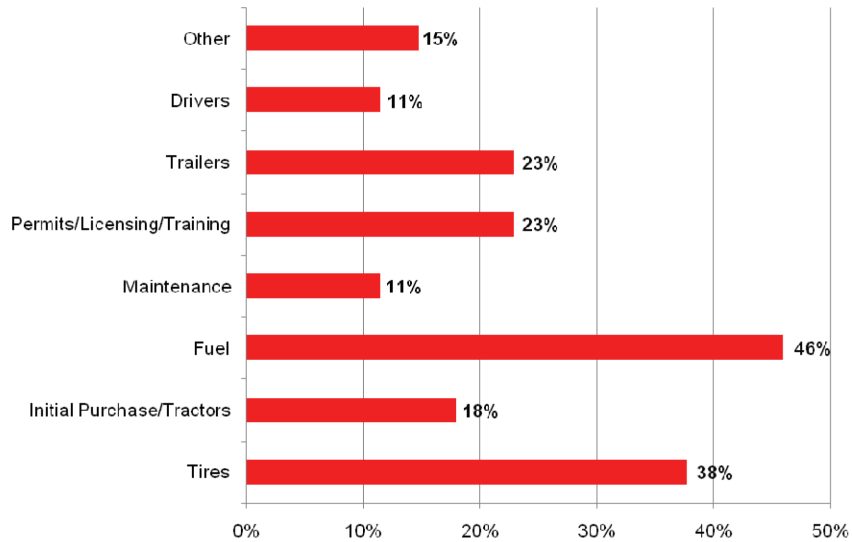
Other noted factors include a reduction in the number of vehicle trips as well as a possible reduction in the number of trucks on the road; enhanced ability to meet axle-weight constraints while moving a greater payload; improved emissions efficiency compared to standard trucks; and an increased capability to diversify what the company may haul due to increased vehicle weight and dimension limits. These factors are important to examine; however, the central LCV benefits for freight companies are two-fold: LCVs allow for a greater payload (and therefore increased revenue per shipment) and improve cost efficiency when compared to standard trucks.



Number of Responses = 139

Figure 8.2: Perceived Benefits of LCV Operations

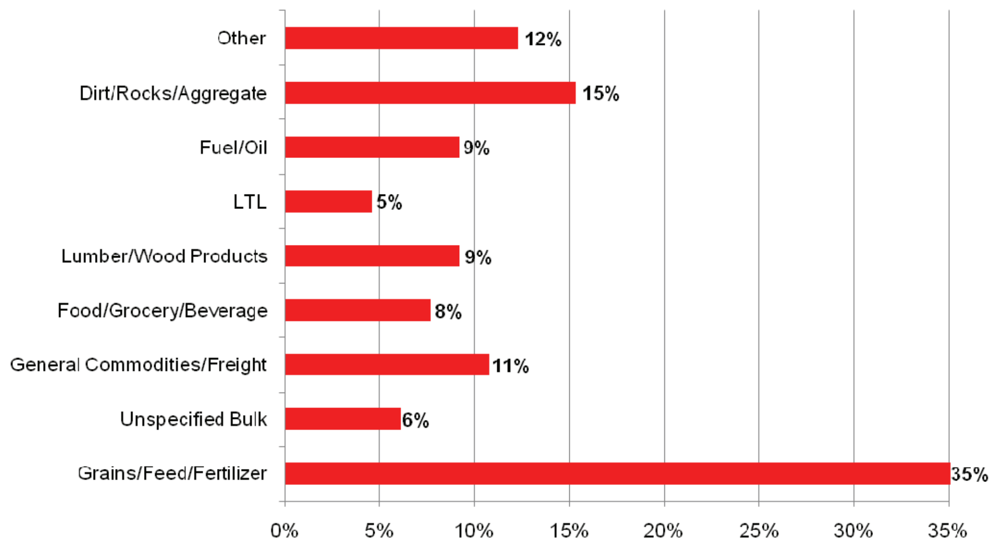
When asked about the major costs in LCV operations, respondents provided a broad range of answers from capital investment for equipment to fuel consumed on a daily basis (see Figure 8.3). As a result, responses concerning costs provide a more general overview of all costs associated with LCV use. Fuel (46%) and tires (38%) were the most frequently cited major costs. Some respondents noted that LCVs did consume more fuel and thus increased the company's costs at least in the initial implementation of the LCV. Some of these respondents would mention, though, that LCV use eventually led to an overall better fuel efficiency and actually saved the company fuel expenses. Roughly one-fourth of respondents cited an initial capital investment in necessary equipment, and approximately one-fifth of those surveyed claimed investment in a second trailer as a primary cost. Licensing and permitting of the vehicle and/or LCV driver training were associated with major LCV costs by 23% of respondents. Other notable costs include maintenance of LCV units and driver pay. Insurance, tolls, and road taxes were mentioned to a much lesser degree than the preceding major costs. Also, one survey question explored the influence of LCVs on the costs associated with handling operations such as loading, unloading, and hooking up or breaking apart trailers. Three-fourths of respondents said that LCV operations had no affect on handling costs; only about one-fifth of respondents claimed LCVs improved handling costs, and several of these respondents also noted that the improvement in handling costs was insignificant.



Number of Responses = 113

Figure 8.3: Perceived Costs of LCV Operations

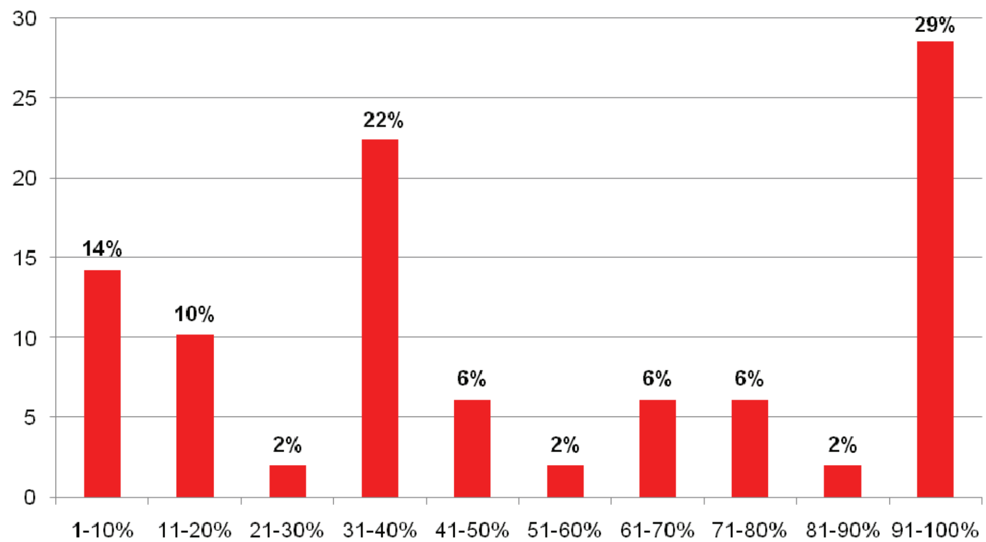
Thirty-five percent of respondents represented companies involved with grain and agricultural products. Other companies range from LTL carriers to lumber carriers to an amusement park equipment mover. Figure 8.4 illustrates the various commodity types reported. Some states exhibit trends in terms of what type of commodity is moved via LCV within the state. Significant LCV operations for moving agricultural products exist in North Dakota, South Dakota, and Kansas. In addition to agricultural operations, LCVs may move a substantial amount of fuel/oil in North Dakota and aggregates, rocks, and dirt in South Dakota. In Oregon, LCVs are used in hauling lumber and wood products as four out of the seven Oregon respondents were affiliated with the lumber/wood industry. Likewise, half of New York State operators moved general freight and commodities via LCVs, and another one-third of the New York respondents moved groceries and/or beverages. Companies within different states use LCVs in different capacities to meet the commercial and industry needs particular to that state or region.



Number of Responses: 72

Figure 8.4: Major Commodities Moved By LCVs

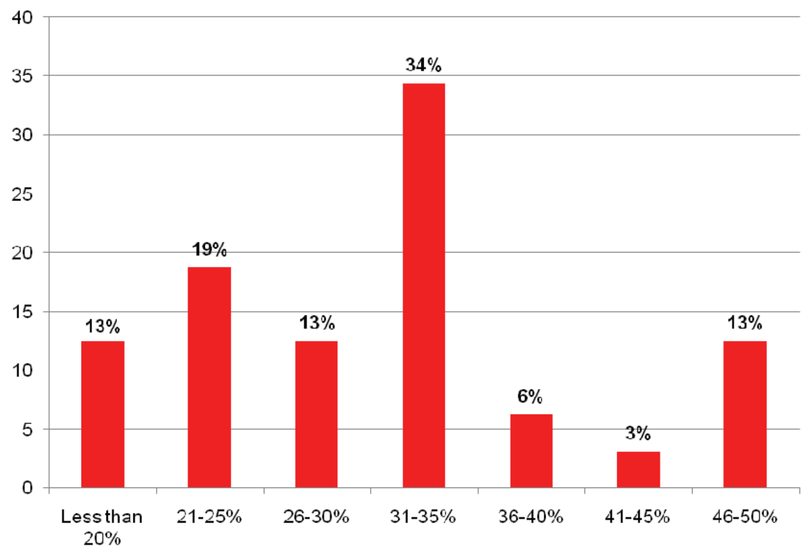
It is also interesting to note that about half of the respondents' companies employed LCV operations minimally or extensively, either 10% or less of the time or greater than 90% of the time. The remaining companies were dispersed between the two extremes of use, although approximately one-third of all the companies used LCVs in 20%–50% of their shipping operations (on a vehicle-miles-travelled basis).The companies interviewed also had varying fleet sizes: of 59 companies, 21 companies (36%) used 5 or fewer truck-tractors in their operations and 21 companies used more than 20 truck-tractors (encompassing both LCVs and non-LCVs). The percentage of the fleet that comprises LCVs was also calculated. From Figure 8.5, it is clear that only 29% of the respondents indicated that 91 to 100% of their fleet is LCVs. Similarly, approximately 45% of the respondents indicated that LCVs comprise more than 50% of their trucking fleet.



Number of respondents: 49

Figure 8.5: LCV Percentage of Total Fleet

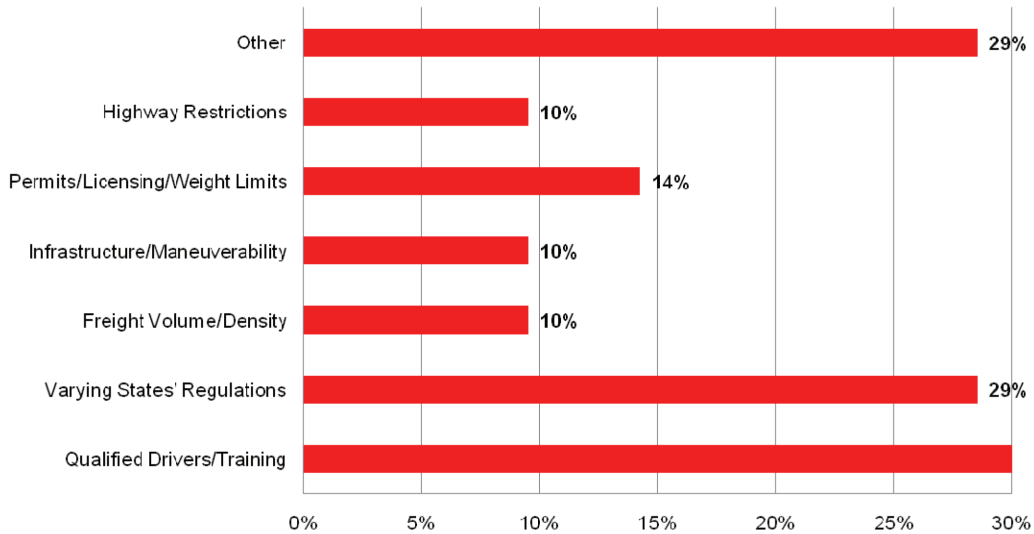
Respondents were asked about the extent to which LCVs reduced the number of truckloads. Figure 8.6 graphically depicts the responses. Two outlier values are not shown because these values were considerably higher than all other values. The greatest number of responses for a particular range occurred within the 30%–35% range. Many double combinations would yield this result because the pup trailer typically is about half the length of the lead trailer, so for every three standard truck loads, only two LCV loads are needed. Hence, a 31–35% reduction in the number of truckloads is consistent with the substantial number of companies in this survey who operated Rocky Mountain Doubles. The responses falling between 21–25% also indicate doubles use with a pup trailer that is slightly less than half as long as the lead trailer. This data is also consistent with the number of surveyed companies who employ doubles. Similarly, the data indicates the use of Turnpike Doubles because these vehicles reduce the number of truckloads by 50% and the data reveals that 13% of the respondents reported a 46-50% reduction in truck loads. This result is consistent with the number of surveyed Turnpike Double operators. Figure 8.6 also accentuates the possible productivity and efficiency (in terms of payload per trip) that may result from using LCVs.



Number of Respondents: 32

Figure 8.6: Percent Reduction in Number of Truck Loads (34 Responders)

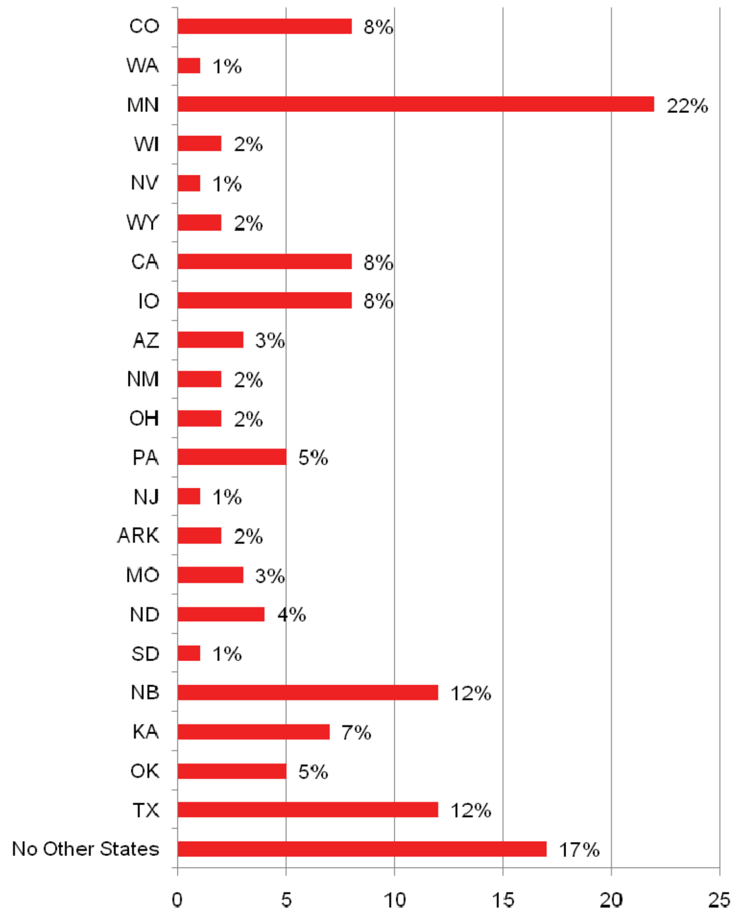
Respondents were also questioned about the major challenges in implementing and/or expanding their use of LCVs. The two most common responses were finding qualified drivers and dealing with varying regulations between states (see Figure 8.7). Many respondents noted that a lack of qualified, experienced drivers currently exists; hence, companies are forced to either limit their LCV operations proportional to the number of qualified LCV drivers available or possibly use less experienced/qualified drivers as LCV operators. Varying regulation between states, including separate weight limits, axle-weight limits, and trailer/vehicle dimension constraints, is a major hindrance and annoyance to LCV operators. Many companies will not expand their business to another state because either the other state does not allow for LCVs or because the company does not want to jeopardize the health of the business to meet the other state's various laws. Many of the respondents commented that harmonization in regulations between states would resolve the greatest challenges shipping companies face as well as improve overall economic health and competitiveness. Other frequently cited challenges include overcoming permits and licensing (especially in relation to weight limits for a state); dealing with an unsupportive infrastructure and maneuvering a more challenging vehicle; and possessing the necessary freight volume/density that would warrant a need for LCV use. Figure 8.7 also demonstrates that almost 30% of the responders answered "Other," which includes responses such as the cost of doing business with LCVs, backhaul (inefficiency and lack of productivity in returning empty trailers from destinations), weather/wind, and having a business in which LCVs do not complement the productivity of the business.



