Highway Safety and Truck Crash Comparative Analysis

Final Draft

Desk Scan

Comprehensive Truck Size and Weight Limits Study

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FINAL DRAFT DESK SCAN

Truck Configuration Definitions

Configuration	Acronym, short form	Definition
Single unit truck	SUT, straight truck	Power unit with permanently attach cargo body.
Truck-trailer		Straight truck pulling a single unit trailer.
Bobtail		Tractor with no trailer.
Tractor-semitrailer	TS, tractor-single or single (in context)	Tractor with a single semitrailer.
Tractor, 2-trailers	Double	Tractor with a single semitrailer followed by single unit trailer in the case of the A-train configuration or by a second semitrailer in the case of a B-train configuration.
Tractor, 2-trailers (28/28)	STAA Double	Tractor with a 28' single semitrailer followed by 28' single unit trailer.
Rocky Mountain double	RMD	Tractor with a long (40-53-foot) first trailer and short (24-28-foot) second trailer.
Turnpike double	TPD	Tractor with 2 long (40-53-foot) trailers.
Tractor with 3 trailers	Triple	Tractor with 3 short (24-28-foot) trailers.
Long(er) combination vehicle	LCV	Includes doubles with trailers longer than "standard" (28-foot), Rocky Mountain doubles, turnpike doubles, triples.
Gross vehicle weight or gross combination weight	GVW or GCW	Gross combined weight of a truck and cargo. Gross weight as loaded.
Gross vehicle (or combination) weight rating	GVWR or GCWR	Gross weight at which a truck or combination is designed. The sum of the axle weight ratings.
A-dolly		Coupling Unit with one or two axles that connect a trailer to the forward trailer or truck by means of a pintle (single point) hitch. The connection creates two articulation points with no roll coupling between the lead vehicle unit and the coupled unit. Used in doubles and triples.
C-dolly		Coupling Unit with one or two axles that connects a trailer to the forward trailer with a double drawbar that prevents yaw displacement of the dolly with respect to the lead vehicle unit. The axles are steerable. The dolly has one point of articulation at the fifth wheel and provided roll coupling between vehicle units. It is used in doubles and triples.
B-train		Multi-trailer combination in which the lead trailer has an extension at the rear with a fifth-wheel attachment point to which the following trailer connects by means of a kingpin. The arrangement provides only one yaw articulation point per trailer and provides robust roll coupling.

1.0 Introduction

The purpose of this subtask *(Task V.A. - Highway Safety and Truck Crash Comparative Analysis, US DOT Comprehensive Truck Size and Weight (CTSW) Limits Study)* is to examine significant studies, pilot programs and policies relevant to truck size and weight within the context of safety performance. The subject of size and weight is highly complex, with far reaching implications. It can be thought of as more of a system level subject rather than a one-dimensional policy issue having limited influence on externalities.

Truck size and weight policy was initially constructed to serve as a means of protecting infrastructure and ensuring that vehicles were compatible with road and bridge geometric constraints. Given that policy constrains vehicle length, width, height, axle weights, the distance between axles, axle groups and the like, size and weight policy has a first order effect on vehicle design, the amount of cargo that a vehicle can haul and vehicle configuration type such as single unit truck, truck trailer, tractor semitrailer and tractors with multiple trailers. Consequently, aspects of size and weight policy that influence vehicle design have a direct influence on vehicle safety. Policy that influences how, when and where a vehicle is operated also contributes to safety performance.

This desk scan provides a brief introduction to the fundamentals of size and weight policy related to safety, a comprehensive analysis of truck size and weight research related to safety and a scan of international activities in the area of size and weight research and policy development.

2.0 Historical Perspective of Size and Weight Policy Related to Safety

NCHRP Report 671 provides a detailed account of US size and weight policy development and contrasts it with the experience in Canada (Woodrooffe, Billing *et al.* 2010).

US truck size and weight limits were the sole jurisdiction of each state up to 1956. Since then, federal legislation has been instrumental in shaping the sizes, weights, and configurations of trucks allowed today, some nationally, and others on designated and more limited networks. The Federal–Aid Highway Act of 1956 established truck size and weight limits for the Interstate System, but states with weight limits higher than the new federal limits were allowed to retain those limits under grandfather authority. Federal weight limits were increased in 1974 to help offset a large increase in fuel prices, but not all states adopted the higher limits. The Surface Transportation Assistance Act (STAA) of 1982 required all states to allow twin trailers, and required all states to allow weights and dimensions of certain configurations not less than specified values. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 limited the authority of states to increase use of double trailer combinations with a gross weight greater than 36,287 kg (80,000 lb.). There have been no broad changes since 1991.

There has been a number of research studies addressing truck size and weight issues, and the following are briefly reviewed here:

- TRB study of the Turner Proposal
- Review of Truck Size and Weight Limits;
- The U.S. Department of Transportation (USDOT) Comprehensive Truck Size and Weight Study, 2000 (2000 CTSW); and
- The Western Uniformity Scenario.

Former Federal Highway Administrator Francis Turner suggested a new approach to truck size and weight regulation in an address to the American Association of State Highway and Transportation Officials (AASHTO) in 1984. The Turner Proposal envisaged trucks with lower axle and axle group weights, on more axles than current vehicles, and with a greater allowable gross weight. AASHTO asked the Transportation Research Board to establish a committee to conduct a comprehensive study of the proposal, and advise states on its merits.

The committee designed a package of changes in size and weight limits, safety restrictions, and procedures pertaining to bridge deficiencies, routing, and enforcement as a means of implementing the Turner proposal (TRB, 1990b). The truck configurations considered by the study utilized a wide range of possible values for axle weights, length limits, and other vehicle characteristics to achieve the best performance in terms of productivity, pavement wear, bridge costs and safety.

A review of truck size and weight limits was initiated in the 1998 Transportation Equity Act for the 21st Century (TEA-21). It directed the Secretary of Transportation to request the Transportation Research Board (TRB) conduct a study of the regulation of weights, lengths and widths of commercial motor vehicles operating on Federal-aid highways to which Federal regulations apply, and to develop recommendations regarding any revisions to law and regulations that the Board determines appropriate. Among the conclusion of this study were that Federal truck size and weight regulations should facilitate safe and efficient freight transportation and interstate commerce, establish highway design parameters and help manage consumption of public infrastructure assets.

The study recommended that Congress should create an independent public organization charged with observing and evaluating commercial motor vehicle performance and the effects of size and weight regulation, which the committee called the Commercial Traffic Effects Institute. The Institute could enter into agreements with private sector entities to conduct joint programs of data collection and research. The legislation creating the Institute should define the scope of its activities by specifying three distinct functions:

- The conduct of pilot studies of proposed new vehicles and related operating principles;

- Monitoring and ongoing program evaluation to measure whether practices intended to control safety and operations were functioning as intended; and
- Support for state implementation of federal size and weight regulations.

It also recommended that safety requirements should be proposed by states, reviewed by the Commercial Traffic Effects Institute and approved by the Secretary.

The USDOT's Comprehensive Truck Size and Weight Study, 2000 (2000 CTSW) was not primarily focused on any policy initiative but more on development and testing of analytical tools to estimate potential diversion of traffic from one type of truck to another, or diversion between truck and rail, if truck size and weight limits were changed. Impacts of proposed size and weight changes considered to be most critical were: safety, productivity, infrastructure (pavements, bridges, and geometrics), traffic congestion, environment, and on railroads. Because safety was and continues to be a contentious issue in relation to increased truck size and weight limits, this study included an extensive review of past safety studies and developed a consensus of results. Therefore, the study used computer simulation tools to evaluate stability and control properties of different vehicle configurations at different weights and dimensions. The tools were intended to provide a measure of the relative safety compared to vehicles in widespread use.

The Western Uniformity Scenario was conducted at the request of the Western Governors' Association (USDOT, 2004). The study found several benefits from allowing more widespread use of LCVs. The benefits included a reduction in fuel consumption, emissions, and noise-related costs. The study included a comprehensive vehicle stability safety analysis using computer simulation and vehicle performance measures using the same methods as in the 2000 CTSW Study. The study recommended that, to the extent possible, the vehicles accepted would be at least as safe as vehicles on the road at the time and that the companies operating those vehicles should have excellent safety records.

3.0 Review of Safety Literature Related to Size and Weight

This section focuses on recent research on the effect of truck size and weight on roadway safety in North America. There have been two recent surveys of research on truck size and weight issues, including safety (AASHTO 2009; Carson 2011). These surveys reviewed most recent significant research and drew conclusions that are broadly similar to each other. The reviews, particularly the work by Carson, extended beyond the safety of heavy trucks to include significant research on infrastructure, pavement, highway geometrics, enforcement and related issues. These surveys report the findings of a broad array of studies of different aspects of larger and heavier trucks. Rather than repeat the work of these two reviews, the focus in this review will be on data and methodology, how the available data constrains the types of research questions that can be addressed, and the different methodologies that have been employed to address those questions.

3.1 Data Issues

A consistent theme of heavy truck research on size and weight issues has been the limitations of crash and exposure data. Most crash data systems are inadequate to identify longer or heavier trucks. No state crash data system includes the operating weight of trucks (or other vehicles) at the time of the crash. Nor do most include lengths of either individual units or combination lengths. A handful of states include some information on the number of axles on trucks, which can be a surrogate to identify trucks designed to carry heavier loads. Most states can distinguish straight trucks from tractor-trailer combinations and single-trailer units from double (or triple) trailer combinations, but cannot identify trucks operating at heavier weights or longer lengths, where heavier weights are considered to be greater than the 80,000 lb. The federal weight limit on the Interstate System portion of the National Network is considered to be beyond that attributed to the federal weight limit as applied to the twin 28.5-foot trailer configuration. (Scopatz 2001) Other issues with developing a good analytical model are the biases that exist in some of the data that are available. Since truck weight data are, to a large extent, collected at weigh stations, the available weight data are likely to be biased toward the legal-weight carriers since overweight trucks are more likely to avoid weigh stations, using alternate routes (Taylor *et al*, 2000).

At the national level, the two primary Federal crash data sets are the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) files. FARS is a census file of all motor vehicles in fatal crashes, while GES is a nationally representative sample of police-reported crashes, so it includes both fatal and nonfatal crashes. Trucks are identified in each but details are lacking beyond basic configurations. Neither data set includes any data on weights or lengths nor even axle counts. (NCSA 2011; NHTSA 2011) The MCMIS (Motor Carrier Management Information Systems) includes crash, census, company, and inspection data. (Examples of some of the analysis done include those of Blower, 2004; Matteson, Blower, 2010; Matteson, 2005, available at: http://141.213.232.243/handle/2027.42/3138, http://141.213.232.243/handle/2027.42/21606, and http://deepblue.lib.umich.edu/bitstream/handle/2027.42/65062/102670.pdf?sequence=1.)

The Trucks Involved in Fatal Accidents (TIFA) crash data set from the University of Michigan Transportation Research Institute (UMTRI) is the only data set that includes detailed information about truck configuration that can address at least some of the gap. The data include power unit type, number of trailers, number of axles on each unit, and the types of connection between the units. For example, tractor-doubles combinations are classified as using either A- or C-dollies or B-trains. Before 2005, TIFA also included the empty weights and lengths of each unit, cargo weight for each unit, and overall weight and length. At that time, TIFA had all the information needed to identify different truck configurations at the required level of detail. But TIFA data collection was stopped after the 2010 data year; hence, this resource is no longer available. In addition, TIFA was limited to fatal crashes only, and did not include exposure (mileage) information (Matteson, Pettis *et al.* 2007; Jarossi, Hershberger *et al.* 2012).

Exposure data are equally, if not more problematic. The Federal Highway Administration (FHWA) *Highway Statistics* publication only distinguishes single unit trucks from combination vehicles, and provides registration and travel estimates by highway type and urban/rural (FHWA 2013). The Vehicle Inventory and Use Survey (VIUS) from the Bureau of Census used a survey of truck users to collect annual estimates of travel for different truck configurations, empty weight and typical gross weight, but the data did not disaggregate travel by road type. Moreover, the data series was discontinued in 2002 (Bureau of the Census 2002) (Campbell, Blower *et al.* 1996).

Other sources include state estimates from vehicle classification stations and weight-in-motion (WIM) stations. The vehicle classification stations classify vehicles by FHWA's 13-level classification. Trucks are classified as single-unit, one or multiple trailers, and by the number of axles. The WIM stations estimate gross weight. This information can be combined to develop estimates of truck travel for the FHWA truck classes and gross weight, but only for the locations where the stations are operating. This technique has been used in several recent studies (Abdel-Rahim, Berrio-Gonzales *et al.* 2006b; Montufar, Regehr *et al*. 2007; Regehr, Montufar *et al*. 2009). But there remains the problem of matching the VMT estimates derived from these sources to trucks in the crash data because of the lack of detailed configuration information in the crash data.

One older source of travel information is worth mentioning here despite its age, because it was the source of VMT data that was used in several of the influential studies that are discussed here. The National Truck Trip Information Survey (NTTIS) exposure database was compiled by the UMTRI. NTTIS was a survey complementary to the TIFA crash data set, and collected VMT data for configurations at the same level of detail as the TIFA crash data. The VMT data was collected for a sample of registered trucks by road type, time of day (day or night), and urban/rural. The combination of TIFA and NTTIS data allowed crash rates to be calculated by performance characteristics (Blower and Pettis 1988). NTTIS was operated only for one year (1987), and the TIFA data collection effort was discontinued as of the 2010 crash year.

There are specific crash-related factors for which either crash or exposure data will not exist. For example, while crash data include weather conditions, truck exposure data will not. A report by Rossetti and Johnsen (2011) focuses on the potential effect of climate change on commercial motor vehicle safety. The concern is developed in response to potential changes in climate that may pose an increase in crash risk to commercial motors carriers and other highway users. The authors make several recommendations for FMCSA consideration in response to their analyses. None of the studies of analyses specifically target larger combination vehicles or vehicles operating over the 80,000lb limit, but concerns expressed for vehicle handling in adverse weather, driver fatigue caused by delays and other factors are applicable to LCVs and heavy CMVs along with all commercial vehicles.

Broadly speaking, there have been two approaches to evaluating the relationship of truck size and weight to safety. The first approach relies on identifying critical performance characteristics of heavier and longer trucks, such as rollover threshold, braking efficiency, and rearward amplification, and then comparing those parameters to the values for trucks in the existing fleet. Relationships for those parameters to crash rates have been estimated (discussed further below). The safety of proposed new configurations is then extrapolated from the existing fleet. The other thing to be noted about configurations is that it is not merely size or weight, but the interaction of the two. That is, a longer wheelbase may carry the same load as a truck with a shorter wheelbase, but the shorter wheelbase will create greater damage. That said, the longer wheelbase creates other safety related issues in terms of maneuvering and ability to see other road users. The second approach relies on observational studies of the operations of trucks of interest in actual operations, insofar as they can be identified. The trucks are operated, often restricted to certain routes or road types, over a certain period of time and then the effect on safety is observed through analysis of crash frequencies and crash rates. Studies using both approaches are discussed.

3.2 Significant Studies Focused on Performance Characteristics

Two TRB reports are discussed first because they laid out the relevant handling and performance characteristics related to safety and provided a model for this approach. They are *Special Report 225: Truck Weight Limits: Issues and Options*, and *Special Report 227: New Trucks for Greater Productivity and Less Road Wear* (TRB 1990a; TRB 1990b). SR225 was requested by the US Congress to assess proposals for changes in Federal weight limits, evaluating the impact on productivity, pavement, bridges, safety and operations, and enforcement. For the safety findings, the study largely relies on existing research and assesses the impact on safety in terms of how increases in size and weight would affect critical performance parameters.

The performance characteristics considered include rollover threshold, rearward amplification, braking, steering sensitivity, low-speed offtracking and high-speed offtracking. Crash analysis used to evaluate the characteristics was based on crash rates calculated using TIFA and NTTIS data, because most of the performance measures can be estimated in those data. The study largely drew on work by Fancher *et al*., and Campbell *et al*. (Campbell, Blower *et al*. 1988; Fancher, Blower *et al*. 1989).

- Rollover threshold, defined as the maximum level of lateral acceleration a truck can achieve without rolling over, decreases as GVW increases. Crash analysis shows that the probability of rollover increases for combination trucks as the GVW increases.
- Rearward amplification is the tendency of trailers to over-respond to rapid steering maneuvers. Simulation and modeling shows that rearward amplification increases with number of articulation points; shorter trailer wheelbases; higher GVW; higher centers of gravity; and lower tire cornering stiffness. Analysis of fatal crash data that includes information on cargo loading, the number of trailers, and trailer lengths, shows that truck configurations with higher measures of rearward amplification have a higher probability of rollover in crashes.
- Based on non-crash analyses, the study reported that increases in GVW of 10-20% are not likely to make a significant difference in stopping distance, though more significant increases would require higher levels of braking. (Note that this assumes that the braking system is adjusted to specifications and operating as designed.) Based on fatal crash data, the study reported that loaded trucks had higher rates of rear-end crashes than empty or lightly loaded trucks.
- Steering sensitivity is a measure of how well a vehicle responds to steering inputs. High values mean better vehicle control. The study reported that increases in GVW reduce sensitivity, and lower sensitivity is associated with higher rates of single-vehicle crashes.
- Low-speed offtracking is the tendency for the rear axles of trailing units to track inboard of the power unit in low speed turns. Low-speed offtracking is sensitive to trailer length, such that shorter trailers tend to off-track less than longer trailers. A doubles combination with two 28-foot trailers (*i.e.*, within Federal length limits) shows less offtracking than a tractor-semitrailer with a 45-foot trailer. While low-speed offtracking can be demonstrated in simulation and observation, the study reported no evidence of a safety effect. This is probably because the only crash file available at the time (or since) with trailer length was restricted to fatal crashes, and low-speed crashes are less likely to cause fatal injuries.
- High-speed offtracking is the tendency of the rear axles of trailing units to track out-board of the power unit in high-speed turns. Tractors with two trailers exhibit more high-speed offtracking than tractors with one trailer. High-speed offtracking also increases with GVW. High-speed offtracking may increase rollover probability if the trailer wheels hit a curb while negotiating an exit ramp, for example. However, as with low-speed offtracking, no research has shown a relationship with crash rates.

The operational effect of higher GVWs and greater lengths include slower speeds on upgrades, increased time/distance to get up to speed on merges, more conflicts in lane changes, increased risk of runaways on downgrades, and conflicts at intersections related to sight distance because of increased time to clear an intersection and accelerate up to speed. These findings are derived from the performance characteristics of the vehicles. There has been no crash data research to validate the relationships.

The second TRB report, *New Trucks for Greater Productivity and Less Road Wear* (TRB 1990b), applied this basic methodology to estimate the safety and other effects of several specific configurations with longer trailers and heavier loads than currently permitted. These are the so-called “Turner Trucks”. The logic of Turner’s proposal was to permit higher GVWs, carried on more axles to reduce individual axle loads. The argument is that lighter axle loads would reduce pavement wear and higher payloads would require fewer trucks to carry the same amount of cargo. Four configurations were considered:

- 9-axle double, trailers 30-35-foot trailer length, 114,000 lb maximum GVW.
- 9-axle B-train double, 67-foot trailer length, 114,000 lb GVW.
- 11-axle double, 33-foot trailer length, 141,000 lb GVW.
- 7-axle tractor-semitrailer, 48-50-foot trailer length, 91,000 lb GVW.