Number of Responses: 82

Figure 8.7: Major Challenges Pertaining to Expanding Use of LCVs

When asked which states their company would like to operate an LCV in which the company could not operate an LCV currently, many respondents named bordering or nearby states that do allow LCV operations. Figure 8.8 illustrates that of the 128 responses received, 17% of the respondents said they would not want to operate in other states. States garnering the most responses included Minnesota (22%), Nebraska (12%), Texas (12%), California (8%), Colorado (8%), and Iowa (8%). The relatively high number of responses for Minnesota is indicative of the high number of respondents in the survey from bordering states North Dakota and South Dakota. The responses for Nebraska and Texas are also important because states surrounding these two states made up a smaller portion of the survey population. Furthermore, Texas is particularly interesting because the only state bordering Texas in the survey is Oklahoma with four respondents from this state. While Texas and Minnesota do not permit any LCV operations, Colorado allows for some LCVs on limited networks within its borders while Nebraska allows empty Triples to operate on a limited network as well. The positive responses for Colorado and Nebraska thus underscore respondents' collective desire for increased access within these two states.



Number of respondents: 128

Figure 8.8: States in Which Operators Want to Use LCVs

8.3 Vehicles

Respondents were questioned about LCVs in relation to standard trucks. Concerning differences in LCV truck-tractors and standard truck-tractors, 57% of responders said no differences existed while 29% stated that the LCV truck-tractor possessed greater horsepower than the standard truck-tractor. The remaining 14% of respondents stated other tractor differences including larger engines, higher torque ratings, longer tractor lengths and wheel bases, and an extra axle on the LCV tractor (as compared to the standard tractor).

When asked about LCV-specific maintenance requirements beyond those of standard trucks, 58% replied that no extra maintenance occurred beyond that of a standard truck. However, many respondents would note that because of the extra trailer and therefore extra axles, tires, and brakes, more equipment would need to be maintained. One-fourth of respondents cited brakes and/or tires as LCV-specific maintenance beyond standard trucks. Some respondents also stated that the tire life is reduced because of using LCVs, particularly tractor tires. Another 17% of those surveyed observed other maintenance issues including dollies, coupling inspections, and panel hooks. When asked to compare the tractor life of an LCV truck-tractor to the tractor life of a standard truck, three-fourths of respondents said no difference existed in the life of each tractor, while the remaining one-fourth stated the LCV tractor life would be reduced, primarily due to the increased wear/tear and demand on the tractor engine.

Respondents were evenly divided concerning the expense of a LCV compared to a standard truck: Half of respondents stated LCVs cost more than standard trucks while the other half of respondents stated LCVs cost no more than standard trucks. Extra equipment including more tires, brakes, axles, and a second trailer was often the chief cause of an increase in expense due to an LCV. Of those who also provided a percentage increase in costs due to LCV usage instead of standard trucks, most respondents said increased expense was between 5%-30% more than a standard truck. Some respondents would note, though, that when the amount of freight moved by each vehicle is considered, LCVs could reduce overall expenses.

8.4 Drivers

Questions also focused on LCV drivers in relation to standard truck drivers. Concerning differences in experience requirements for LCV drivers compared to standard truck drivers, 84% of respondents said that experience requirements exist or should exist. Many respondents identified one requirement as obtaining a doubles/triples licensure from a state to operate an LCV. Others surveyed mentioned that LCV drivers need to be more experienced in general as well as be more cognizant of the larger equipment they are operating, while still other respondents provided specific experience requirements. For example, New York LCV operators must have 5 years of provable Class A license experience before being allowed to operate LCVs on the New York Thruway. Respondents from Utah noted that LCV drivers must have proper LCV endorsements as well as state-mandated training to drive an LCV.

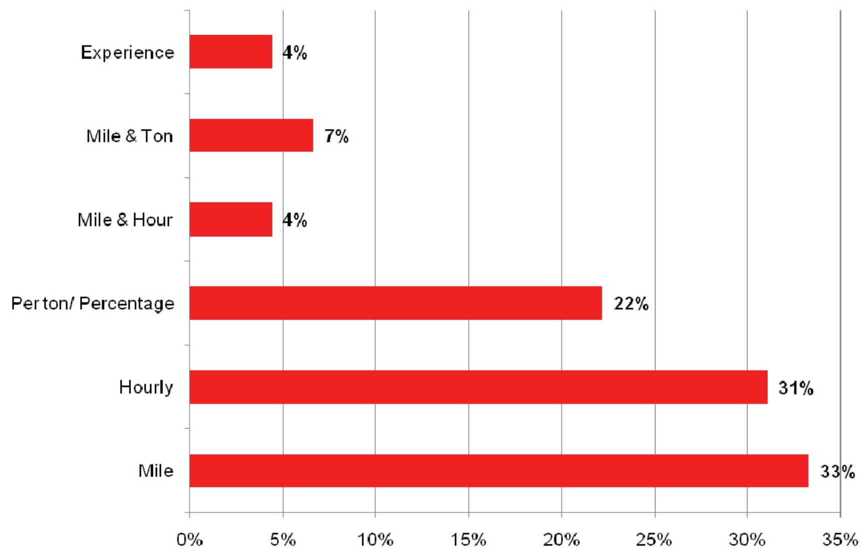
Fifty-eight percent of companies provided additional training for LCV drivers. Depending on the company the additional training could consist of a written test, a driving test with an experienced driver, an equipment walk-thru check, refresher courses, or a combination of these tests. Some companies had specific safety instructors or directors, while owners or even experienced drivers of other companies, principally small companies, would evaluate the ability of prospective drivers. Larger trucking firms (greater than twenty total trucks) generally required additional LCV driver training.

When asked about violations that disqualify drivers from operating LCVs that do not disqualify the same drivers from driving standard trucks, most respondents said such violations did not exist (at least to their knowledge). However, some New York respondents noted that a "points system" is in place that holds LCV operators to a higher standard than standard truck drivers. Such a "points system" promotes safe driving because license revocations for violations are more probable for LCV operators and because LCV operators' driving records are more stringently maintained.

Two-thirds of respondents stated that no special weather or hour-related restrictions applied to LCV drivers when compared to standard truck drivers. However, one-fifth of respondents noted weather restrictions specifically for LCVs did apply. Most companies of these respondents were located in the northern United States and likely experienced ice and snow weather conditions during winter. Ice, snow, and poor visibility are specific factors which often cause state governments to restrict LCV operations in these northern states. The remaining 13% of respondents cited hour-related restrictions which included not operating during nighttime hours and not driving through a city during normal business hours (e.g., 6:00 a.m.–6:00 p.m.). The previous two restrictions may have had different purposes: The former possibly promoted safety while the latter may have provided better utility to city commuters.

LCV drivers predominantly are assigned to the same vehicle or vehicle type. Forty-two percent of respondents stated that LCV drivers are assigned to the same routes. Many respondents noted that their company sends drivers where business demands and/or work exist.

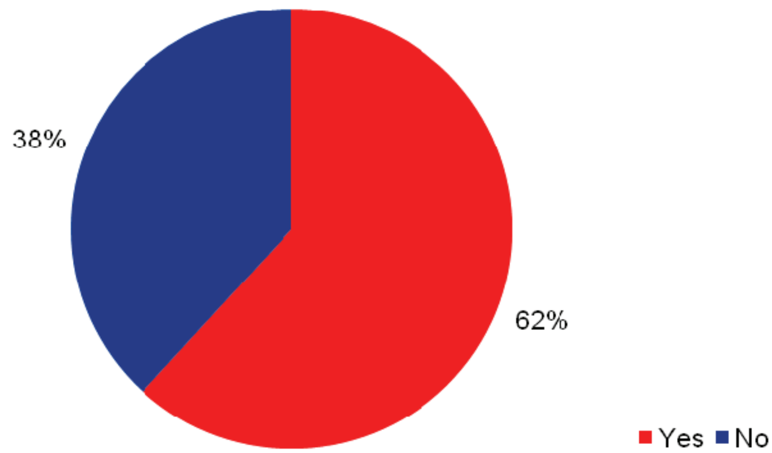
Concerning driver compensation for LCV drivers compared to standard truck drivers, one-third of companies pay their LCV drivers on a per mile basis while another approximate one-third pays on an hourly basis (see Figure 8.9). Another 22% of companies pay their LCV drivers based on the amount of freight they haul (per ton basis or percentage basis). No one pay structure stands out as the preferred industry method of payment. The remaining companies pay their LCV operators based on experience or some combination of the previously discussed pay structures.



Number of Respondents: 46

Figure 8.9: LCV Driver Compensation

Sixty-two percent of companies compensate their LCV operators more than standard truck operators (see Figure 8.10). However, no conclusion can be made as to the method or structure of a premium paid to LCV operators. Of the respondents who said LCV drivers did earn a premium because of operating an LCV, some noted that LCV operators earn more because they haul more freight and are paid on a tonnage basis and thereby stand to earn more money.



Number of Respondents: 55

Figure 8.10: Premium Paid to LCV Drivers

Other respondents said LCV operators earn more just for the sake of driving a larger, heavier vehicle. LCV operators also might receive extra payment when they have to spend time hooking and unhooking trailers. Of those paying LCV drivers strictly on a per mile basis, 73% of companies reported to pay the LCV drivers a premium compared to standard truck drivers.

8.5 Performance

Approximately half of respondents said their company did not experience operational concerns with its LCVs such as issues related to acceleration, braking, and climbing speed. Of those who did express concern for the vehicle performance, 37% cited braking as a major issue and one-third of respondents noted an effect on climbing speed due to LCV use. An LCV's ability to brake may be a complex issue as some respondents claimed braking distance would increase due to the LCV's greater payload, while some respondents noted that due to the presence of more axles/brakes, the LCV could stop better. Some respondents stated that multiple performance characteristics are affected negatively because of the greater payload that is hauled. Similarly, LCVs that operate in rugged terrain such as mountainous or hilly locations often would perform more poorly as would some LCVs that operate in locations which frequently experience adverse weather conditions. In fact, 81% of companies that had an operational concern are based in North Dakota, Oregon, or South Dakota. North Dakota and South Dakota drivers experience very adverse weather conditions involving snow and ice, while Oregon drivers operate in mountainous terrain and experience snow and visibility issues.

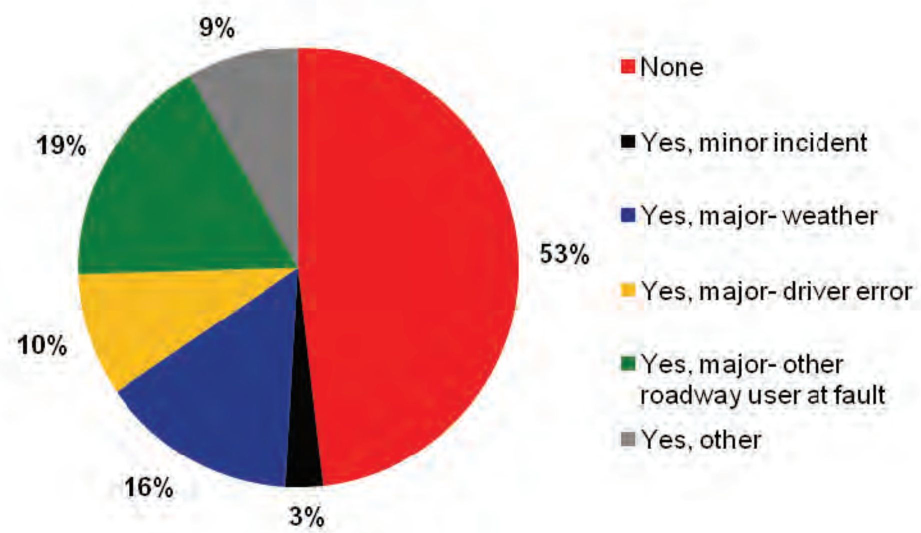
Other frequently mentioned issues include the LCV's ability to accelerate and to maintain a cruising speed comparable to that of the standard truck. In some instances, respondents associated an overall slower operation with LCVs. When asked about the relative travel times of LCVs and standard trucks for a given route, though, half of respondents said the travel times for each truck were the same and some respondents mentioned any increase in travel time due to the LCV was minimal. Thus, the issue of cruising speed may have relevance only in regions with variable terrain where vehicles constantly change speeds, accelerate, and brake. Acceleration appears to be a more universal issue for LCVs that transcends geography and weather conditions, and is likely more significant than speed issues.

Regarding geometric design limitations, about half of respondents stated they had no concerns. Approximately one-third of respondents cited maneuverability issues which predominantly were associated with the LCV's lack of ability to back up. The LCV turning radius was also a concern. However, several respondents noted that LCVs had smaller turning radii than some of the longer (48 ft—53 ft) standard trucks and thereby were easier to turn. Respondents commented that maneuverability issues could be mostly resolved by planning for the anticipated travel route and following the plan so as to avoid unfamiliar infrastructure and reduce the likelihood of "getting stuck." Also, two respondents mentioned that off-tracking was better for LCVs compared to the longer standard trucks.