Since these truck configurations are not found in crash data, their safety cannot be assessed directly and was instead inferred from their performance characteristics. This was done by, comparing them to existing truck configurations for which there are some crash experience, and estimating crash rates. The study projected that the 9-axle, two 33-foot trailer, combination would have slightly lower crash involvement rates than current 5-axle, 28-foot trailer double combinations because of better braking efficiency, higher rollover threshold, and lower rearward amplification.

However, the study cautions that these findings assume that components such as brakes are not downsized to take advantage of the lower axle loadings. If the components were downsized, some of the advantages of the Turner configurations would be reduced. The study also noted that some operational conflicts, such as during merging, changing lanes, and clearing intersections, would be increased by the greater overall lengths and lower engine horsepower-to-GVW ratios.

Finally, the study cautions that the conclusions are based on performance characteristics derived from simulation and controlled testing rather than operational experience, that the safety inferences are based on extrapolation from the population of existing truck configurations, and that there is statistical uncertainty in the crash rates of truck configurations currently in use.

Harkey *et al*. considered the performance characteristics of different types of LCVs, including Rocky Mountain doubles, turnpike doubles, and triples, in relation to highway geometric design (Harkey, Council *et al*. 1996). The goal of the study was to project how current design practices might be affected by these characteristics. The measures included offtracking, stability (rollover, trailer sway, and rearward amplification), braking and stopping distance, and speed and acceleration.

Based on other studies, Rocky Mountain and Turnpike doubles have greater (worse) low-speed offtracking than tractor-semitrailers, while triples are similar to tractor-semitrailers in terms of offtracking. LCVs potentially can have better braking results because they have more axles than standard tractor-semitrailers, but additional axles also means more brakes to keep in adjustment, which has historically been a challenging issue with air brakes. In terms of stopping distances, the authors noted that past research reports mixed results from tests, but no conclusive evidence that LCVs are any better or worse than conventional tractor-semitrailers. The various studies reviewed indicated that factors such as the driver's skill level, load distribution, and road conditions can affect stopping distances for any of the LCVs. Maintaining speeds on upgrades can be a significant problem for LCVs because of heavier weights. Significant slowing on upgrades can produce speed differentials that may be unsafe. Unless power-to-weight ratios are maintained, there can be similar problems for LCVs to accelerate adequately to merge into traffic streams. In passing maneuvers, LCVs take longer to pass on two-lane roads, which may make passing unsafe or impossible on roads with relatively high traffic volume.

At about the same time, Fancher and Campbell identified and assessed the primary handling and stability characteristics of heavy vehicles, which directly affect their ability to maneuver safely in traffic. The focus of the work was only on physical characteristics, though the authors noted that "differences in operating environment can overshadow the influence of vehicle characteristics" (Fancher and Campbell 1995).

The paper reviewed the experience of twin-tank trailers in Michigan as showing that heavier vehicles can be designed to provide safety performance equivalent to other trucks. The twin-tank configurations used in Michigan were evaluated and redesigned to improve their stability. The point is to include safety – in terms of handling and stability – as explicit goals of policy. "Simply adding weight to existing vehicles is a poor idea, but new vehicles that are designed to carry more weight can well be safer than less productive, current vehicles."

The paper reviewed the following handling and stability characteristics: Offtracking in turns; rollover in turns related to radius of curvature and superelevation of the roadway; weight-to-power ratios to sustain speed on hills and merge safety; acceleration at intersections in relation to available sight-distance; braking in relation to available sight-distance; braking capacity on downgrades; and adequate sight-distance for passing. TIFA and NTTIS data were used to support the analysis.

Findings:

- Rollover probability in a crash is inversely related to roll threshold, such that trucks with roll thresholds of about 0.4*g* are significantly more likely to rollover in a crash as trucks with roll thresholds of 0.6*g*.

- Rearward amplification, which is the ratio of the lateral acceleration of the last unit in a multi-unit combination to the lateral acceleration of the first unit, is directly related to rollover risk. Controlled-steering C-dollies can reduce rearward amplification of standard doubles from 2.3 to 1.5 (lower is better).
- Braking efficiency is defined as the ratio of deceleration to the highest friction level required at any axle; it is the fraction of tire/road friction that can be used without wheel lockup. Jackknife risk goes down as braking efficiency goes up.
- Low-speed offtracking in principle is directly related to crash risk: as low-speed offtracking increases, crash rates would be expected to increase. However, it appears to have only a small effect on fatal crashes; it is more likely to show up in property damage crashes.
- Crash rates tend to increase with increases in GVW. The other characteristics discussed tend to be associated with changes in the rates of specific types of crashes, where the way the crashes occur is related to the performance characteristic. For example, low roll threshold is associated with higher rates of rollover, but not with higher crash rates overall. Weight is different and is associated with higher crash rates overall. Only tractor-semitrailers were analyzed for the report and the authors caution that this result cannot be extended to different designs because they may have been designed to different handling and stability levels. That is, they may have been designed for a heavier weight without degrading characteristics below the existing fleet.

Overall, the authors state that the *direction* of the relationships between the physical parameters and crash risk follows from physical principles, but the *magnitude* depends on operations and environment and so must be determined by actual experience. Moreover, trucks can be designed to have handling and stability characteristics similar to or better than the existing fleet.

USDOT's 2000 CTSW Study that followed shortly thereafter took a similar approach in analyzing safety, with the safety discussion largely focused on the effect of the usual vehicle characteristics. Given the lack of adequate and appropriate crash and exposure data, the analysis drew on the results of engineering tests of performance measures. Qualitatively, the study reported that GVW, weight distribution, and the center of gravity height all had negative effects on static and dynamic vehicle stability, braking and offtracking. The number of units in a combination had a negative effect on dynamic stability, braking and high-speed offtracking, but positive effects on low-speed offtracking. The number of axles, similar to the Harkey *et al*. finding above, had positive effects on vehicle stability, braking, and low- and high-speed offtracking (2000 CTSW Study).

The *Western Uniformity Scenario Analysis* was undertaken by the USDOT as the 2000 CTSW Study was being completed. The Western Governors' Association requested an analysis of the consequence of lifting the existing freeze on LCV sizes and weights and allowing harmonized limits across 13 Western states (*i.e.,* Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, Wyoming). Weights for LCVs would be limited only by the Federal bridge formula and limits to axle weights, resulting in a maximum GVW of 129,000 lb. The study used the same methods as the 2000 CTSW Study and relied on the substantially the same studies and data.

The study analyzed the performance of 17 configurations, including STAA doubles (two 28-foot trailers), tractor with a 53-foot semitrailer, turnpike doubles (two 45- or 48-foot trailers), several types of Rocky Mountain doubles defined by different combinations of cargo body type and connection type (A- or B-train), A-train and C-train conventional triples (28-foot trailers), and a tank truck-trailer. Some of the vehicles were in current operation in the West and others would potentially be permitted. The work focused on handling and stability properties of the vehicles. The study found that most of the LCVs currently in use had roll thresholds as good as or better than STAA doubles, as did most of the LCV configurations proposed. In terms of rearward amplification all but one of the current LCVs had better values than the STAA double, as did all of the scenario vehicles, except triples with A-dollies, which had by far the highest value at 2.72. Using C-dollies, which eliminates two points of articulation reduced the rearward amplification value to 1.66. Load transfer ratio, which is a measure of load transferred laterally in transient evasive maneuvers, was worse for two configurations in current operations: STAA doubles and triples using A-dollies. All other configurations, both LCVs currently in use in the West and proposed scenario vehicles, had substantially better load transfer ratios.

Only limited crash and exposure data analysis was undertaken, comparing crash rates for single-trailer versus multi-trailer trucks by road type. The study relied on FARS data and FHWA estimates for travel, and so was unable to disaggregate different current or proposed LCV types. Although the data were unable to resolve any of the specific combination types, the authors emphasized the influence of road type–crash rates on non-limited access roads were estimated to be two to three times higher than limited access–and by extension operating environment.

3.3 Significant Studies Focused on Configuration

Campbell *et al*. (1988) used the TIFA and NTTIS data to calculate crash rates for fatal accidents by truck configuration, operating environment (road type and time of day), and GVW. The study was not an evaluation of LCVs or an evaluation of trucks configured to operate beyond current limits, but instead to establish fatal crash rates for common configurations and to determine the effect of different dimensions of operating conditions. Estimated fatal crash rates vary by a factor of three to a factor of five depending on the type of road and time of day. In addition, it was noted that different truck configurations have substantially different patterns of travel across road types, making simple comparisons of crash rates between configurations misleading. Adjusting rates to remove the influence of these different travel patterns, the study reported that fatal crash rates for doubles (primarily STAA doubles) are about 10% higher than tractor-semitrailers. Rates for bobtail tractors, however, were over twice as high, while straight trucks as a whole had adjusted fatal crash rates about 10% lower than singles. The study also noted an increase in fatal crash rates at higher GVWs. Because of data limitations, only gross weights up to 80,000 lb were considered; the adjusted rate for the 65-80,000 lb GCW group was about 40% higher than the 50-65,000 lb GCW group. This implies that van tractor-semitrailers loaded to 65-80,000 lb would have a 1.42 times higher rate than all tractor-semitrailers *if* they had the same distribution of travel (Campbell, Blower *et al*. 1988).

Blower *et al*. (1993) used crash and VMT data to develop a log-linear model to predict crash rates using truck configuration, road type, time of day, and urban/rural location as predictor variables. Crash data from Michigan were used, along with VMT data from a survey of truck-tractor operations. In the statistical model, there was no statistically significant difference in crash rates between tractor-semitrailers and doubles. The type of road had the largest effect on crash rates, with non-limited access roads having crash rates 6.8 times higher than limited access. Crash rates for doubles were about 10% higher than singles, but the difference was not statistically significant. GVW was not part of the data, so the effect of weight was not examined (Blower, Campbell *et al*. 1993).