Sixteen percent of respondents cited concerns pertaining to the infrastructure. Shipper facilities and urban and/or rural infrastructure may not easily accommodate the larger dimensions of LCVs and therefore limit the maneuverability of the vehicles. As mentioned earlier in the context of challenges facing companies using LCVs, limited infrastructure may frustrate LCV operators, which ultimately could deter a company's investment either in a certain product or in a particular region. Some frustration was expressed due to a company's inability to operate LCVs beyond a certain distance from an allowed route. Companies would sometimes have to break down LCVs and continue shipping to a destination with singles units, thus decreasing overall operating efficiency. New York respondents appreciated trucking compounds located directly off certain exits because these compounds easily facilitate combination vehicles that need to break down to form single-trailer vehicles in order to continue shipping off the New York Thruway to final destinations. Such a system and infrastructure may be an achievable and practical solution to improve shipping efficiency and promote business throughout LCV-operating states.

8.6 Safety

Respondents were asked if any of the company's LCVs had been in an accident within the past 10 years. The results are depicted in Figure 8.11. Fifty-three percent reported no LCV accidents while another 19% said accidents that did occur were the fault of other system users and not of their LCV operators. One reason for these accidents was four-wheeled drivers cutting off or running into LCVs. Some of these accidents also occurred in adverse weather conditions. "Other" causes for accidents included poor road conditions, LCVs being rear-ended while pulling out, mechanical problems, and road obstructions such as deer that may cause avoidance maneuvers.



Number of Respondents: 58

Figure 8.11: Incidents Involving LCVs

A possible means to reduce accidents may be to limit LCV operations during adverse weather conditions. This measure may benefit both the general public from a safety perspective as well as trucking companies by lowering financial risks associated with vehicular accidents.

8.7 Concluding Remarks

The major benefit of LCV operations in the U.S. is an increased payload capacity that may yield greater revenue and productivity gains and therefore improve and stimulate business. Another primary benefit of LCV operations is overall cost efficiency that may stem from cost savings due to fuel efficiency, a reduction in the number of drivers and tractors, and a reduction in the number of trips undertaken as well as a general time-savings benefit.

This survey provided a broad view of costs associated with LCV operations. Fuel and tires were the most frequently cited costs by respondents, and several of those interviewed mentioned the initial investment in equipment as a major cost. Other noted costs include licensing and permitting vehicles and training LCV drivers, investment in a second trailer, driver pay, and maintenance of the LCV unit. Handling costs such as hooking and unhooking trailers do not have a significant impact on LCV operations.

A significant portion of the survey population (35%) employed LCVs in agricultural and/or grain operations. Several states used LCVs for operations that appear to be unique to the state.

Fleet sizes vary but most (92%) responding companies had fewer than 20 LCV units. Rocky Mountain Doubles are the most employed LCV vehicle type. Turnpike Doubles are used much less in the western and midwestern states (relative to Rocky Mountain Doubles), but all New York operators employed Turnpike Doubles. Triples operations did not comprise a considerable portion of the survey population.

The primary challenges hindering companies from implementing and expanding LCV use are two-fold: finding qualified LCV operators and dealing with varying LCV regulation between states. Not only is finding a qualified LCV operator difficult, but a challenge exists in also finding drivers who are willing to operate larger and heavier trucks. Also, the lack of harmonization in regulation between states discourages some companies from expanding their business into other states. Harmonizing regulation between states would encourage companies to expand their business and possibly promote economic growth and competition.

Other encountered challenges include overcoming licensing/permitting of trucks and training of LCV drivers, maneuvering a larger vehicle in an unsupportive infrastructure, and possessing the necessary freight volume/density to warrant the use of an LCV.

The majority of companies want to operate LCVs in other states in which they currently cannot or do not operate LCVs; the most commonly cited states include Minnesota, Nebraska, Texas, California, Colorado, and Iowa. The predominant reason for not operating LCVs in a particular state is because the state does not allow LCV use. However, some states, such as Colorado, have limited networks for LCV use while other states, such as Nebraska, are more restrictive on what type of LCV may operate within the state. Thus, companies are prevented from expanding business because a state does not allow LCV operations, the LCV-allowed network is very limited and not conducive to profitable operations for a particular company, or a certain type of LCV is prohibited within a particular state.

LCVs may not require much, if any, additional increase in engine horsepower to meet the "grandfathered limits"[32], and the extent of increased horsepower varied between companies and was not typically proportional to the increase in load. Increases in horsepower were generally small. LCV truck-tractors may also have an additional axle depending on the company and its operations.

Maintenance requirements for LCVs are generally not much greater than standard trucks. Increased tire and brake wear do occur, particularly for truck-tractor tires and brakes, and more equipment (like fifth wheel dollies") must be maintained when using a second trailer. Generally, LCVs cost more than standard trucks although half of respondents stated LCVs do not cost more than standard trucks—possibly because driver costs were not counted. The other half of respondents reported a higher vehicle cost due to an increase in the number of axles, tires, and brakes as well as an additional investment in a second trailer. However, it is unclear as to whether respondents considered just an initial equipment investment or if respondents considered the overall life of the vehicle. In addition, fewer tractors are needed for any given level of cargo and this clearly reduces maintenance levels. The truck-tractor life for LCVs did not differ from the standard truck-tractor life for most companies, while one-fourth of companies reported some decrease in life span due to increased engine wear and tear cause by moving a greater payload.

Obtaining licensure for doubles/triples operation is a minimum experience requirement. Over half of companies provided additional LCV driver training, but the extent of the training is unclear. Some companies directed intensive, hands-on safety programs with safety directors while other companies with probably smaller operations conducted driving tests typically administered by the company owner or a veteran operator. Many companies relied upon just the licensed certification as a requirement for operating their LCVs. Individual states have differing requirements before drivers are certified to operate: many of the western states appear to require only doubles certification while New York requires LCV operators possess at least 5 years of Class A driving experience. Because individual companies and states possess a broad range of requirements, no coherence or unity appears to exist as far as LCV driver training and certification. This lack of coherency may deter some companies from investing in LCV operations. New York has a stringent and comprehensive driver certification process as well as a

[32] This is not case for most LCV power units proposed for use in Texas.

"points system" which evaluates current LCV driver records in an effort to promote better driving behavior.

One-third of respondents experienced either weather or hour-related operating restrictions. Such restrictions may be in place to improve safety for the general public and LCV drivers during both adverse weather conditions and evening hours. Similarly, cities may restrict LCV operations during business day hours to promote better transportation system operation for their citizens and workers.

No one pay structure stands out as the preferred industry method of LCV driver compensation. One-third of respondents' companies paid their LCV drivers on a per mile basis while another approximate one-third paid on an hourly basis. Another 22% of companies paid their LCV drivers based on the amount of freight they haul (per ton basis). Companies may be prone to compensate LCV drivers more than standard truck drivers for a number of reasons: LCV drivers operate larger and heavier vehicles, have doubles and/or triples licensure and possibly more driver training, must be knowledgeable with hooking and unhooking trailers, and generally haul a greater payload. Some companies pay LCV operators more because the drivers haul more tons of freight while many companies may just have a predefined premium specifically for LCV operators. However, the extent of the percentage of companies which compensate LCV drivers more remains unclear.

Performance characteristics were an issue for half of companies, particularly companies that operate in regions that have rugged or hilly terrain and/or experience adverse weather. Braking distance and climbing speed were the two main concerns of respondents. Acceleration and cruising speed were less frequently cited

Most trucking companies do not have geometric design limitation concerns other than that LCVs practically cannot back up. Some companies, however, did mention that infrastructure such as shipper facilities and some roadway intersections present challenges to LCV operators. As stated by many respondents, drivers who follow planned routes avoid most, if not all, geometric design issues. A supportive infrastructure such as the New York Thruway with compounds at certain exits designated for LCVs to hook and unhook trailers abates geometric design issues significantly.

Approximately half of companies had an LCV accident within the past 10 years. Many of these accidents were the fault of non-LCV drivers, while some of these incidents resulted from LCV driver carelessness and error. The most common element to accidents is adverse weather conditions. A very substantial portion of accidents occurred during adverse weather such as snow, ice, and/or poor visibility; only about one-fifth of respondents reported weather restrictions imposed on their LCV operations by the state government. A possible solution to reducing accidents may be to restrict LCV operations during adverse weather conditions.

The surveys described in this chapter comprised the final piece of analytical work undertaken in the first year of the study. The work plan comprised two basic programs, each lasting one year. The first year was to review LCV literature and suggest a variety of methods to analyze LCV use in Texas. In addition to the TxDOT advisory panel assigned to the work, the study proposal incorporated the use of technical experts from other transportation centers and Texas operators who were interested in adopting LCV vehicles. It was decided to hold a meeting with all interested parties where the first-year results would be presented and the proposed method for the second year discussed, changed if necessary and then approved. The next and final chapter presents the outcome of this workshop, together with some concluding remarks.

Chapter 9. Workshop and Recommendations for Future Work

At the inception of this work it was recognized that the topic of LCV adoption in Texas would generate widespread interest from TxDOT Divisions, truck operators, the logistics sector, state legislators, and the general public. Above all, it was important that the proposed work be subjected to close scrutiny by specialists prior to the second-year program of LCV impact measurement. The study benefited from a wide ranging technical advisory team comprising members from TxDOT right-of-way (ROW), general services (GSD), construction (CST), transportation planning and programming (TPP), and the bridge (BRG) divisions. The team met regularly with this advisory group during the first year and then prepared an agenda to be described to a wider audience at a workshop held near the end of the first year.

9.1 Workshop

The workshop agenda and list of invited attendees are given in Appendix E. It began with a reprise of U.S. long combination vehicle operations and regulations, followed by a discussion on the operational characteristics of various types of LCVs. This was led by Dr. Walton, who played a central role in several TRB initiatives into LCVs in the early 1990s and has kept up to date with developments since that time. Clearly, these characteristics vary substantially with the type of LCV being studied. The simplest type—a 97,000 lb tridem semi-trailer (not a true LCV)—has similar characteristics to the current 80,000 lb semi-trailer, while the road train would require an entirely new category of highway on which to operate safely. The safety issue—of paramount importance in LCV deliberations—was then provided by Dr. Kockelman who presented the preliminary findings of an analysis on heavy goods vehicle accidents using a technique to "tease out" the LCV vehicles from the general heavy truck group.

The results of the LCV truck survey—described in the previous chapter—were then presented by Jolanda Prozzi, followed by the environmental and energy benefits within the trucking sector from LCV adoption. The trucking sector participants were then invited to comment and comprised two large companies wishing to operate LCVs in Texas, one favoring additional weight and the second favoring higher volumes, both reflecting the "weigh out" and "cube out" categories of LCV operations. They provided important information on the benefits gained from LCVs and described their programs to maintain safe operations should they get permission to run the vehicles. One of the companies operated LCVs under the current "grandfather" regulations and was able to provide data on current and future operational benefits, together with confirmation of the low accident rates of their LCVs. The comments revealed a high level of professionalism linked to substantial "sunk" costs in testing LCV equipment at U.S. test facilities.

Dr. Weissmann of UTSA then gave the next two presentations on bridge and pavement impacts and described the two broad methods proposed for the measurement of these important categories of impacts. TxDOT is mindful of its stewardship of the large highway network, especially so at this time of financial constraint. Accurate measurement of these impacts is central to a change in policy allowing LCV operations in Texas. This measurement is central to the preservation for the system, the financing of any increase in preparation and subsequent maintenance of highways, and the marginal impacts (costs) imposed only by LCVs that would form the basis of additional fees (either fixed or on a per mile basis). The operators already know what the marginal benefits will be from LCV operations, and LCV adoption would be dependent on this being higher than the fees.

The study benefitted greatly from the expertise of two external academics, both of whom have a wide experience in LCV operations, particularly in Canada and Australia. The experts then commented on what they had heard and offered a range of constructive comments, particularly on LCV performance standards and safety analysis. The second-year program was then described as initially proposed by the team and modified by discussions with truck operators. Previous LCV studies had largely used a policy approach to evaluate a high level of LCV federal or state use. Using this approach, for example, study 0-6095 would evaluate three LCV types on the entire Texas state highway system. The team has chosen a different direction—to identify specific routes where operators would run LCVs in Texas. This cuts down the computational needs and reflects a trucking "fact," namely that truck VMT is concentrated on only a part of the 186,000 lane miles on the TxDOT system[33].

9.2 Future Work

It was agreed that the impacts of a 97,000 lb tridem semi-truck, a turnpike double, and a triple would be used as the Texas truck types for the bridge and pavement analyses. It was further agreed that they would be evaluated over up to four major routes used by truckers who have the freight volume that would justify the investment costs in up-grading or purchasing new equipment. There remains one serious problem to be addressed—namely that of interstate highway (IH) use. The current LCV freeze extends over the entire inter-state system yet almost every current route uses part of the IH to complete a trip, even if it only a few miles. A decision will be made on how to address this issue.

The operator survey made a contribution to current LCV research and a paper presented at the 2010 TRB Annual Meeting was favorably received. Comments from the audience included a recommendation that the survey be examined to cover more "grandfathered" states and different operators—for example, less than truckload (LTL) and owner-driver operators. This is again something to be considered as a second-year activity. Another important measure to be taken from existing LCV operators is safety information so that actual accident data derived from operators (or insurance companies) can be reported. Public reaction to LCV use, notwithstanding the social benefits of a potential reduction in truck numbers and an actual reduction in ton-mile emissions, will depend crucially on the ability to operate LCVs at a higher level of safety than current heavy trucks. A combination of state oversight, operator management, and technology are capable of providing this and it would be critical to provide this if, and when, new LCV regulations are proposed.

The team will work closely with the trucking sector to derive the gross and axle loads of each LCV type so that the pavement and bridge modeling reflects the desired industry levels. These values will change—sometimes significantly—depending on the types of operation. Refrigerated commodities (milk, frozen foods) may travel only one way, for example, from distribution center to points of consumption. If the LCV returns empty, then the pavement and bridge consumption is reduced, perhaps significantly. The position of those taking a neutral but rational position is clear—LCVs should be charged their full marginal cost, which in the case just described means a variable consumption charge for the trip. If an average charge is levied it is likely to be inefficient, sometimes higher and sometimes lower, on a per-mile basis.

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[33] Over 70% of the state truck miles of travel (VMT) operates over 21% of the TxDOT lane miles.

This brings up the long-standing issue of highway cost allocation and trucking. In rebuffing previous attempts to raise vehicle size and weight in the U.S., opponents (like the railroad companies) have claimed that trucks do not pay their “fair share” of highway construction and maintenance (while railroads do). Several state studies, including those conducted in Texas, have indicated that some cross-subsidization between vehicle classes is apparent. LCV operation could be timed with an entirely new method of assessing state truck use, namely vehicle ton-miles of travel. Pavement research and technology have now reached a point where this is possible and furthermore desirable, as it is both equitable and economically efficient. It is hoped that the results of the second-year program will therefore address elements of this issue.