Using a case/control methodology, Braver *et al*. compared the crash risk of singles and doubles in Indiana. Cases were crash-involved singles and doubles and the controls were tractor combinations that passed the case crash sites one to four weeks after the crashes, at the same time and on the same day of the week. Both cases and controls were limited to interstate highway locations. LCVs were not distinguished in the crash population, but the authors state that most doubles were likely to be STAA doubles. The study found no difference in crash risk between singles and doubles. However, drivers of doubles in the crash population on average were older than singles drivers, and doubles tended to be operated in larger fleets. Data on drivers and companies was not collected for the controls so the effect of these potentially confounding factors could not be determined. The study also found higher crash risk for doubles on ice and snow, which may be related to handling properties (Braver, Zador *et al*. 1997).

Jovanis *et al*. used fleet data to compare crash rates for singles and doubles. This study is one of the few that used operational data from fleets, which has the advantage of controlling for differences in fleet operations. The study used randomly selected origin-destination terminal pairs for a national less-than-truckload (LTL) carriage. Both singles and doubles operated over the same roads at approximately the same times, controlling for road type, though the road types were all ones that had been approved for doubles operations. The study reported that accident rates for doubles were somewhat lower than singles on every road type and that the differences, though small in some cases, were statistically significant (Jovanis, Chang *et al*. 1989).

Forkenbrock and Hanley compared crash conditions for single and multi-trailer trucks and concluded that multi-trailer truck crashes were more likely to occur on high speed roads than singles, more likely to involve two or more other vehicles and more likely to occur in conditions of darkness and on low friction roads, than single-trailer truck crashes. The analysis was performed using UMTRI's TIFA fatal crash data (Forkenbrock and Hanley 2003).

Since only crash data were used, the study was unable to conclude anything about the risk of singles and doubles crashes. Crash risk is the product of the probability of crash involvement per unit exposure times exposure. Without exposure, risk cannot be determined. The Forkenbrock study identifies the tendency of conditions for singles and doubles crashes, but crash data alone cannot show if such conditions are more risky for doubles or if doubles are more exposed to the conditions. The overinvolvement of doubles at night could be because doubles may operate more at night than singles. Overinvolvement in low-friction conditions is consistent with the less-favorable stability characteristics of doubles relative to singles, but crash data alone cannot show that this results in higher crash risk in actual operations.

Hanley and Forkenbrock also developed a model of the effect of LCV length on the safety of other vehicles passing LCVs on two-lane highways. Policy and economic factors may direct LCVs to interstate-quality roads, but there will be a need for "reasonable access" in order to use the interstates. This will require some travel on lesser-quality roads, likely including two-lane highways. Hanley developed stochastic (probabilistic) models of passing that account for differences in performance between LCVs (impeding vehicle) and light vehicles (overtaking vehicle); driver aggressiveness; traffic volume and spacing of oncoming vehicles, lengths of the impeding vehicles, and speeds of the impeding vehicles. They found that as impeding vehicle length increases, odds of failure to pass increase. Odds of failing to pass a 120-foot long LCV are 2-6 times a 65-foot long truck. (Hanley and Forkenbrock 2005)

Lemp, *et al*. (2011) identified factors contributing to crash severity in large truck crashes using the Large Truck Crash Causation (LTCCS) and GES crash data, using the Bureau of Census's Vehicle Inventory and Use Survey (VIUS) to measure exposure. The LTCCS data were used to develop statistical models of the factors increasing crash severity. Crashes were more likely to include a fatality in dark or low-light conditions and when the roadway was snowy or icy. The number of trailers was directly related to the probability of a fatality (more trailers increases the chance of a fatality in a crash), but somewhat paradoxically overall truck length and higher gross vehicle weight rating were associated with *lower* probability of fatality. This result is interpreted as meaning single-trailer trucks have a lower probability of fatality, bobtail tractors have the highest, and single unit trucks and two-trailer LCVs and non-LCVs are in between. The authors caution that "[i]f truck length and/or GVWR increase past the levels common in the LTCCS sample, the model's estimates may not be valid."

The study also used GES and VIUS data to compute crash rates for straight trucks, bobtail tractors, tractor-semitrailers and tractors with two or three trailers. LCVs cannot be distinguished in the GES crash data, so the rates are for all tractors with two or more trailers. Moreover, the crash rates are not disaggregated by road type, time of day or any other relevant factors. The calculated rates show crash rates for two-trailer tractor combinations about half tractor-semitrailers, though when combined with the finding on crash severity, average crash costs for doubles are about twice those of singles. Thus on a per mile basis, estimated crash costs are about the same in these data, for tractor-semitrailers and doubles (Lemp, Kockelman *et al*. 2011).

3.4 Observational and Pilot Studies of Longer/Heavier Trucks

Woodrooffe reviewed the safety performance of LCVs in Alberta, Canada between 1995 and 1998 (Woodrooffe, 2001). LCVs include doubles and triples longer than 25 m, including Rocky Mountain doubles, turnpike doubles, and triples. LCVs are restricted to certain routes (highway types), certain times of day in holiday periods (when there might be more congestion from holiday travelers), specific driver training and experience requirements, minimum required power-to-weight ratios, and the use of certain hitch types. In addition, LCVs are restricted from operating in adverse weather conditions, and at certain times of day in and around specified cities. Finally, there were time-of-day restrictions on two-lane highways.

Crash rates were estimated from crash involvement counts and VMT estimated from traffic counts on road segments, supplemented by data from a survey that classified trucks by specific configurations. Urban travel was excluded because of problems estimating travel within urban areas. Accordingly, the results are for operations on roads designed to the highest geometric standard. The use of short-term surveys to partition traffic counts by truck configuration also added uncertainty to the results.

Overall, it was found that crash rate of LCVs as a whole (comprising RMD, TPD, and triples) is one-fourth that of tractor-semitrailers and one-fifth of all multi-trailer trucks. Among LCVs, triples have a much higher rate than Rocky Mountain doubles, but the rate for triples is based on only six crashes. Adverse road conditions were noted in 42% of LCV crashes, despite the fact that operations in bad weather were restricted. Woodrooffe attributed the good safety performance of LCVs to the permit conditions under which they are operated in the province (Woodrooffe 2001).

Montufar *et al*. (2007) extended and expanded the Woodrooffe work in Alberta in 2007. The study developed exposure measures using vehicle count data on roadway segments, distributions of gross weight from WIM stations, a survey of vehicle length on one stretch of highway for one year, vehicle classification counts at selected stations, and a roadside survey of fleet mix data. These data were used to develop estimates of VKT (vehicle kilometers of travel) for routes on which LCVs were permitted to operate.

As is the case with most police-reported crash data, specifics of truck configurations are not identified at sufficient detail to distinguish of interest, so the researchers contacted the operators of all crash-involved multi-trailer trucks to determine the details of the configuration. Configurations considered in the analysis include straight trucks, tractor-semitrailers, “legal-length” doubles (STAA doubles), Rocky Mountain doubles, turnpike doubles, and triples.

Alberta has among the most stringent driver, carrier, and vehicle regulations on LCVs in the CANAMEX corridor (Canada, US and Mexico). The study was restricted to network of roads where LCVs are allowed to operate, including multi-lane highways with four or more lanes, plus two-lane highways to allow reasonable access. Exposure estimates (vehicle kilometers of travel or VKT) were developed for the four-lane road network but as in the Woodrooffe study, the estimates excluded urban areas.

LCVs were found to have the lowest collision rate by VKT. For all LCVs, the overall crash rate was 25 per 100 million VKT (42/100 million vehicle miles of travel or vmt). The rate for tractor-semitrailers was 42/100 million VKT (134/100 million vmt); 44/100 million VKT (71/100 million vmt) for “legal length” (STAA) doubles; and 83/100 million VKT (134/100 million vmt) for passenger cars. Thus, LCVs as a whole were estimated to have lower rates than standard tractor-semitrailers and passenger cars. Within the LCV set, turnpike doubles had the best performance at 16/100 million VKT (32/100 million vmt), followed by Rocky Mountain doubles at 32/100 million VKT (52/100 million vmt) and triples at 62/100 million VKT (100/100 million vmt).

The computed crash rates are restricted to the LCV network and so reflect only operations on the highest standard roads. No statistical tests were performed to test the significance of the differences between rates, and the number of specific LCV types in crashes is small. Over the seven years of the study, there were 36 crash-involved RMDs, 21 TPDs, and eight triples. Sensitivity tests were done by computing crash rates varying VKT estimates plus/minus 10 percent. The sensitivity tests showed that the estimated crash rates for LCVs would still be significantly below the estimated rates for passenger vehicles and tractor-semitrailers.

In terms of crash severity, LCVs were underinvolved in fatal and injury crashes, compared with other truck types. For example, tractor-semitrailers and STAA doubles accounted for 43% of trucks in property-damage-only crashes, but almost 66% of trucks in fatal crashes and 57% of trucks in injury crashes. In contrast, LCVs accounted for 1% of trucks in fatal, injury, and property damage crashes.

Driver errors and environmental conditions were identified as the main contributors to crashes for LCVs. Among the errors, improper turning and lane changes were predominant, which may be due to the overall lengths of the vehicles. Wet, snowy or icy road conditions were noted in 40% of LCV crashes in urban areas, compared with about 25% for all trucks and all passenger vehicles. Statistical tests of differences were not calculated. Overinvolvement on poor road conditions may reflect the handling differences of multi-trailer trucks, and apparently occurred despite the restrictions on operating in adverse weather (Montufar, Regehr *et al*. 2007).