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Appendix A: European Union Long Combination Vehicle Regulations and Operations

Directive 96/53/EC sets out the maximum allowable vehicle and loading dimensions in national and international road transport in the EU. However, while the Directive harmonizes across the EU the maximum dimensions of road vehicles and sets agreed levels for weights that would circulate freely throughout the EU, it also allows different national rules on the maximum dimensions. Member States may deviate from the maximum limitations in national transport in certain pre-authorized circumstances (De Ceuster, et al., 2008).

Also, various industrial sectors have argued for an easement in the weights and dimension restrictions to accommodate more efficient loading or to carry a heavier payload (De Ceuster, et al., 2008). Currently, several EU members have adopted legislation that allows for dimensions and weights exceeding the maxima set in Directive 96/53/EC. In some cases, this legislation is valid all around; in others, it concerns trials for specified periods and/or trajectories.

Background

According to European law, Member States are entitled to allow longer and heavier trucks (modular concept) to circulate in their country, provided that this does not affect international competition. Until recently, only Sweden and Finland made use of this possibility (UIC, 2008). The specific conditions (long distances, low population density) of the latter allowed the circulation of these trucks.

Public authorities are concerned about the forecasted growth in transport—a 50% growth by 2020 (UIC, 2008). Among the many ways to absorb this growth, increasing the currently allowed dimensions of road vehicles seems, at first glance, to be a possible solution. For this reason, some European countries with different geographic characteristics than Sweden and Finland are currently looking into this option.

Current Regulatory Framework

The regulatory framework in the UK and the EU is, in general, not designed with LCVs in mind. However, there are a variety of regulations that would have an effect on, or be affected by, any decision to allow such vehicles. These include (Knight, Newton, 2008):

- Member Country regulations that would need to be amended to permit LCVs in national transport
- European regulations limiting what can be permitted in the member states national transport
- Existing regulations that may impose constraints on LCV use, if they were to be permitted

European Union

The majority of European Union Member States imposes a 40–44 ton weight (88, 185 lb to 97,003 lb) restriction and maximum of 61.5 feet length for truck and trailer unit combined, as outlined by Directive 96/53/EEC. However, longer and heavier vehicles ("gigaliners") are permitted in Finland and Sweden, and are being tested in pilot projects in several other EU jurisdictions. Gigaliners have a length of 82.8 feet and maximum load weight of up to 60 tons (approximately 132,277 lb). However, it is important to note that several other countries that have evaluated these trucks, including Germany and the UK, have rejected their use.

In theory, it would be possible to include additional vehicle configurations under these regulations if they were amended to permit LCVs. Already, the Directive permits different weights for differing axle numbers and vehicle constructions; vehicles with "road friendly suspension" are permitted to have higher axle weights (Knight, Newton, 2008). Under current EU rules, trucks transporting goods between member states are limited to a maximum weight of 40 tons (ENDS Europe, 2009).

An Example

In the UK, the maximum weight of vehicles in national transport is prescribed by the Road Vehicles (Authorized Weight) Regulations 1998 as amended (Knight, Newton, 2008). It is these regulations that specify the current maximum permitted 44 tones on 6 axles equipped with a road-friendly suspension for articulated vehicles and rigid vehicles towing drawbar.

If consideration were given to permitting LCVs in excess of 44 tons, it is possible that this regulation could be amended to permit their general use, but any changes would need to conform with the requirements of the EC Directive 96/53/EC (Knight, Newf, 2008). Additionally, in June 2008, the British Department for Transport rejected the EU proposal to introduce longer and heavier trucks on British roads, following the publication of an independent report stating that the latter were not compatible with British roads (UIC, 2008).

Recent Developments

As of January 2009, the European Commission is unlikely to propose allowing Gigaliner trucks of up to 60 tons to operate between EU states before 2010 at the earliest (ENDS Europe, 2009). The latter decision was taken despite the publication of a consultancy report for the commission concluding that the move would deliver economic, environmental, and safety benefits (De Ceuster, et al., 2008). Given the commission's reluctance to revise the current legislation, one possible alternative is that neighboring member states could agree jointly to allow Gigaliners to operate between their territories, as is currently the case in Sweden and Finland (ENDS Europe, 2009).

Pilot Projects: The European Gigaliner

Some stakeholders are urging the European Commission to bring forward a proposal allowing general introduction of Gigaliners on the trans-European network roads. However, the latter has not yet announced an official position but will bring the matter forward for discussion in advance of the forthcoming Logistics Action Plan (No Mega Trucks, 2009). LCVs have been permitted in Finland and Sweden for some time. After joining the European Union, Finland and Sweden's LCVs were given special protection and are permitted to continue operating within their own borders. However, Gigaliners are not currently allowed to cross into other European countries (No Mega Trucks, 2009).

The Netherlands

For some years, the Netherlands have been carrying out a series of LCV operations trials and in November 2007, longer vehicles with a weight of 110,231 lb were allowed as part of an "experience phase." At that time, transport authorities rejected a maximum GVW of 110,231 lb, because of possible infrastructure wear and tear (No Mega Trucks, 2009). The Dutch transport sector reacted to the restriction and commissioned its own research that finally led to the authorization of 60 ton LCVs starting May 2008.

Germany

Longer and heavier vehicles are still being driven on German roads even though the transport minister decided in October 2007 that there would be no further trials of Gigaliners (No Mega Trucks, 2009). Germany's policy makers are divided on the issue of whether or not to permit LCVs.

Denmark

As of November 2008, 132,277 lb, 82 feet long LCVs are allowed on Danish roads. There is no official obligation to register a LCV but the road transport association DTL is expecting 1,000 participating companies (No Mega Trucks, 2009). Officially the trial is restricted to major highways and will be carried out over a three-year period (an "experience phase").

Belgium/Flanders Region

Shortly after taking up his new position as transport minister, Yves Leterme announced trials of longer and heavier vehicles in Flanders (No Mega Trucks, 2009). Interest groups are lobbying for LCVs to be permanently allowed in Flanders and to start a trial period in Wallonia.

Vehicle Configurations

Figure A1 illustrates the vehicle configurations currently allowed under EC Directive 96/53/EC. As was discussed, the 6-Axle Semi-trailer is a common vehicle configuration operating in the UK and on the European continent. Operating this vehicle in the U.S. would require an increase in the weight limit allowed on tridem axles. Different trailer length combinations can operate as Gigaliners; however, the length restriction for these vehicles is similar to that for a Rocky Mountain Double in the US. One additional fact about European trucks that should be noted in consideration of length restrictions is that most European tractors are cab-over-engine, meaning that the length of the cab itself will be shorter than a standard North American cab. As a result, more trailer length can be carried under the same length restriction.

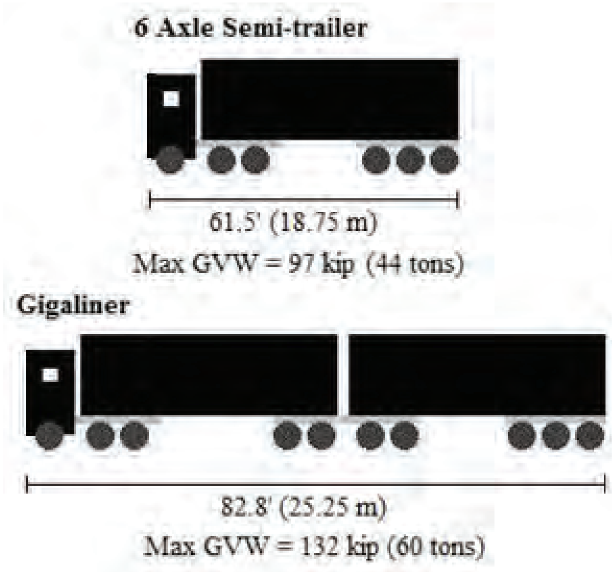


Figure A1: Vehicle configurations currently allowed under EC Directive 96/53/EC

Appendix B: Australian Long Combination Vehicle Regulations and Operations

The Australian continent comprises of 7.7 million square kilometers yet contains only 20 million inhabitants, giving it one of the lowest population densities in the developed world. Rail (freight, given low density and small markets has been limited to metropolitan passenger movements, regional intercity passenger routes and mining operations. The remainder of land-based freight flows moves by truck. Agricultural activities, dispersed throughout the “outback” or rural areas are dependent on trucking which uses a network of unpaved roads which generally have little or no vertical elevation.

The flat, unpaved roads enabled trucks to employ single drives, multi-trailer, multi-axle units which have are more commonly known as “road trains.” This appendix, based on a variety of Australian sources, describes vehicle types, the regulatory framework governing their operation, LCV history, and describes a selection of performance-based specifications used to develop these varities of LCV types seen in the country.

Australian Road Train

Road trains and the Australian outback are synonymous: there is a correlation of bigness and vastness, of imposingly large vehicles serving a region where neighboring homesteads can be hundreds of miles apart. Admired at times, detested by other road users, road trains have played a key role in opening up the nation’s more remote regions to that which the iron railroad did elsewhere in Australia and other countries (Maddock, 1988).

It was the reluctance of successive Australian governments to extend rail routes beyond termini established in the early part of the 20th century that led to the development of the trackless multi-unit vehicle that has become a unique part of Australia’s history (Maddock, 1988). The birthplace of the modern Australian road train operation was Alice Springs, and its genesis was an unfulfilled agreement and a successful experiment with an unusual vehicle in the 1930s. The agreement was that the federal government of the day, upon taking over the area at the time known as North Australia from the South Australian government, would complete the rail line that had been planned for many years between Adelaide and Darwin. That construction never came about.

The experimental truck was conceived in Britain by the Oversea Mechanical Transport Directing Committee to meet the problems of transport in undeveloped regions of the British Empire (Maddock, 1988). It involved a multi-wheeled road vehicle designed and built to run on rough bush roads, pulling a set of trailers.

In 1934, the Australian government imported one such vehicle and put it into service in the Northern Territory, operating out of Alice Springs and at time moving north to Katherine to serve the Victoria River region (Maddock, 1988). It alternated between these towns according to the seasons. The camel trains that had served the Territory since the days when the Afghans and other teamsters had supplied the needs of construction gangs in the Overland Telegraph Line in the 1870s thus faded (Maddock, 1988).

The “government road train” as it became known was a big advance in motor vehicle technology because trucks of the early 1930s were of elementary design and questionable reliability. Yet they and their owners battled on and coped with an unforgiving environment to carry supplies and mails to settlements. The road train had no competition; its task was to extend the supply routes beyond those served by other means (Maddock, 1988).

Road Development

As for infrastructure development, up till 1940 the Australia's road system could best be described as "rudimentary" (Maddock, 1988). Then the exigencies of war led to rapid upgrading of the rough tracks that connected Alice Springs with Darwin. In the following three or four decades, "beef roads," mining development roads, and general highway improvement programs gave the Northern Territory a network of routes which have been essential to the development and economy of Australia (Maddock, 1988). Although considerable construction and maintenance of roads was carried out in the 1950s and 1960s, it was not until 1971 that major construction of bridges and roads started in the Northern Territory and other isolated areas.

Road Trains Become an Industry

Before World War II, the preponderance of freight was handled by ship and the Australian Railway (Maddock, 1988). A few truck operators offered services over various sections or routes. From Alice Springs, where the railroad ended, road trains and other vehicles in the government fleet moved materials to remote stations and a few individual carriers took general consignments and perishables.

After World War II the pattern of freight movement underwent major change. Shipping services to Darwin were reduced and as a consequence there was a reversal of direction of freight flow from South Australia into the Northern Territory to Alice Springs (Maddock, 1988). The early road haulers were able to adapt quickly to this change in demand and were able to cover that sector quicker than the train. Commonwealth Railways (Comrails) was displeased with this rival freight development and went as far as proposing legislative changes to inhibit competition by hauliers (Maddock, 1988).

Comrails' dissatisfaction with the situation was shared by many of the users of road freight services for different reasons. However, Comrails was the only competitor that proposed to coordinate road and rail services, bridging the railless gaps in the Territory—but the implementation proved to be almost impossible (Maddock, 1988). Hauliers were individuals, unorganized, some of them competitive pioneers in their own right ("battlers"); organizing them proved to be a difficult task.

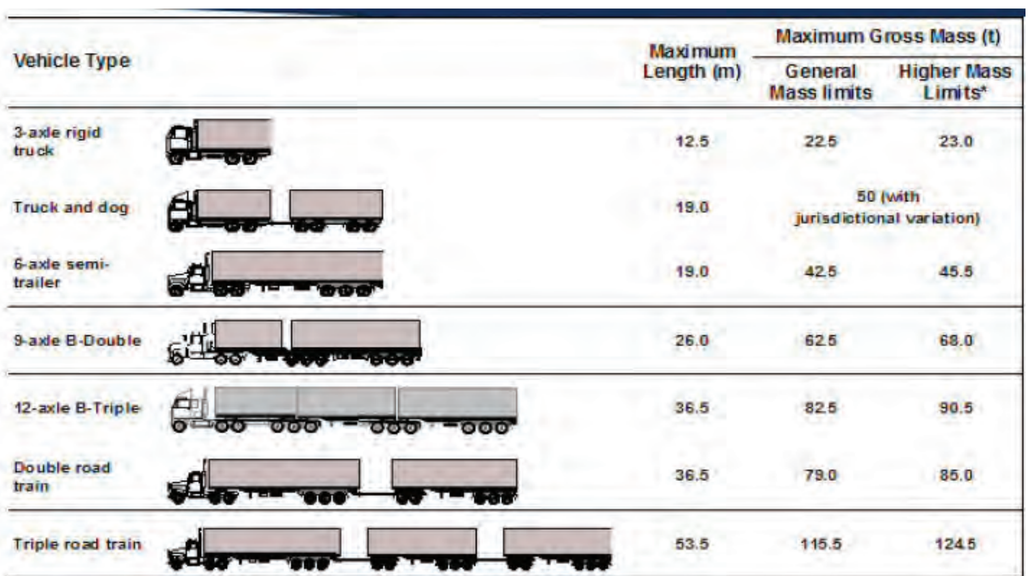
Finally, after being postponed several times during a three-year period, a contract signed between Comrails and the newly created TTA (Territory Transport Association) and the service was implemented *de facto*. Between 1955 and 1970 this coordinated service reached its peak. At the same time, cattle transport became extremely important for the development of road trains ("beef roads") (Maddock, 1988). The first program of beef road construction was commenced in Queensland in 1961 and soon after in Western Australia, South Australia. and the Northern Territory.

Cooperative business activities between government and private enterprise are rare but even rarer are those between railways and road transport operators (Maddock, 1988). However, in the Northern Territory interaction between rail and road not only resulted in the adoption of the road train as the basis of the Territory's transport system.

Current Regulatory Framework

Although constitutionally the Federation has powers over the states/territories, and the National Transportation Council (NTC) also has constitutional power over road and road transportation over state/territory's governments, national regulations and standards have been difficult to implement. Therefore, currently, there are few harmonized parameters to regulate the road train industry (Moore, 2007).