This work was also summarized in Regehr *et al*., which concluded, "The relatively superior safety performance of LCVs in Alberta may result in part from the stringent conditions placed on their operations through the design and enforcement of special permits. Principal along these is the requirement for experienced, specially-qualified driver for LCV movements" (Regehr, Montufar *et al*. 2009).

Abdel-Rahim *et al*., performed a similar study of LCVs in several western states, which includes some of the states on the CANAMEX corridor referred to above. LCVs are defined as tractor combinations with two or more cargo spaces, with at least one trailer longer than 28.5 feet and registered to gross more than 80,000 lb. Thus defined, LCVs includes Rocky Mountain doubles, "intermediate doubles" (trailers 30-35 feet), turnpike doubles, B-train doubles, triples, straight trucks with two trailers, and other combinations with two trailers registered over 80,000 lb GCW. The truck configurations are not distinguished by number of axles.

A goal of the study is to calculate crash rates for the different LCV configurations. A survey of existing crash and VMT data showed that despite the fact that different types of LCVs are allowed to operate on the highways in several Western states, only Utah can identify in its crash data standard doubles as well as RMD, TPD and triples. Singles, doubles and triples can be identified in Colorado, Idaho, Montana, Nevada, and Oregon, but without distinguishing individual LCV types, and only singles and doubles are identified in Washington and Wyoming. In terms of VMT, none of the states collected exposure data by LCV type. Most use count-based methods using the FHWA's 13-vehicle classification scheme.

The authors developed a method to estimate LCV travel using WIM-station data and vehicle classification counts. (The method is documented in a companion report (Abdel-Rahim, Berrio-Gonzales *et al*. 2006a).) Crash rates were calculated for Utah and Idaho. Because of limitations in the Idaho crash data, crash rates could only be calculated by truck configuration, distinguishing singles, doubles and triples. Specific LCV types such as turnpike doubles and Rocky Mountain doubles cannot be identified in the crash data.

In terms of severity, singles and doubles had similar distributions of crash severity in the states examined. For example, in Idaho, about 3% of crash involvements for each involved a fatality, about 30-33% included an injury, and the remainder involved only property damage (PDO). Among crashes involving triples, only about 2% were fatal crashes and only 13% involved an

injury. However, there were only 14 triples crashes over the entire period covered by the data (1999-2005), limiting the usefulness of this finding. In all the states, though, triples had the highest proportion of PDO crashes. Montana had no triples involved in a fatal crash over the period. Utah crash data can identify RMD, TPD and triples, as well as singles and standard doubles. In the Utah crash data, the proportion of fatal crashes was about the same for each of these truck types.
In Idaho, crash rates were calculated by year for singles, doubles, and triples, on state roads and on interstate highways. On state roads, doubles and triples consistently had higher crash rates than singles, ranging from about 25% to about 50% higher. Triples had somewhat lower crash rates than doubles on state roads, though it should be noted that there were only six crashes involving triples combinations in three years on Idaho state highways. There were 469 singles and 85 doubles crashes. On Interstate highways, triples had lower crash rates than either singles or doubles – about 15% lower than singles and about 30% lower than doubles. There were 887 singles crashes, 109 doubles and 36 triples. Tests indicated that the differences between singles and doubles and between singles and triples were statistically significant.

For Utah, crash rates could be calculated for singles, standard doubles, RMD, TPD, and triples. The results showed tractor-semitrailers with the lowest overall crash rates, compared with standard doubles and each of the LCV types. On average, crash rates for RMD were about 60% higher, rates for TPD were over twice as high, and triples' crash rates were 38% higher. Statistical tests showed that each of the differences was statistically significant (Abdel-Rahim, Berrio-Gonzales *et al*. 2006b).

There has been a series of recent pilot studies within states or groups of states to test the effect of temporarily increasing weight limits on selected roads. Reports have been issued on the results of these studies in Idaho, Vermont, and Maine. In addition, there have been studies to estimate the effect of increasing state weight limits in Wisconsin and Minnesota, based on currently available data.

In 2013, the State of Idaho issued a final report on the ten-year project to determine the effect of increasing weight limits on state highways (Department of Transportation Idaho, 2013). The project was initiated as a pilot in 2003. Weight limits were raised from 105,000 lb to 129,000 lb on 16 routes. Beginning in 2005, 19 more routes were added. Truck operators wishing to take advantage of the heavier weights applied for permits and were required to use truck combinations with additional axles. A typical doubles combination with a 105,000 lb GCW was configured as a 3-axle tractor, 2-axle semitrailer, and 3-axle 2nd trailer for 8 axles. Typical 129,000 lb configurations were configured as 3-4-3 for ten axles or 3-4-5 for 11 axles. Five-axle straight trucks pulling a 5-axle "pup" trailer were also used.

The carriers were required to report trip and crash data, with no field data collection. There were 264,169 pilot project trips and 1,359 trucks operated by 127 different shipping companies. However, most of the trips were accounted for by three companies. Most carriers were not willing or able to change equipment or operations to take advantage of the higher permitted weights. The trucks were primarily used to haul bulk commodities, including sugar beets, hay, agricultural feed, aggregates, coal and hazardous waste.

The effect on safety was measured by comparing crash rates before the pilot and over four periods within the pilot project term, and by comparing crash rates on pilot and non–pilot routes. Crash rates were calculated for all vehicles by route (including light vehicles) and for trucks as such and not the pilot trucks. The data used were not able to break out the pilot trucks either in the exposure (VMT) or crash data. Thus, crash rates for the 129,000 lb trucks were not measured directly, but rather their effect was inferred from the effect on crash rates for all vehicles and for trucks.

No statistically significant effect was observed. There was a 4.1% increase in truck crash rates on pilot routes in comparison with non-pilot routes. Pilot routes with the greatest utilization by the 129,000 lb trucks also experienced a slight increase, but again, it was not statistically significant. The study was unable to control for any potentially confounding factors, such as changes in the operating environment

Vermont also implemented a pilot project to assess the effect of increasing weight limits on interstate highways. The pilot allowed 6-axle, 99,000 lb GCW tractor-semitrailers on interstate highways. In addition, restrictions were dropped on several other configurations that had been allowed on state roads, but would be allowed on Interstates under the pilot. These trucks include 3-axle 55,000 lb GVW, 4-axle 69,000 lb GVW, 5-axle 90,000 lb GVW, and 6-axle 99,000 lb GVW. The project was a one-year study that assessed effects on truck volumes, the vehicle fleet, damage to pavement and bridges, and fuel consumption, in addition to safety. Highway safety was measured in terms of the number of truck crashes on the interstate and state highways, and the number of fatal truck crashes (FHWA, 2012).

The results with respect to safety were inconclusive. Total truck crashes on interstate highways increased by 10%, compared with 4% increase nationally. The number of fatalities increased from one to three. On non-interstate highways, safety gains were expected because it was expected truck travel would shift to interstates. But the number of crashes on non-Interstate highways actually increased by 24%, and this increase occurred despite a 2% decrease in truck VMT on non-interstate routes.

The study reported that none of these differences were statistically significant. Crash rates were not computed because VMT data were not available for the pilot year. The pilot period came after two years of severe decline in freight movement in the state, and the pilot year itself was one of only modest recovery. Thus, fluctuations from year to year are difficult to interpret. Any safety effect was too small to detect in the circumstances.

The state of Wisconsin commissioned a study to evaluate the consequences of increasing weight limits on Wisconsin roads (Cambridge Systematics, 2009). The study evaluated several specific configurations, which were not currently in use on any roads in the state, but which might be permitted in the future. The possible configurations, called "scenario trucks" in the study, include:

- 6-axle, 90,000 lb tractor-semitrailer;
- 7-axle, 97,000 lb tractor-semitrailer;
- 7-axle, 80,000 lb straight truck;
- 8-axle, 108,000 lb tractor-double combination.

The goal of the report was to assess the impact of permitting the above vehicles on the economy, infrastructure, and safety.

The safety effects of the scenario trucks were estimated by characterizing the performance characteristics of the vehicles and estimating the effects of those characteristics on crash rates. In other words, the study did not measure crash rates for the scenario trucks directly, because they are not operating on the roads. Rather, the approach taken was to estimate the marginal impact of increasing weight limits by applying fundamental assumptions derived from previous studies. These include:

- Crash rates increase by 0.25% for each 1% increase in gross weight;
- 5-axle tractor-double combinations have about a 10% higher crash rate than tractor-semitrailers; and
- To account for the safety effect of increased braking power because of additional axles, for every 20% increase in axles, crash rates decline by 5%.

These relationships were taken from the two TRB reports (TRB 1990a; TRB 1990b) discussed earlier, and assume that all else remains equal, *e.g.*, that tractor-double trailer combinations are operated in the same environment and under the same regulatory policy as tractor-semitrailers, that all brakes are properly adjusted and so on. Under the assumptions given, any increase in size-and-weight limits will result in an increase in crash rates on a per-vehicle basis, albeit possibly mitigated by additional axles. There would be a net saving in crashes if allowing heavier trucks resulted in fewer total trucks on the road, or if trucks were diverted to safer roads. Overall, the study estimated net benefits to safety, expressed as a cost savings, for each of the scenario combinations. However, it is important to bear in mind that the results depend on the validity of the assumptions made, rather than direct measurement of crash rates.

The goal of a Maine/New Hampshire study was the opposite of the other recent states studies: instead of the evaluating the consequences of raising allowable weights on interstate roads, the study addressed the consequences of reversing an exemption that allowed trucks over 80,000 lbs. on the Maine Turnpike. In 1998, Maine allowed 6-axle tractor-trailer combinations with GVW up to 100,000 lb In addition, a 10% GVW tolerance was granted on 5-axle tractor-semitrailers transporting certain special commodities, primarily agricultural, mining, or materials related to forestry or fisheries. New Hampshire followed the same policy on the New Hampshire turnpike. Removing these exemptions would divert the previously exempted trucks onto lower-standard roads. The study addresses the safety, infrastructure, social and economic impacts of this change in policy.