Established in 2004, NTC has led regulatory and operational reforms for road, rail, and intermodal transport by making recommendations to the Australian Transport Council and helping to implement the measures in Australian states/territories. However, this last step has been problematic (Moore, 2007). Also, there have been difficulties in national decision-making mechanisms on operational issues (including performance based standards). Variant jurisdictional regulations have created a barrier of entry. A general regulatory overview is presented in Figure B1 and Table B1.



Vehicle Type	Maximum Length (m)	Maximum Gross Mass (t)	
		General Mass limits	Higher Mass Limits*
3-axle rigid truck	12.5	22.5	23.0
Truck and dog	19.0	50 (with jurisdictional variation)	
6-axle semi-trailer	19.0	42.5	45.5
9-axle B-Double	26.0	62.5	68.0
12-axle B-Triple	36.5	82.5	90.5
Double road train	36.5	79.0	85.0
Triple road train	53.5	115.5	124.5

Source: Moore, 2007

Figure B1: Allowable truck sizes

Table B1: Equivalencies Length (Approximate)

Meters	12.5	19	26	36.5	53.5
Feet	41	62	85	120	175.5

Performance Based Standards (PBS)

Adoption of PBS in Australia

The Australian road transport industry has undergone significant changes over the last 30 years. There have been three reviews and increases in the mass carrying limits of trucks (Raptour, 2006). An Economic Review of Vehicle Limits (ERVL) was performed in the 1970s. In the mid 1980s, the Review of Road Vehicle Limits (RoRVL) was undertaken. In the mid-to late 1990s, the Mass Limits Review, which utilized the introduction of "road friendly" suspension systems to allow higher mass to be carried, was implemented in most regions (Raptour, 2006).

Mass limit increases were, however, just one means of delivering productivity gains. In the mid 1980s the adoption of a variation of the Canadian B-train (the B-Double) was introduced into Australia (Raptour, 2006). This vehicle, although longer, could achieve payloads some 30% to 40% higher than the more conventional tractor-trailer combinations.

In 1999, the Australian National Road Transport Commission (NRTC, now NTC) extended the Canadian and New Zealand frameworks for the development of Performance Based Standards (PBS) for flexible truck design (Raptour, 2006). These frameworks, in brief, suggested that as long as a vehicle performed against some 16 specific technical performance criteria then prescriptive regulations need not apply to the weights and dimensions of a specific vehicle. In effect the operator could design their own truck (Raptour, 2006). Whilst the OECD (2005) also formed an international working party for this project in 2002, and reported in late 2005, several major new truck designs were being implemented in Australia under permit.

Studies Conducted

PBS have the ability to change from a prescriptive framework and to still put an "equivalently performing" vehicle on the road (OECD, 2005). These PBS-approved vehicles can deliver both significant safety and huge productivity benefits to the operator.

The NTC has established a framework of approvals, testing, and accreditation for the approval of such vehicles seeking operational approvals under the PBS process (Raptour, 2006). PBS approvals process is different from the state-approved permit system, by the fact that it is a national process and not restricted to a particular region or jurisdiction. This does not, however, mean that the vehicle can operate anywhere: the approvals will be very specific on the road classes and regions for future operations (Raptour, 2006).

The current incremental approach or "creep" is also a significant concern for the transport industry and the public, as are the limitations to innovation and productivity of an overly prescriptive approach to regulation (Prem, 1999). AUSTROADS and NTC jointly commenced a research program to develop and to adopt a PBS approach to the regulation of heavy vehicles in Australia. In defining this research program, the following key objectives and benefits were analyzed (Prem, 1999):

- Increased productivity and innovation in vehicle design and operation;
- Improvements in road safety, traffic operations and asset management (infrastructure)
- A national basis for the regulation of heavy vehicles
- Consistency in the application of assessment techniques that are performance based
- Better matching of the capabilities of vehicles and the road system
- Consistency in permitting local and specific-use vehicles.

Performance Based Standards (PBS) Criteria

Examples of key PBS compliance measures that road trains and freight transport need to comply with are outlined in Figure B3. For a complete list of all measures, see: http://www.ntc.gov.au/filemedia/Reports/PBSSchemeStandsVehAssRule24Nov08.pdf

Proposed PBS Vehicle Performance Criteria

1. Startability
2. Gradability
3. Acceleration
4. Overtaking
5. Tracking ability
6. Low speed off tracking
7. Frontal Swing
8. Tail swing
9. Steer tyre friction
10. Static Rollover
11. Rearward amplification
12. Yaw Damping
13. High Speed Transient Off tracking
14. Standard axle repetition
15. Horizontal Tyre forces
16. Bridge weight limits
17. *** Australian Design Rules, and*
18. *** Australian Vehicle standards.*

Source: NRTC 1993. This list is still not totally agreed as yet by all the jurisdictions.
*Note **These criteria are being refined.*

Source: Raptour, 2006

Figure B2: Proposed PBS Vehicle Performance Criteria

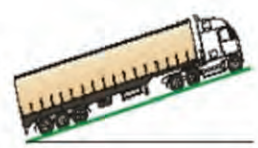
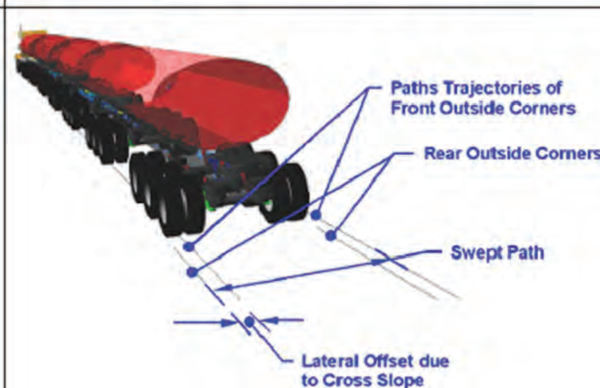
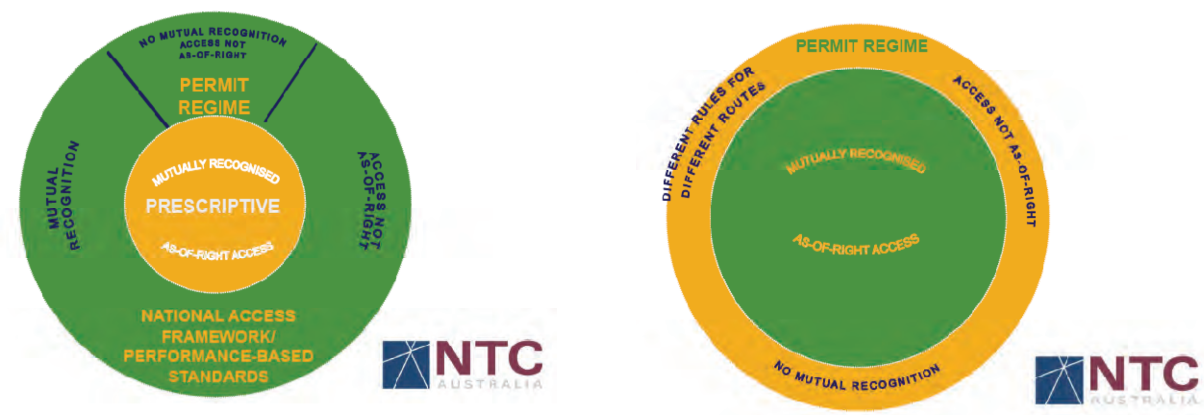
Startability	Ability to commence forward motion on specified grade	
Gradeability	Ability to maintain forward motion on specified grade; and achieve a minimum speed on 1% grade	
Acceleration capability	Ability to accelerate either from rest or to increase speed on a road	
Tracking ability on a straight path	The total swept width while travelling on a straight path	

Figure B3: Primary PBS considerations
Source: NTC, 2008

Regulatory Goals

The most recent PBS standards and vehicle assessment rules were published in a manual in October 2008 (NTC, 2008). The current regulatory regime for road freight in Australia is based in prescriptive regulations (height, width, length, mass, etc.), permits, and PBS. The merger of three types of regulatory tools creates a *sui generis* panorama for commercial vehicles regulation. The following graphics in Figure B4 reflect the current regulatory mélange and a forecast for 2025 of what the NTC intends to achieve. A national framework is seen as an important part of the commercial vehicle's regulation for the future.



Source: Moore, 2007

Figure B4: NTC regulations

Vehicle Configurations

As discussed above, the potential combinations of combination and road train vehicles operating in Australia under performance-based regulation are vast. The vehicles shown in Figure B5 are those currently permitted to operate in the state of Queensland. As in Canada, vehicles with different connection types are classified separately. The maximum length of the B-Triple and Prime Mover towing two trailers connected by drawbar is approximately equivalent to that of the Queen City Triple, the longest vehicle currently allowed to operate in North America. The maximum lengths of the other road trains far exceed that of vehicles currently operating in other nations.

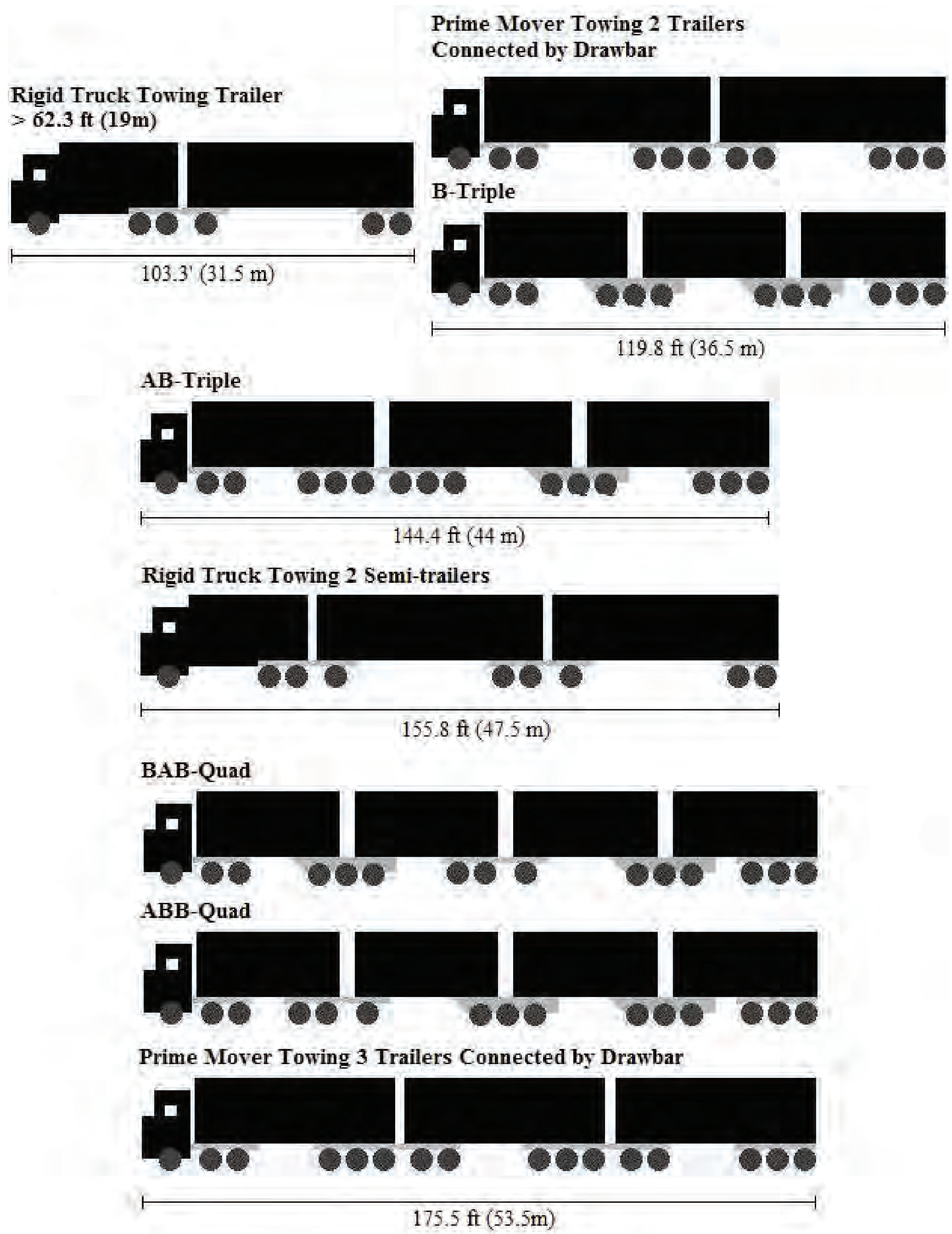


Figure B5: Vehicles currently permitted to operate in the Queensland

Appendix C: NAFTA Harmonization

The North American Free Trade Agreement (NAFTA) required that a three-year trilateral review of truck size and weight be undertaken in an effort to promote greater truck harmonization among the three countries. Although the size and weight issues addressed by NAFTA were not entirely related to LCVs, NAFTA did reopen the truck size and weight debate (Maze, 1994). Truck size and weight regulations are a significant issue because more than two-thirds of all merchandise traded among the three economies is moved by heavy trucks. Hence, the three countries benefit economically from efficient and reliable commercial trucking operations (Mercier, 2007) and problems translate into additional direct and indirect trade transaction costs. As noted in chapter one of this report, the three NAFTA partners have widely different truck size and weight rules which together prevent the most efficient vehicle type – the LCV – from being the representative NAFTA truck design. This appendix documents the Canadian and Mexican LCV regulations and operations, before highlighting some of the issues concerning harmonization among the NAFTA countries.

Canadian Long Combination Vehicle Regulations and Operations

Regulatory Framework

In terms of the Constitution, the 10 Canadian provinces and 2 territories are responsible for and have authority over the highway system within their jurisdiction. The exception is federally owned roads in national parks, national defense installations, and northern resource roads. Currently, the provinces and territories thus have direct responsibility for 34% of the network; responsibility for 64% of the network has been assigned to the municipal governments, and 2% of the highway system is under federal jurisdiction (NAFTA Land Transportation Standards Subcommittee, 1997).

Because the provinces and territories are responsible for the majority of the highway system in Canada, they enacted the first legislation regulating the trucking industry (Mercier, 2007). In 1954, the federal government formally delegated authority over extra-provincial trucking operations to the provinces. This resulted in 12 different jurisdictions, leading to regulatory inconsistencies, particularly in the regulation of truck size and weight (Mercier, 2007). In 1985, the provinces and territories formed the "Council of Ministers Responsible for Transportation and Highway Safety" (Council of Ministers). The Task Force on Vehicle Weights and Dimensions Policy was created specifically to harmonize regulations concerning truck size and weight across the country (Mercier, 2007). In 1988, the Task Force entered into a Memorandum of Understanding (MOU), which was endorsed by the Council of Ministers, that established the first national truck size and weight standards in Canada (Mercier, 2007). Under the MOU, all provinces thus agreed to allow vehicles which comply with a set of national weight and dimension standards to travel on the designated provincial highway system (NAFTA Land Transportation Standards Subcommittee, 1997).

Although the 10 provinces and 2 territories have retained authority for establishing weight and dimension limits on all roads within their jurisdiction, the MOU achieved uniformity by establishing a set of minimum vehicle weight and dimension standards that each province and territory would permit on designated highways within their jurisdiction. Unfortunately, inconsistencies remain because only minimum truck size and weight standards were set, which has allowed the provinces and territories to set varying maximum limits[34] (Mercier, 2007).

Furthermore, it is the responsibility of each province and territory to identify its respective designated highway system to which these standards will apply. Highway improvements and bridge rehabilitation programs have thus resulted in changes to the designated highway systems of some provinces (NAFTA Land Transportation Committee, 1997). Table C1 provides the designated roads by province/territory accessible to vehicle configurations that comply with the national MOU.

Table C1: Provincial/Territorial Highways Accessible to MOU Compliant Vehicle Configurations

	MOU Dimensions			MOU Weights		
Jurisdiction	*All Roads*	*All Main Routes*	*Restricted Network*	*All Roads*	*All Main Routes*	*Restricted Network*
British Columbia	X			X		
Alberta	X				X	
Saskatchewan	X					X
Manitoba	X					X
Ontario	X			X		
Quebec		X			X	
New Brunswick	X					X
Nova Scotia		X			X	
Prince Edward Island		X			X	
Newfoundland	X			X		
Yukon	X			X		
Northwest Territories	X			X		

Source: NAFTA Land Transportation Committee, 1997

LCVs are not covered in the MOU. In Canada, LCVs are usually defined as tractor/trailer combinations with two or three semi-trailers/trailers exceeding the normal vehicle length of 82 feet. Each province has its own regulations concerning LCV operations. LCVs currently operate in British Columbia, Alberta, Saskatchewan, Manitoba, and Quebec and have for many years been allowed in the Northwest Territories under special permits (Schulman, 2003). LCV equipment and drivers operate under special provisions, specifically safety requirements and other restrictions, including authorization to drive only on certain routes, at certain times or seasons, and within certain speed limits (Schulman, 2003).

Vehicle Configurations

The following are typical LCV configurations operating in Canada (Schulman, 2003), illustrated in Figure C1.

[34] In some cases, the MOU limits are lower than the provincial standards. In these cases, the provinces have generally retained the higher regulatory limits. The provincial and territorial governments also have authority for issuing special operating permits for oversize and/or overweight loads (trucks that exceed the normal size or load limits), movement of selected commodities, or other permit provisions that depart from normally regulated limits (NAFTA Land Transportation Standards Subcommittee, 1997).

- Rocky Mountain Double—The Rocky Mountain Double typically comprises a tractor, a 40 to 53 foot semi-trailer, and a 24 to 28 foot semi-trailer. These vehicles are typically used for cargo that "weight out" as opposed to "cube out."
- Turnpike Double—The Turnpike Double typically comprise a tractor and two semi-trailers. Each semi-trailer is typically 40 to 53 feet long. These vehicles are typically used for cargo that "cube out."
- Triple Trailer—The Triple Trailer typically comprises a tractor plus three semi-trailers of 24 to 28 feet. These vehicles are also typically used for cargo that "cube out."

In addition, B Train Doubles, which connect trailers using a B type connection, are commonly used and allowed to operate with generally higher weight limits than Doubles using A and C type connections. The Queen City Triple, a semi-trailer equipped with one 48 ft trailer and two 28 ft trailers, is allowed to operate only on a very limited network in Saskatchewan.

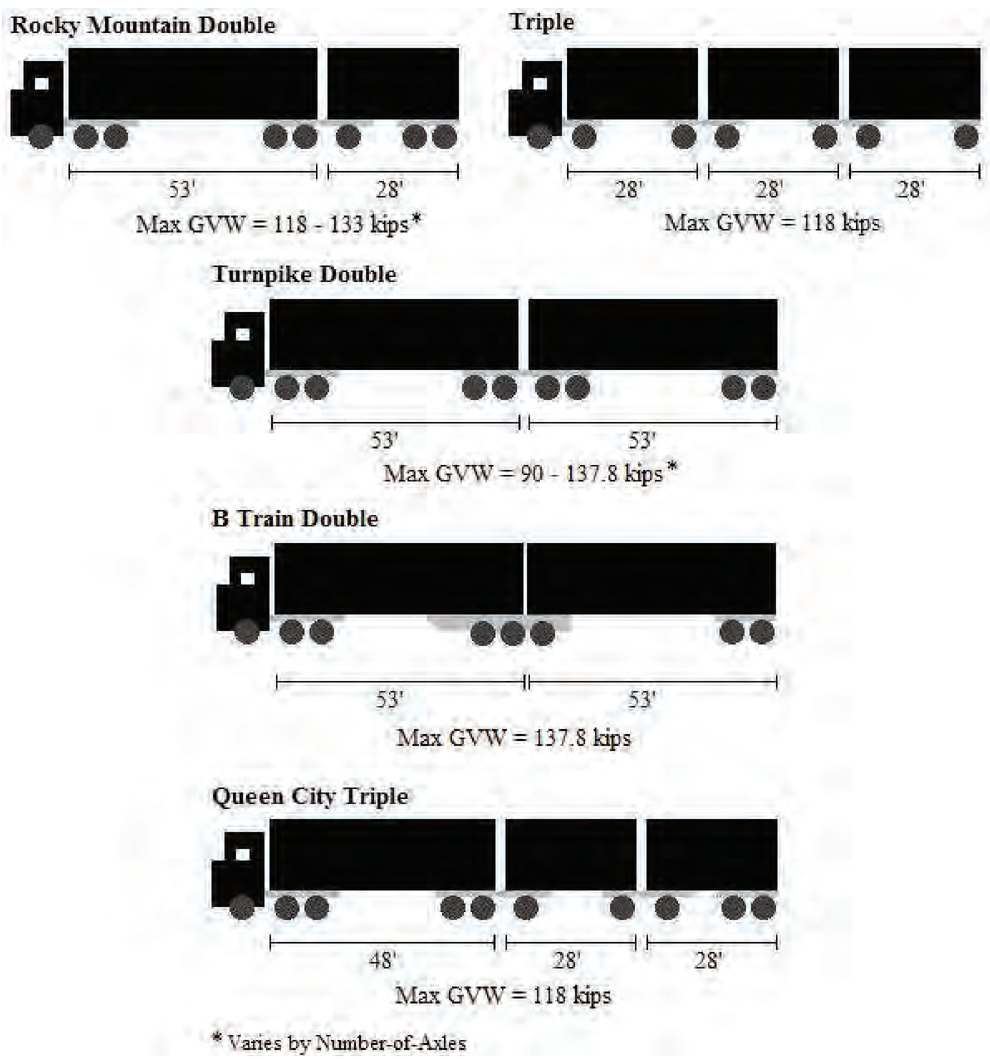


Figure C1: Typical Canadian LCV Configurations

Canadian LCV Operations

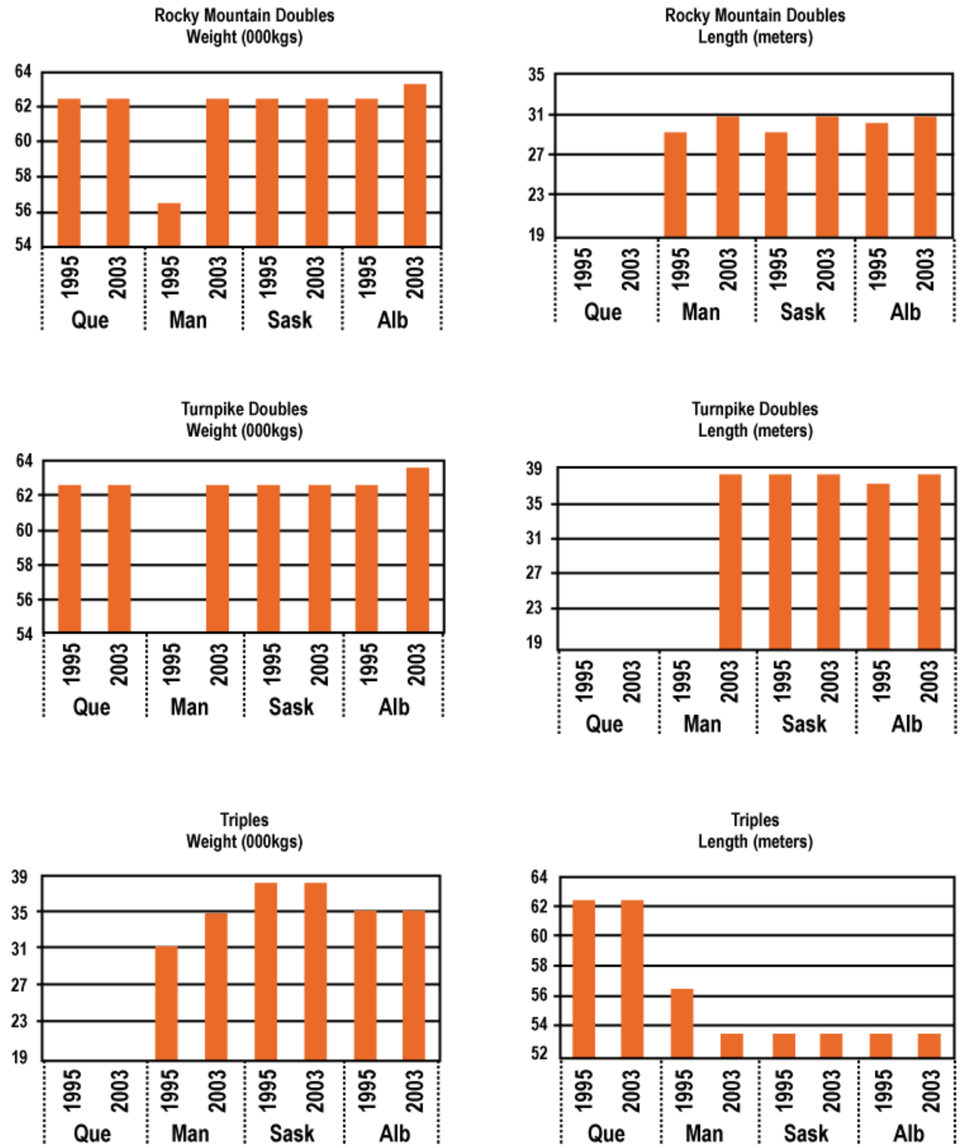
LCVs have operated in Canada for many years under special permit. For example, Triple Trailers have been operating in Alberta since 1969 (Schulman, 2003) and in Quebec, current regulations permitting double 48 foot semi-trailers date back to 1986. Table C2 illustrates the LCV configurations that are allowed to operate in Canada currently by province/territory.

Table C2: LCV Configurations Permitted in Canadian Provinces/Territory

	RMD	TPD	TRPL
British Columbia	✓		
Alberta	✓	✓	✓
Northwest Territories	✓		
Saskatchewan	✓	✓	✓
Manitoba	✓	✓	✓
Quebec		✓	

Source: LP Tardiff & Associates, 2006

Although LCVs have been operated in Canada for many years, changes to the length and weight limits, and permitted use of LCVs have occurred since the mid-1990s. Figure C2 illustrates the changes in LCV weight and length limits in selected Canadian provinces since the mid-1990s. As can be seen from Figure C2, Alberta allows the highest weight limit for Doubles (i.e., Rocky Mountain Doubles and Turnpike Doubles) at 63,500 kg (140,000 lbs), while in Quebec, Manitoba, and Saskatchewan the maximum weight limit for Doubles is 62,500 kg or 138,000 lbs (Schulman, 2003). From Figure C2 it is also evident that the maximum weight limits of the Rocky Mountain Doubles have increased between 1995 and 2003 in both Manitoba and Alberta, while the maximum length limits have increased in the three western provinces (i.e., Manitoba, Alberta, and Saskatchewan). In Quebec vehicle length limits do not exist for Rocky Mountain Doubles and Turnpike Doubles, because the province regulates box length and not the overall length of the vehicle. Manitoba did not allow Turnpike Doubles in 1995, but did in 2003. Also, the allowable weight and length limits for the Turnpike Doubles was increased in only Alberta between 1995 and 2003. Finally, the maximum weight limit for Trailers was reduced in Manitoba, but the length limit was increased between 1995 and 2003.



Source: Schulman, 2003

Figure C2: Evolution of LCV Dimensions in Selected Canadian Provinces

Mexican Long Combination Vehicle Regulations and Operations

Regulatory Framework

In Mexico, the federal government has the authority for setting truck size, weight, and dimension limits that apply to an extensive system of federal highways. The federal government is also responsible for issuing special permits for oversize and/or overweight loads or the movement of loads that deviate from the regulated limits (NAFTA Land Transportation Committee, 1997). The 31 state governments have the authority for establishing truck size and weight limits on roads under their jurisdiction, but no state has exercised this authority to date (NAFTA Land Transportation Committee, 1997).

The current *"Weight, Capacity and Dimension for Motor Transportation Vehicles Circulating on Federal Jurisdiction Roads and Bridges"* Regulation (the *"Weight and Dimension Regulation"*) provides a general and basic framework for LCV operations in Mexico. The Regulation was enacted in January 1994 and stipulates that the Mexican Official Norm (NOM) NOM-012-SCT-1995 would regulate specific vehicle combinations, weight, dimensions, and the operational requirements for commercial trucks. In October 2000, the Weight and Dimension Regulation was modified and in 2002 the Secretaria de Communicaciones y Transportes (SCT) started to adapt the corresponding NOM. Although SCT had until 2006 to modify the new NOM, SCT presented in 2004 a new version of the NOM to the Regulatory Improvement Commission. The Commission, however, required SCT to conduct further research (TTI, 2006). The most controversial modifications compared to the earlier regulations were:

- a decrease in the Gross Vehicle Weight (GVW) of *doble semi remolque* combinations (i.e., double trailer vehicle or known as *"fulls"*) from 81.5 to 66.5 tons. These vehicles represent only 5% of commercial trucks in Mexico (SCT, 2008) and
- the prevention of *doble semi remolque* combinations from using Type C (i.e., secondary) roads unless the vehicle has a special permit for a specific route. The Texas Transportation Institute (2006) recommended that the maximum GVW on these roads should be 58 tons.

A study commissioned by SCT and conducted by TTI (2006) to evaluate and comment on the benefits of the proposed changes, as well as estimating the reduced infrastructure consumption resulting from the GVW decrease, drew extensive criticism from at least a dozen trucking and industrial associations. After extensive discussions, SCT finally reached an agreement with the private industry in April 2008 and the new NOM-012-SCT-2-2008 was enacted.