The basic study approach is to compare the safety of the exempt trucks on the Maine turnpike with their crash experience on the roads to which they would be diverted. Estimates of VMT were developed from commodity flow data and models, along with vehicle classification counts and weigh-in-motion data from roadway segments. Using this information, VMT was estimated for different truck types and routes, along with estimated changes to VMT if the exemption was removed. The study assumed that drivers would choose the most time-efficient route between origin and destination. As policy changes available routes, it is assumed that drivers will choose the next most efficient route.

Maine crash data are “geo-coded,” meaning that the specific locations of crashes are identified in the crash data. In addition, Maine records the number of axles on certain truck configurations, so it is possible to count crashes for 5- and 6-axle tractor-semitrailers on roadways for which estimates of VMT were derived from commodity flow data, as described above. Crash rates were calculated for the current exempt (turnpike) routes and for the “diversion” routes, the routes to which the trucks would be diverted if the exemption was removed. Crash rates were calculated for 5- and 6-axle tractor-semitrailers combined. Only Maine could be included in the crash rate analysis since only Maine has geo-coded data.

The results show that crash rates for 5- and 6-axle singles on the Maine Turnpike are 1/4th the rates on the diversion routes. Three years of crash data (2000-2002) were used in the calculation, amounting to a reported 1,000 crashes, so the result should be statistically robust, even though confidence intervals were not determined. The difference was consistent with the common finding that crash rates are lower on higher quality roads.

The study also considered the effect on crash severity. Off the Turnpike, crashes on the diversion routes include more intersection, head-on, opposite direction sideswipe, and rear-end/sideswipe (likely same-direction sideswipes). Most of the roads the exempt trucks would be diverted to are two-lane -way roads. Crash rates by severity are all higher on the lower-quality roads. Overall, the analysis found that removing the exemption from Federal weight limits would result in an increase of 1.2 crashes per year and increased crash costs (Wilbur Smith Associates, Woodrooffe and Associates *et al*. 2004).

4.0 International Experience

4.1 Contrasting the Canadian and Australian Approach

In general, the evolution of commercial vehicle configurations internationally is bifurcated in terms of configuration dominance. In Europe, the single unit truck and truck trailer dominate largely because of strict overall vehicle length requirements brought on by the restrictive geometrical characteristics of the European road network that existed at the time that size and weight regulations were developed. In North America and Australia, the tractor semitrailers dominate particularly on the open road network. Both Canada and Australia have reformed their size and weight regulations with the special focus on improving safety through the use of Performance Based Standards (PBS), which define vehicle dynamic and road occupancy performance characteristics of vehicles.

The European Automobile Manufactures' Association (ACEA) recently published a study describing the characteristics of the Australian and Canadian approach to PBS size and weight regulation (Woodrooffe 2013).

4.2 Australia

Australia has implemented a nationwide PBS system for regulating weights and dimensions tied to a road access network based on vehicle class. As with Canada, the Australian PBS was developed in response to what were broadly agreed as inflexible prescriptive vehicle regulations. The reformed system provides for flexibility in vehicle design allowing creative forces to be applied to the development of specialized vehicles that improve the efficiency and safety of particular transport tasks. Australia took PBS to a higher level by largely replacing the prescriptive system with a unique PBS regulatory instrument. The original objectives of the Australian PBS effort can be summarized as follows:

1. Provide more sustainable transport systems through improved road vehicle regulations controlling heavy vehicle safety and infrastructure impacts; and
2. Provide more flexible road transport regulations that allow increased innovation and more rapid adoption of new technologies, while providing seamless operations nationally.

The national Australian PBS legislation classifies heavy vehicles on the basis of freight task as follows.

- **General access** vehicles, which are those complying with the vehicle standards and mass and loading regulations (*e.g.,* rigid trucks, semitrailers, standard type truck trailers).

- **Class 1** vehicles are engaged in "special purpose" transport operations, which include oversize and over mass, agricultural and mobile plant vehicles (*e.g.*, low loaders, concrete mixer trucks).
- **Class 2** vehicles are specific types and combinations, which are compliant with applicable model regulations. As a result of their size and/or mass they are subject to restricted access (*e.g.,* B-doubles, road trains and long buses).
- **Class 3** vehicles are non-standard heavy vehicles, which do not fall within the class 1 or 2 categories. These are typically higher productivity vehicles, which operate under concessional access/permit schemes or under the PBS scheme (*e.g.*, super B-doubles and under existing legislation, all PBS vehicles). Their access to the road network is either restricted or in accordance with the PBS access levels.

Sixteen standards relating to the operational performance of a vehicle form the basis of the Australian PBS system, which represents a distillation of the measures outlined in the Definition of Potential Performance Measures and Initial Standards study (Prem, Ramsay *et al*. 2001). The measures are organized under the following general classifications and expanded in Table 1.

- Vehicle stability standards
- Trailer dynamic performance standards
- Vehicle powertrain standards
- Vehicle maneuverability standards
- Infrastructure standards

There is well-defined protocol detailing the procedures by which a candidate vehicle is assessed using PBS. (NTC 2008) The assessment may be carried out by a qualified certifier using either field tests or numerical simulation. Vehicle characteristics such as engine, gearbox, differential, mass, wheels, tires, axles, couplings, suspensions and dimensions must be formally recorded in a specified format. At the discretion of the assessor, a sensitivity analysis may be required if it is believed that small changes in "risk sensitive parameters" will likely result in large variations in vehicle behavior. Once the candidate vehicle is found to be in compliance with the individual standards, a "certificate of compliance" is issued. The assessor is required to retain all documentation related to the analysis for a period of five years.

Table 1: List of Australian Performance Standards

#	Performance Standards	Description
Vehicle stability standards		
1	Static rollover threshold	Ensures that geometry and suspension provide a set level of vehicle stability
2	Directional stability under braking	Ensures that vehicles remain controllable when braking in a turn
3	Yaw damping coefficient	Ensures that vehicles do not suffer excessive roll oscillation after maneuvers
Trailer dynamic performance standards		
4	High-speed transient offtracking	Ensures that trailers follow the path of the prime mover during unbraked avoidance maneuvers
5	Tracking Ability on a Straight Path	Ensures that trailers of multi-articulated vehicles do not swing excessively after avoidance maneuvers
6	Rearward Amplification	Ensures that trailers do not have excessive lateral response during evasive maneuvers
Vehicle powertrain standards		
7	Startability	Ensures that the fully laden vehicle may start on a hill of set grade
8	Gradeability	Ensures that the fully laden vehicle may maintain speed on a hill of set grade
9	Acceleration capability	Ensures that a vehicle may accelerate at an appropriate rate to clear traffic lights, etc.
Vehicle maneuverability standards		
10	Low-speed swept path	Ensures that a vehicle may safely maneuver around corners typical of those found on its compatible network without cutting the corner
11	Frontal swing	Ensures that a vehicle may safely maneuver around corners typical of those found on its compatible network without contacting the rear of the vehicle
12	Tail swing	Ensures that a vehicle may safely maneuver around corners typical of those found on its compatible network without contacting the rear of the vehicle
13	Steer tire friction demand	Ensures that steering axle will be effective in changing the course of the vehicle as required by driver input
Infrastructure standards		
14	Bridge loading	Ensures that vehicle mass is compatible with bridge infrastructure for set route
15	Tire contact pressure distribution	Ensures that pressure transferred to the road surface by the tires is compatible with road infrastructure for set route
16	Pavement horizontal loading	Ensures that horizontal force transferred to the road surface by the tires is compatible with road infrastructure for set route

Source: ACEA

4.3 Canada

Canada was the first country to develop and use PBS during a successful effort to harmonize heavy vehicle weight and dimension regulations. This was accomplished through a scientifically structured size and weight research program that was conducted from 1983 to 1986. It included full scale testing of vehicles including computer simulation analysis and validation of vehicle dynamic performance. Through this process it was recognized that vehicle configuration type, axle layout, and the characteristics of the load profoundly influence vehicle stability and control characteristics as well as the compatibility of the vehicle with highway geometry. To objectively assess various truck size and weight policy options, a set of "Performance Based Standards" were created. These performance measures are summarized as follows:

- Static Rollover Threshold;
- Rearward Amplification;
- Load Transfer Ratio;
- Low-Speed Offtracking;
- High-Speed Offtracking;
- Transient High-Speed Offtracking; and
- High-speed friction utilization.

Static Rollover Threshold
Steady-state roll stability is an expression of the magnitude of lateral acceleration required to produce vehicle rollover. It is given as a proportion of gravitational acceleration (g).

Rearward Amplification
When articulated vehicles undergo rapid steering, the steering effect at the trailer is magnified and results in increased side force or lateral acceleration acting on the rear trailer. This in turn increases the likelihood of the trailer rolling over under some circumstances. As an example, a truck faced with the need to change lanes quickly on a freeway to avoid an accident can do so at less risk if it has favorable rearward amplification characteristics.

Load Transfer Ratio
Load Transfer Ratio (LTR) is defined as the proportion of load on one side of a vehicle unit transferred to the other side of the vehicle in a transient maneuver. It established how close a vehicle unit is to rollover during an evasive maneuver.

Low-Speed Offtracking
Low speed offtracking represents a measure of the swept path of the vehicle and its lateral road space requirement when turning at intersections or when turning into loading areas.

High-Speed Offtracking

High-speed offtracking is defined as the extent to which the rearmost tires of the vehicle track outboard of the tires of the hauling unit in a steady-turn at highway speed. High-speed offtracking relates closely to road width requirements for the travel of combination vehicles.

Transient High-Speed Offtracking

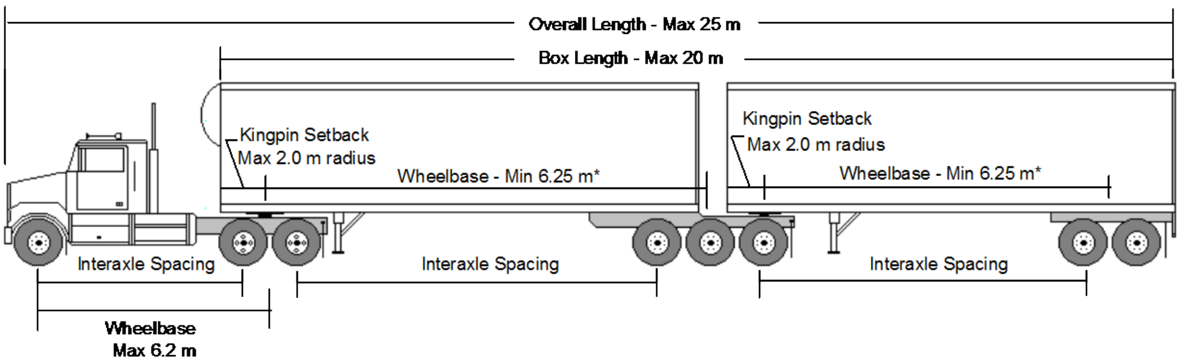
Transient high-speed offtracking is a measure of the lateral excursion of the rear of the vehicle with reference to the path taken by the front of the vehicle during a dynamic manoeuvre. It expresses the amount of additional road space used by the vehicle combination in an avoidance manoeuvre.

Using the PBS and the results of a sensitivity analysis, Canada developed truck size and weight policy consisting of a number of “vehicle envelopes” that provide flexibility in design for various vehicle classes while ensuring that the vehicles would have desirable safety performance attributes. The envelope concept reduced the burden of compliance evaluation when small variations in vehicle design were required. An example is shown in Figure 1.

The vehicle categories covered include the following:

- Category 1: Tractor Semitrailer;
- Category 2: A Train Double;
- Category 3: B Train Double;
- Category 3: C Train Double;
- Category 5: Straight Truck;
- Category 6: Truck - Pony Trailer;
- Category 7: Truck - Full Trailer; and
- Category 8: Intercity Bus.

The manner in which the size and weight policy was implemented is noteworthy. The responsibility for size and weight regulation in Canada rests with the provinces and territories. The federal government has no central role in size and weight policy making. In order to facilitate the implementation, the provinces agreed to a Memorandum of Understanding (MOU) which laid out the vehicle system requirements. It was done through the Council of Ministers Responsible for Transportation and Highway Safety support Task Force on Vehicle Weights and Dimensions Policy, which publishes the size and weight requirements of the vehicle envelopes (see http://www.comt.ca/english/programs/trucking/MOU%202011.pdf).



DIMENSION	LIMIT
Overall Length	Maximum 25 m
Overall Width	Maximum 2.6 m
Overall Height	Maximum 4.15 m
Box Length	Maximum 20.0 m
Tractor:	
Wheelbase	Maximum 6.2 m
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Lead Semitrailer	
Wheelbase	Minimum 6.25 m
Kingpin Setback	Maximum 2.0 m radius
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Tridem Axle Spread	Minimum 2.4 m/Maximum 3.1 m
Track Width	Minimum 2.5 m/Maximum 2.6 m
Fifth Wheel Position	No more than 0.3 m behind the center of the rearmost axle on the semitrailer
Second Semitrailer	
Wheelbase	Minimum 6.25 m
Kingpin Setback	Maximum 2.0 m radius
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Tridem Axle Spread	Minimum 2.4 m/Maximum 3.1 m
Track Width	Minimum 2.5 m/Maximum 2.6 m
*** Sum of Semitrailer Wheelbases**	Maximum 17.0 m
Interaxle Spacings	
Single Axle to Single or Tandem Axle	Minimum 3.0 m
Tandem Axle to Tandem Axle	Minimum 5.0 m
Tandem Axle to Tridem Axle	Minimum 5.5 m
Tridem Axle to Tridem Axle	Minimum 6.0 m

Figure 1: An example of an envelope vehicle used in Canada

The MOU allows each province to maintain their legislative independence in size and weight policy making with the understanding the vehicle envelopes specified by the MOU would be included in the provincial regulatory instrument. Task Force on Vehicle Weights and Dimensions Policy has continued to exist and meets on a regular basis. As such, size and weight policy development is a continuous process in Canada and the MOU is updated when necessary. This institutional structure greatly simplified the implementation process and allows for periodic updates when conditions warrant.

5.0 LCV Systems

Canada has developed unique policies with respect to the operation of long combination vehicles and select provinces use PBS to approve candidate vehicles (Woodrooffe, Anderson *et al*. 2004). In most provinces LCVs operate under a special permit program governed by strict operating conditions. The structure and enforcement mechanisms of the policy engender a level of safety consciousness within the LCV fleet, which far exceeds that found in other vehicle classes. The principal motivating factor for heightened safety performance is related to the special safety requirements and fact that a special permit can easily be revoked for safety performance failure. The special permit system requires that operators be trained to meet and maintain the requirements outlined in the Canadian Trucking Alliance's "Longer Combination Vehicles Driver's Manual."

The province of Alberta has the following requirements for LCV drivers. Drivers must obtain an annual certificate verifying that they are in compliance with certain requirements related to the type of license, training, driving experience, physical fitness and criminal records. The permit conditions also place controls on where LCVs can operate including hours of operation (time of day), vehicle dimensions such as wheelbase, hitch offset and dolly drawbar length. The policy also contains operational requirements such as adverse weather restrictions, requirements that the vehicles track properly and do not sway, and requirements that vehicles do not cross opposing lanes of traffic unless absolutely necessary.

The Provinces of Alberta and Ontario have developed policy governing LCV movements so as to reduce high-risk travel of the LCV fleet. This is done by restricting movement in urban areas during peak hours, public holidays or during inclement weather. The safety performance of the Alberta LCVs was found to be in the order of 3 to 5 times better than the standard tractor semitrailer fleet operating on identical roads (crashes, fatalities and injuries per distance travelled).

5.1 Alberta LCV Program

Details on the Alberta LCV program were found on the Provincial website (Alberta Transportation). Long Combination Vehicles (LCVs)[1] are truck and trailer combinations, consisting of a tractor with two or three trailers or semitrailers, in which the number of trailers and/or the combined length of the combination exceed the regular limits of 25 meters (82 feet). These vehicles have been operating on Alberta highways since 1969, when triple trailer combinations were introduced. Currently in Alberta, the maximum gross vehicle weight applicable to LCVs is 62,500 kilograms while the maximum configuration length is 37 meters (121.4 feet). A description of the Alberta LCV configurations follows:

[1] Also known as Energy Efficient Motor Vehicles (EEMVs).

- **Rocky Mountain Double –** A combination vehicle consisting of a tractor, a 12.2 m (40 feet) to 15.2 m (53 feet) semitrailer, and a shorter 7.3 m (24 feet) to 5.5 m (28 feet) semitrailer. The total length does not exceed 31 m (102 feet). These vehicles are typically used when cargo considerations are governed by weight rather than the cubic capacity of the trailer.
- **Turnpike Double –** A tractor plus double trailers. Each trailer is between 12.2 m (40 feet) and 16.2 m (53 feet) long. The Turnpike Double is typically used for carrying cargo that benefits from the additional cubic capacity of the trailer arrangement.
- **Triple Trailer –** This combination consists of a tractor with three trailers of approximately the same length. The typical trailer length is approximately 7.3 m and 8.5 m (24 to 28 feet). The Triple Trailer is used for carrying cargo that benefits from the additional cubic capacity of the trailer arrangement or from the operational flexibility of having three smaller trailers that can be easily redistributed as separate vehicle units at the point of origin and destination.

The province of Alberta has had long standing policy governing LCV operations under a special permit system. The policy is structured to maximize safety by placing controls on the operation and driver qualifications. The policy can be found on the province of Alberta's website (http://www.transportation.alberta.ca/Content/docType276/Production/lcv.pdf).

<u>General Provisions</u>

The following is an edited summary of the provisions that apply to the permit holders.

- The permit holder must formally agree to abide by the routes, vehicle dimensions, equipment and conditions specified and carry a copy of the appropriate permit in each power unit.
- The permit holder must provide any reasonable statistics related to LCV operations to the province.
- The permit holder must investigate and document the findings of every traffic accident involving a vehicle registered to the permit holder for more than 4,500 kilograms (9,920.8 pounds) or a passenger vehicle originally designed to transport 11 or more persons, including the driver, that resulted in:
    - The death of a person;
    - An injury requiring treatment by a medical doctor;
    - A condition that causes an employee to lose consciousness; or
    - Damage to all property, including cargo, totaling $2,000 or more.
- Collisions found to have occurred while operating under permit must be evaluated to determine if the collision was preventable on the part of the permit holder and/or their driver(s). Each evaluation must use the criteria established by the National Safety

Council (www.nsc.org). Verified non-preventable collisions are not used when evaluating the carrier's risk associated with operation under the permit.