Mexico's new NOM includes 25 commercial vehicle configurations of which 12 can be considered LCVs (or *doble semi remolque*). LCVs may have 6, 7, 8, or 9 axles. The new NOM presents a number of changes to LCV movements, and operations, and includes extensive restrictions on the operation of 9 axle LCVs, commonly known as "*fulls"* or T3-S2-R4. The most relevant changes to LCV regulations are (SCT, 2008):

- A reduction in the GVW. The maximum GVW for *fulls* were reduced to 66 tons—i.e., approximately 135,000 lbs as opposed to the earlier 81.5 tons or 180,000 lbs. TTI (2006) concluded that the majority of Mexican bridges could not accommodate a heavier weight than 66 tons. However, SCT estimates that the median GVW for LCV operations in Mexico would probably be 71 tons, because SCT can permit *fulls* to operate at a maximum GVW of 80 tons if these vehicles comply with additional performance, mechanical, and operational requirements.
- The abolishment of the *"150 km rule."* Under the previous NOM LCVs were allowed to use secondary roads for up to 150 km (i.e., approximately 92 miles). This previous rule was practically unenforceable because it was very difficult for police officers to prove that the truck have been operating on the secondary road for more than 150 km unless it followed the truck (SCT, 2008). Under the new NOM,

SCT will issue a permit for secondary road use because considerable pavement damage was imposed by excessive LCV operation on secondary roads.

- New productivity, safety, and environmental requirements. The new NOM requires new vehicle specifications, including mechanical and emissions checks, electrical motor requirements, minimum axle requirements, and additional certification of drivers. Some of these requirements have a three year grace period to facilitate compliance.

To ensure the enforcement of the new NOM, SCT is planning to invest in new weight and dimension centers (i.e., 51 additional centers) and any permit issued to allow a vehicle to operate with additional weight will require a U.S. $100,000 bond.

Vehicle Configurations

The two Mexican LCV configurations most relevant to the discussion of LCV harmonization in the NAFTA region (as will be discussed in the next section) are the T3-S3 and the T3-S2-R4, shown in Figure C3. The T3-S3 is the Mexican 6-Axle semi-trailer, which operates at a maximum weight of approximately 105,800 lbs. This vehicle is extremely heavy for its length. The T3-S2-R4 is the approximate equivalent to a Turnpike Double operating in Mexico, although the trailer length will be shorter than 48 ft because the overall length limit is only 102 ft. Again, the weight-to-length ratio for this vehicle operating on the highest class of Mexican highways is much higher than that of vehicles operating in the U.S. and in Canada.

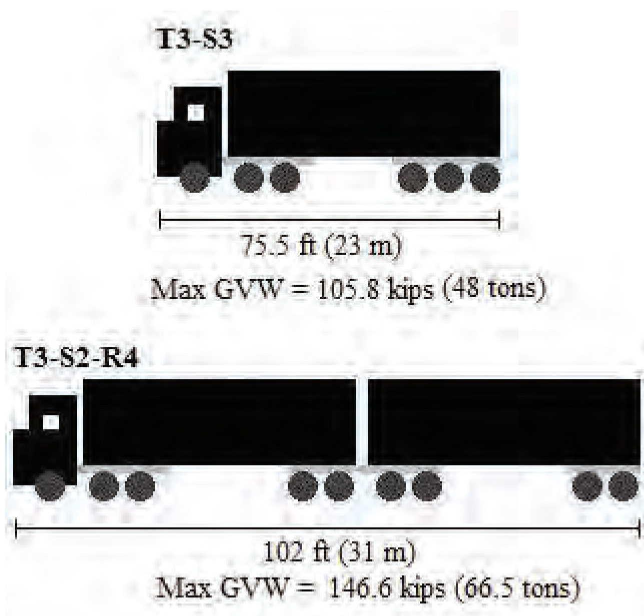


Figure C3: Typical Mexican LCV Configurations

Harmonization in the NAFTA Region

NAFTA called for the unimpeded movement of trucks across the borders of the treaty partners and for the harmonization of truck standards (Luskin & Walton, 2001). Specifically, Part 3 and Annex 913.5A1 of the NAFTA agreement called for truck size and weight regulation uniformity to be achieved in a mere three-year time frame, thereby signaling the urgency that was to be accorded to removing the perceived trade barrier (Mercier, 2007). Although the agreement was ratified in January 1994, implementation of the NAFTA provisions had been slow and the harmonization of truck standards has yet to be negotiated.

State and federal governments continue to be responsible for setting size and weight limits on vehicles operating on roads in their jurisdiction. The U.S. operates under a prescriptive system of fixed size and weight regardless of vehicle performance, specifying a maximum 80,000 lbs GVW limit for all configurations that operate on the federal highway system. Canada and Mexico use a performance-based system, thereby considering vehicle specifications in setting weight limits. The effect is that in Canada and Mexico, tractor-semi-trailer and tractor-double-trailer combinations commonly operate at much higher weights than permitted by the U.S. federal system (Mercier, 2007). Table C3 illustrates prevailing weight restrictions in the three NAFTA member countries for the most popular truck configurations, as well as the maximum weight limits permitted in U.S. states that are subject to STAA grandfather clauses.

Table C3: Weight Limits Imposed by NAFTA Member Countries

Truck Type	U.S. Federal	U.S. State Maximum	Canada Provincial Minimum	Canada Provincial Maximum	Mexico
Tractor Semitrailer[35] (5 axles)	80,000	86,498	86,900	91,300	96,800
Tractor Semitrailer (6 axles)	80,000	99,792	102,300	116,600	105,800
A Train Double (5 axle)	80,000	94,802	83,600	95,700	104,500
A Train Double (6 axles)	80,000	105,780	104,720	105,600	123,200

Source: Mercier (2007) and NAFTA Land Transportation Committee (1997)

In Mexico and most Canadian provinces, LCV use is permitted and has increased over the past decade. By contrast, LCV use has been frozen in the U.S. since 1991. Furthermore, most Canadian provinces that currently do not permit LCV operations do permit operation of tractor semitrailer and double trailer (A Train Doubles) configurations at heavier weights than the U.S. (Mercier, 2007). Some of these provinces are also currently conducting pilot LCV programs and it is anticipated some will permit LCV operations in their jurisdictions in the near future.

LCVs thus currently comprise only a small percentage of cross-border trucking operations on the continent (Mercier, 2007). For example, there is significant use of LCVs at the Alberta-Montana border crossings (Ang-Olson, Cowart, 2001). On the other hand, the use of LCVs in the Winnipeg-Fargo corridor is much more limited. North Dakota allows trucks up to 47,854 kg (105,500 lbs) on Interstates with a permit, and also allows Rocky Mountain Doubles

[35] Currently, the most popular configuration for the movement of international freight is the 5 axle tractor-semi-trailer (commonly known as the 18 wheeler) loaded to U.S. federal limits, as this unit is permitted in all NAFTA jurisdictions (Mercier, 2007).

and Turnpike Doubles (Ang-Olson, Cowart, 2001). However, many of the states south and east of North Dakota do not allow LCVs, which tends to limit their use in the corridor[36].

Table C4 presents the authorities that would need to effect changes in truck size and weight regulation to achieve harmonization in the NAFTA region.

Table C4: Authorities Involved in Truck Size and Weight Regulations

Authority	*Size and Weight Limits*	*Route Restrictions*	*Special Permits*
Federal Government:			
Canada			
United States	X	X	
Mexico	X	X	X
State/Province Government:			
Canada	X	X	X
United States	X	X	X
Mexico	X	X	X
Private Road Authorities:			
Canada			
United States	X	X	X
Mexico			

Source: NAFTA Land Transportation Committee, 1997

The large number of authorities involved in truck size and weight regulations complicates any harmonization prospective for the region. Size and weight harmonization requires agreement by the state and provincial governments in the three countries, as well as federal authorization in Mexico and the U.S. The same scenario applies to route restriction regulation. In the case of special permits, only Mexico restricts this authority to the federal level. In addition to the jurisdictional complexity, there also seems to be a lack of political will to implement harmonization, partly fueled by the long dispute between the U.S. and Mexico to implement the NAFTA provisions pertaining to cross-border trucking (Mercier, 2007). There are also some issues relating to the NAFTA text used. For example, the terms *"national treatment"* and *"most favorite nation treatment"* require that the parties apply the same truck size and weight standards to the two other member countries' trucking fleets as it does to its own domestic trucking fleet.

According to Mercier (2007), there are primarily two schools of thought on how to achieve harmonization of truck size and weight regulations. The first is to move to the lowest common denominator, which is the U.S. federal standards—a view promoted by railroads and safety coalitions. The second is to increase the U.S. federal limits to allow heavier and longer trucks—a view promoted by trucking interests. The different and often opposing views held by stakeholders, including the railroad lobby and safety advocacy groups, or even engineering assumptions related to LCV impacts on pavements and bridges, thus further complicate harmonization.

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[36] Analysis of commodity flow data suggests that only 10% of trucks crossing at Emerson/Pembina border crossing have a U.S. trip end in North Dakota, while a much larger share (45%) of the trucks traveling in this corridor are moving between Manitoba and the states of Minnesota, Iowa, Illinois, Wisconsin and Missouri, which generally do not allow LCVs (Ang-Olson, Cowart, 2001).

Concluding Remarks

NAFTA has been successful in facilitating trade growth among its three members. Although harmonization efforts to standardize truck size and weight limits in the NAFTA region have failed thus far, NAFTA did initiate examination of new transport planning policies. Although it is claimed that harmonizing commercial truck sizes, weights, operating practices, and enforcement would result in more efficient freight movements in the NAFTA region (Montufar, 2007), at the present time this is not seen as a major focus of trilateral member negotiations.

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Weight, Capacity and Dimension for Motor Transportation Vehicles Circulating on Federal Jurisdiction Roads and Bridges Regulation (*Reglamento sobre el peso, dimensiones y capacidad de los vehículos de autransporte que transitan en los caminos y puentes de jurisdicción federal*)

Appendix D: Project Database for Pavement and Bridge Analyses

This appendix documents the data mining process performed for this project, and the subsequent data organization in a statewide geo-referenced database developed specifically for this project. Geo-referenced database approaches create a spatial dimension to the data that adds significant visualization capabilities, expedites the data retrieval process and increases the reliability of the massive modeling anticipated for this project.

Framework and Contents

The research staff responsible for analyzing pavement and bridge impacts collected pavement and bridge data available for the TxDOT road network, and organized all the available information in a GIS platform (ArcMap) in order to streamline the future analysis for specific LCV routes.

Currently, the geo-referenced database contains data from the following statewide data sources, briefly discussed in this section:

- NBI: FHWA's National Bridge Inventory System (FHWA, 2009)
- BRINSAP: TxDOT's Bridge Inventory, Inspection and Appraisal Program (FHWA, 2009)
- PMIS: TxDOT's Pavement Management Information System (TxDOT, 2009)
- LTPP: FHWA's Long-Term Pavement Performance (FHWA, 2009)
- RHiNo: TxDOT's Roadway Highway Inventory Network (Weissmann, 2009)

NBI Database

The NBI covers approximately 600,000 of the nation's bridges located on public roads, including Interstate Highways, U.S. highways, state and county roads, as well as publicly accessible bridges on federal lands. It presents a state-by-state summary analysis of the number, location, and general condition of highway bridges within each State. Information includes, but is not restricted to, materials report on new bridge construction and rehabilitation; wearing surface; year built; mobility performance measures; area; length; deficiency measurements; material type of structure; and unit cost (FHWA, 2009).

BRINSAP Database

At the national level, the FHWA maintains the National Bridge Inventory database to track the conditions of the nation's bridges. In Texas, the BRINSAP database is equivalent to the NBI.

The BRINSAP database contains 135 fields for each bridge record and provides a comprehensive account of the physical and functional characteristics of each bridge and bridge class culvert in the state. The database consists of two major categories of structures: on-system and off-system. In general, the on-system structures are those that belong to and are the responsibility of the state highway department or some other state or federal agency to maintain. The off-system structures generally belong to local municipalities. Roughly 98% of the structures in the state are maintained by the same agency that owns the structure (Weissmann, et al., 1999).

PMIS Database

TxDOT's Pavement Management Information System (PMIS) is an automated system for storing, retrieving, analyzing, and reporting information to help with pavement-related decision-making processes. PMIS began in fiscal year 1993, and includes Pavement Evaluation System (PES) data collected from fiscal years 1985–1992 (TxDOT, 2009).

PMIS contains pavement evaluation data on all major pavement types used in Texas, including asphalt surfaced pavement, continuously reinforced concrete pavement, and jointed concrete pavement. These data include distress data (surface defects), riding quality data (pavement roughness), deflection data, and skid resistance data (surface friction measured with the TxDOT Skid Truck).

LTPP Database

LTPP collects information on pavement performance and the elements that may influence pavement performance. Pavement types include both asphalt and portland cement concrete pavements, with and without various types of overlays and surface treatments. The performance information includes pavement roughness measures, the type and quantity of pavement distress, deflection testing, and skid information. The elements that are considered to have an effect on performance include material characteristics; climatic conditions; pavement loading (traffic); and maintenance and construction activities, including routine maintenance conducted at a site and information on both original construction and rehabilitation activities. Data are generally presented using customary terms and statistics, such as International Roughness Index (IRI), pavement thickness, annual and monthly precipitation totals, and equivalent single-axle loads (ESALs) (FHWA, 2009).

RHiNo Database

The RHiNo database is updated annually by the TxDOT Transportation Planning and Programming (TP&P) division. RHiNo contains the statewide road network information, geospatial information, and an extensive block of data that is linked to each road segment. There are over 135 data records that includes lane design, AADT, shoulder geometry, functional data, and many others (Weissmann, 2009).

Bridge Data

Chapter 4 recommended a methodology consisting of the following steps:

1. Retrieve bridge data for the route in question
2. Post-process the data with the SAS routine being developed and tested by this project, to obtain input file for program MOANSTR
3. Compare moment envelopes for the proposed LCV to those of the rating load
4. Screen deficient bridges
5. Estimate costs
6. Calculate LCV bridge cost responsibility.

In order to efficiently implement the proposed methodology, it is imperative to efficiently retrieve all the bridge records along a study route in a format that is compatible with the subsequent post-processing of the information listed above.

With this GIS system, it is possible to streamline the bridge analysis as well as ensure its consistency. Following the plan of integrating all the pavement and bridge data into a GIS system, the project staff obtained the latest BRINSAP information in GIS format and added it to the project's GIS platform. Figure D1 shows an example of the BRINSAP information: a specific data block for a bridge located on SH16 south of San Antonio.

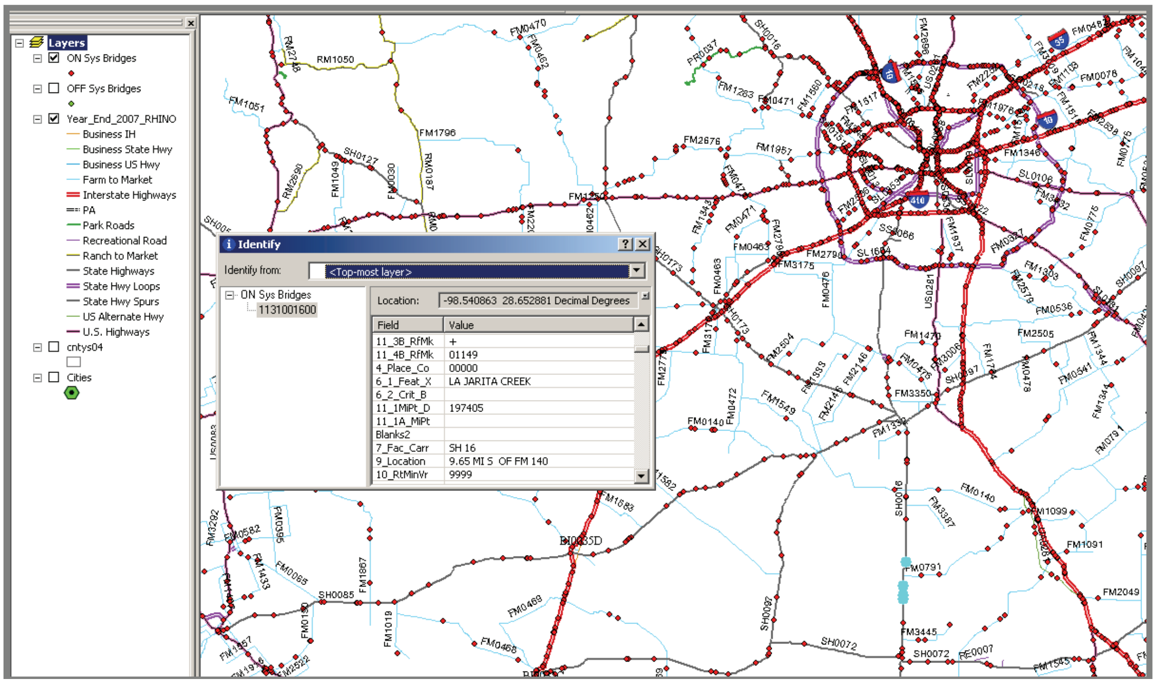

Figure D1: Example of GIS Bridge data

Figure D2 illustrates the power of this GIS-based approach for streamlining step 1 of the proposed case study analysis sequence. One of the potential case studies for this research project involves evaluation of a proposed HEB 97,000 lb truck configuration. In this figure, all the potential routes for connecting HEB warehouses in San Antonio and Weslaco in the Valley are displayed with all the bridges spatially coded and ready for data retrieval.

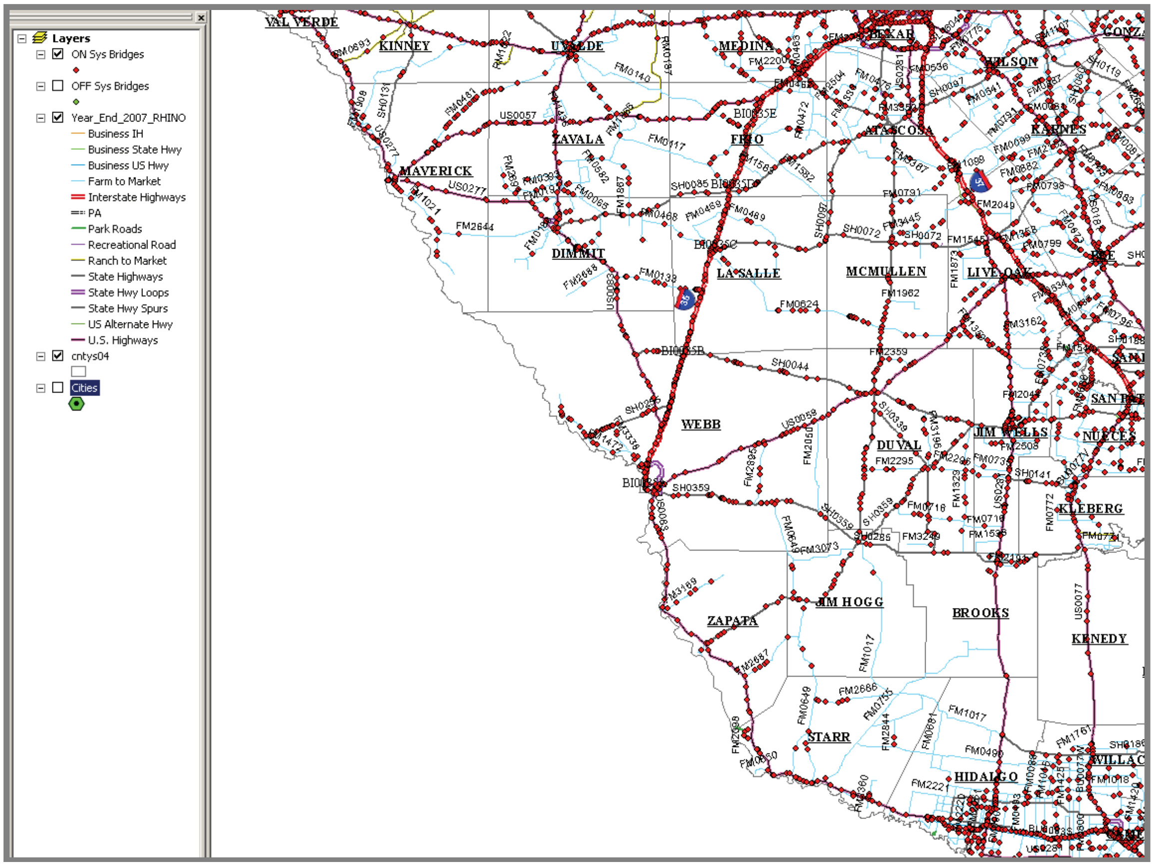

Figure D2: Bridge Data Retrieval with GIS Database

Pavement Data

Road alignment data, basic geometric information, and traffic information for roadway segments as summarized by TxDOT's RHiNo data maintained by TPP are included. Pavement data from PMIS are also included. Figure D3 shows the GIS system displaying the RHiNo information for a specific segment of SH 16 to the south of San Antonio. Figure D4 shows an example of the PMIS and LTPP information. The map displays a pre-selected are and shows the pavement types according to the color-coding legend on the left.

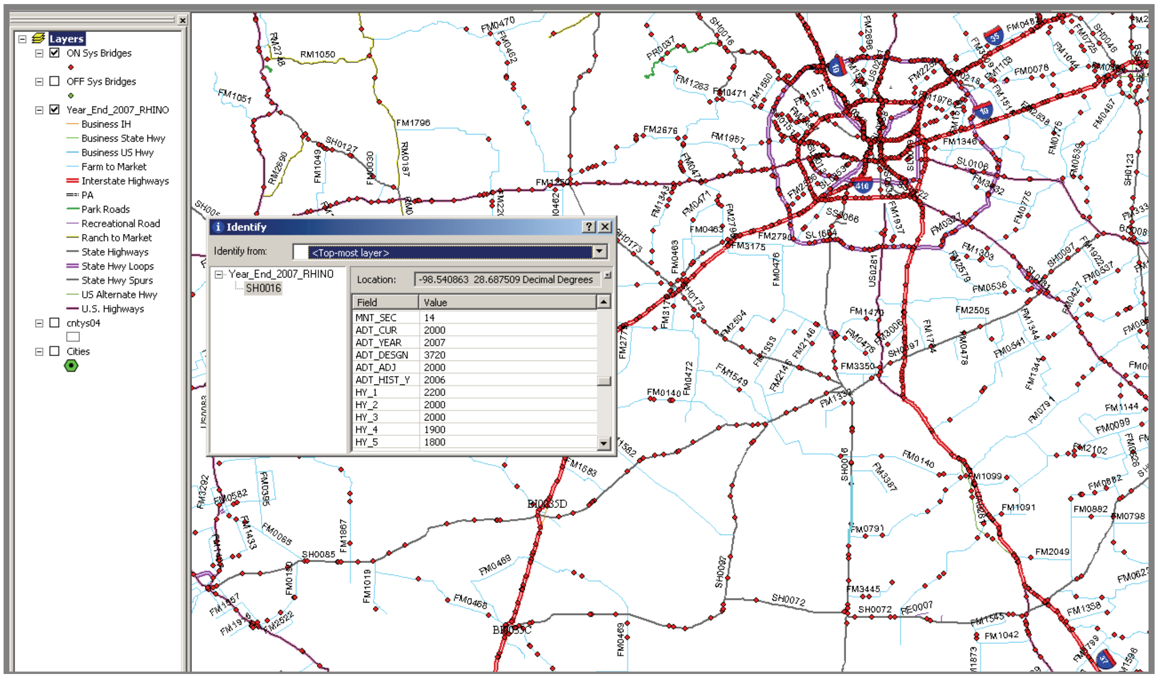

Figure D3: GIS Roadway Data

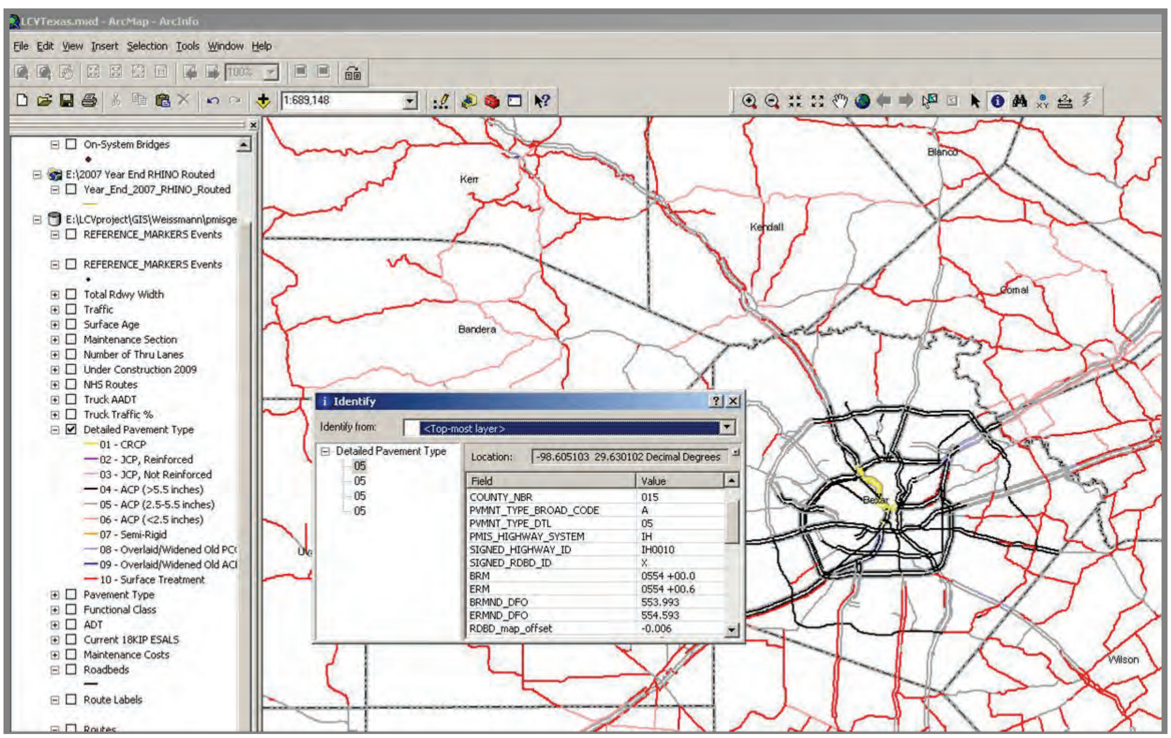

Figure D4: Pavement Data

Concluding Remarks

This appendix documents the development of an automated geo-referenced database containing all the available highway data that is relevant for bridge and pavement analysis. This geo-referenced database will streamline calculations and ensure the consistency of input files of bridge and pavement evaluation programs such as MOANSTR or EverStress.

Nevertheless, if necessary, the project staff will complement the electronic database information with pavement data manually collected from plans at TxDOT. A manual procedure may be necessary to retrieve pavement data for a specific LCV route where all information is not yet available in electronic format. In addition, data will be supplemented by the flexible and rigid research databases that are currently being maintained by UT Austin and Texas Tech respectively.

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Appendix E: Workshop Agenda and Attendees

This appendix details the study workshop held on August 21 2009 and lists the attendees who participated in the event.

Longer Combination Vehicles & Road Trains for Texas?

August 21, 2009
9:30 AM to 3:00 PM
CTR, 2nd floor conference room

AGENDA

1.	Introductions	*All*
2.	Overview of Project	*Michael Walton*
3.	Project Progress-to-Date	
	a. U.S. Long Combination Vehicle Operations and Regulations	*Alejandra Cruz*
	b. Harmonization	*Alejandra Cruz*
	c. Operational Characteristics	*Michael Walton*
	d. Safety Issues	*Kara Kockelman*
	e. Large Truck Operations	*Jolanda Prozzi*
	f. Environmental and Energy Issues	*Alejandra Cruz*
	g. Industry Perspectives	*PepsiCo/HEB*
	h. Bridge Impacts	*Jose Weissmann*
	i. Pavement Consumption	*Jose Weissmann*
	j. Response	*Messrs. Sweatman and Woodrooffe*
4.	Next Stage of Research	*Michael Walton*
	a. Case Studies	*Rob Harrison*
	b. Evaluation Approach	*Rob Harrison*
5.	Other Business	*All*

Longer Combination Vehicles & Road Trains for Texas?

August 21, 2009
9:30 AM to 3:00 PM
CTR, 2nd floor conference room

ATTENDEES

TxDOT Project Monitoring Committee:

Randy Anderson
Raymond Hutchinson
Don Lewis
Jianming Ma
Jim Randall
Duncan Stewart
Jefferey Tomkins

Research Team:

C. Michael Walton, Research Supervisor, UT Austin
Kara Kockelman, Professor, UT Austin
Robert Harrison, CTR Deputy Director, UT Austin
Jolanda Prozzi, CTR Assistant Director, UT Austin
Khali Persad, Research Engineer, UT Austin
Alejandra Cruz, Research Associate, UT Austin
Melissa Thompson, Graduate Research Assistant, UT Austin
José Weissmann Associate Professor, UT San Antonio

Advisory Team:

Peter Sweatman, University of Michigan Transportation Research Institute
John Woodrooffe, University of Michigan Transportation Research Institute

Invited Guests:

Ken Allen, HEB
Doug Miller, PepsiCo/Fritolay
Mike Moynahan, HEB
Matt Stalter, Pepsi/Quaker Oats

Invited Colleagues:

Jin Li, Associate Professor, Jilin University
Jorge Prozzi, Associate Professor, UT Austin
Guohui Zhang, Postdoctoral Fellow, UT Austin