- The permit holder must ensure, and be able to provide proof, that their drivers and driver trainers meet and maintain the requirements specified by the program.
- Prior to issuing an LCV Driver's Certificate, the carrier must ensure the driver meets the following qualifications:
  - Holds a valid Class 1 driver's license or equivalent;
  - Has a minimum of 24 months or 150,000 km (93,206 miles) of driving experience with articulated vehicles;
  - Has passed a Professional Driver Improvement Course within the past 48 months;
  - Has passed the Alberta Motor Transport Association's "Longer Combination Vehicles Driver Training Course";
  - The driver's abstract, dated not more than one month prior to the issue date of the Drivers Certificate, must show no driving-related criminal code convictions in the prior 36 months; no more than 2 moving violations in the prior 12 months; and no more than 3 moving violations in the prior 36 months; and
  - In the past 12 months the driver has reviewed all current regulations, permit conditions and issues covering the operation of LCV's.
- A driver-in-training may operate a long combination vehicle, while accompanied by a driver who holds a valid LCV Driver's Certificate

Equipment Requirements

- All tractors must feature a maximum gross weight to power ratio of no more than 160 kilogram per horsepower (353 pounds/horsepower) or 120 kilogram/kilowatt (120 kg/kW equals 265 pounds /kilowatt).
- Tractor air supply – compressors must be capable of raising the air pressure from 50 pounds per square inch (PSI) to 90 PSI with the engine idling at 1,250 revolutions per minute (RPM) in two minutes or less with the tractor alone and four minutes or less with the trailers hooked up and the complete air system energized.
- Air reservoirs – tractors must be equipped with at least two air reservoirs. Each reservoir must have at least 41,000 cm^3 (2,500 in^3) of capacity. The two tanks must have a combined capacity of 82,000 cm^3 (5,000 in^3).
- Brake relay valves – compatible relay valves are required to reduce the time lapse between treadle application and brake application at the rear most trailer.
- The rear axle group of the power unit and all axle groups of the trailers and converters must be equipped with mud flaps or splash guards that are constructed to ensure that they remain in a rigid downward position at all times. All mud flaps or splash guards shall be mounted behind the wheels at a distance not exceeding 25.0 cm (10 inches) to the rear of the wheels.

- The trailers of the combination shall be joined together by means of no-slack pintle hook(s), equipped with an air or hydraulic ram. The no-slack ram is to be incorporated in either the pintle hook or the pintle hook eye of the coupling apparatus.
- The allowable tire and axle weight limits are specified by the special permit program

<u>Operational Requirements</u>

- Any breakup or makeup of an LCV must be done off public roadways on private property or as directed by an authorized Alberta Transportation staff member or peace officer.
- The vehicles in a combination shall be so loaded and coupled together so as to ensure that any such combination travelling on a level, smooth, paved surface will follow in the path of the towing vehicle without shifting, swerving, or swaying from side to side over 10 cm to each side of the path of the towing vehicle when it is moving in a straight line.
- Drivers shall avoid crossing opposing lanes of traffic unless absolutely necessary.
- Maximum speed shall be the lesser of 100 km/h (62 mph) or the posted speed limit.
- The permit cannot be combined with any other permit for overwidth, overheight, overhang, or overweight.
- All provincial and municipal road bans shall be observed unless specified otherwise.

<u>Adverse Weather</u>

For multi-lane highways:

- LCV's shall not cross oncoming lanes where visibility does not allow it to be done safely.
- Where there is accumulated snow on the highway or when the highway is icy, LCV's shall not pass any other vehicle unless that vehicle is traveling at a speed of less than 70 km/hr. (45 mph).
- Where a highway becomes impassible due to icy or slippery conditions, LCV’s will obey all advisories posted by the authority of Alberta Transportation.

For two lane highways

LCV’s shall not operate during adverse weather or driving conditions (including but not limited to rain, snow, sleet, ice, smoke, fog or other conditions) which:

- Obscure or impede the driver’s ability to drive in a safe manner; and
- Prevent the driver from driving with reasonable consideration for the safety of persons using the highway.
- The permit holder is required to make a reasonable effort to determine the driving conditions on the route. Vehicles must not be dispatched when adverse conditions are known to be present on the route. Drivers encountering unexpected adverse conditions must stop at the next safe location (or as directed by an authorized Alberta Transportation staff member or a peace officer) and wait for the adverse conditions to abate.

Hours of Operation

Operation will be allowed 24 hours per day except in the following cases:
On all Highways, movement will not be allowed after 4:00 pm on December 24 and December 31. On Two-lane Highways for weekends with no special holiday on the Friday or the Monday, movement will not be allowed from 4:00 pm to 8:00 pm on Friday and from 4:00 pm to 8:00 pm on Sunday. For a long weekend when a special holiday falls on a Friday, movement will not be allowed from 4:00 pm to 8:00 pm on the preceding Thursday and from 4:00 pm to 8:00 pm on Sunday. For a long weekend when a special holiday falls on a Monday, movement will not be allowed from 4:00 pm to 8:00 pm Friday and from 4:00 pm to 8:00 pm on the Monday.

In addition to the general hours of operation restrictions, there are workday and weekend time of day restrictions tied to specific road sections where congestion is problematic.

Exemptions for Vehicle length

Aerodynamic devices are excluded from the measurement of overall length, provided that:

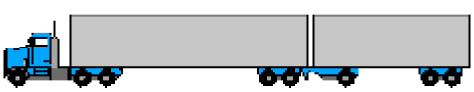
- Any portion of the device more than 1.9 meters (6 feet) above the ground does not protrude more than 0.61 meters (2 feet) beyond the rear of the vehicle; and
- Any portion of the device within 1.9 meters (6 feet) of the ground does not protrude more than 0.30 meters (1 foot) beyond the rear of the vehicle.

Heavy duty bumpers and devices designed to reduce the impacts of wildlife collisions are excluded from the measurement of overall length, provided that:

- Bumpers and devices do not extend more than 0.30 meters (1 foot) beyond the front of a truck tractor.

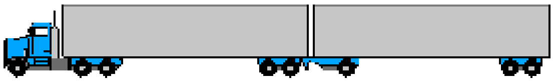
In addition to the requirements listed above, there are configuration specific requirements with respect to vehicle weight that are specified in the policy document for safety reasons.

For the Rocky Mountain Double configuration:



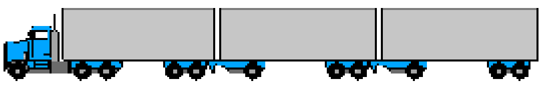
- In all cases, the lead semitrailer of the configuration must be heavier than the second trailer or semitrailer; and
- An empty converter dolly may be towed behind the combination so long as the overall length does not exceed the limits stated on this page, and the dolly is equipped with all legally required lights and equipment.

For the Turnpike Double configuration:



- In all cases, the lead semitrailer of the configuration must be heavier than the second trailer or semitrailer;
- Turnpike doubles may include a tridem axle group on the second trailer; and
- An empty converter dolly may be towed behind the combination so long as the overall length does not exceed 41 meters (135 feet) and the dolly is equipped with all legally required lights and equipment.

For the Triple Trailer configuration:



- In all cases, the lead semitrailer of the configuration must be heavier than the second trailer or semitrailer and the third trailer or semitrailer is the lightest;
- An empty converter dolly may not be towed behind a triple trailer combination; and
- In order to qualify for the 38 m length (125 feet), both trailers two and three must be coupled by a B converter.

5.2 Ontario LCV Program

Long Combination Vehicles began operating in Ontario in August 2009 under a program similar to the Alberta LCV program. However unlike Alberta, the Ontario program is seasonal in that LCVs are not permitted to operate during the winter months of December, January and February. The program is tightly focused on safety and has the following objectives taken from a program review published by Ontario Ministry of Transportation, Transportation Policy Branch (MTO) (Ontario Ministry of Transportation 2011):

1. Safety – Ontario's top priority is to make Ontario's roads the safest in North America.
2. Through strong program conditions, Ontario ensures LCV operations are safe.
3. Economy – LCVs have economic benefits for shippers and carriers with consolidated loads using fewer resources. LCV program is part of the harmonization efforts with Quebec to make it easier for shippers to move goods across provincial boundaries.
4. Environment – Greenhouse gas emissions are directly linked to the amount of fuel consumed.
5. LCVs use approximately 1/3 less fuel than two tractor-trailers.

6. Infrastructure Protection – LCV vehicle weights and dimensions standards minimize damage to roads and bridges.
7. Congestion Reduction – LCVs operate outside of rush hour periods in the Greater Toronto Area (GTA).

Limited capacity at rest stops for carriers to use in emergencies has been identified as a potential challenge with expanded LCV operations. Carriers are confident that their dispatching procedures will allow them to work their way through bad weather or traffic issues. MTO continues to work with the industry to address the need for additional rest/emergency stops in key parts of the LCV network.

MTO maintains a careful approach to LCV program management and monitoring to ensure safe and efficient operations. Regular program management tasks include monitoring monthly carrier trip records, and continued random checks of specific trip details to ensure compliance with program conditions. With respect to broader aspects of the program, MTO continues to work with Ontario Trucking Association (OTA) to develop an improved Rest/Emergency Stop Network, as well as work with Quebec and other provinces to better harmonize LCV program conditions.

Monitoring Performance of LCVs

Several sources of data and information are used to monitor ongoing performance of LCVs, including information obtained from program participants.

1. All carriers participating in the program are required to maintain a record of each LCV trip. The recorded trip information includes the driver's name, the trip origin and destination, commodities carried and the trip distance. For each trip, carriers must also indicate the probable alternative mode of transport (truck, rail, other) had LCVs not been available. This information is submitted to MTO on a monthly basis and provides a basis for certain components of this review.
2. MTO also requests additional data related to driver qualifications, vehicle standards and speed recordings for selected trips from a random sampling of carriers on a regular basis. This is one of the methods used to verify compliance with program requirements.
3. Ontario LCVs are made up of a tractor pulling two full-length semitrailers up to 40 meters (131 feet) in overall length.
4. Participating carriers are responsible for verifying that drivers and instructors meet the specified qualifications, training and experience, and have obtained an OTA-issued certificate. This includes ensuring that:
    - LCV drivers are proven safe and reliable tractor-trailer operators with a minimum of 5 years of experience;

- All LCV drivers successfully complete specified LCV driver training that includes classroom, yard and on-road training and evaluation, including at least 1,000 km of practical LCV experience;
- LCV instructors have at least 10,000 km of LCV experience; and
- Carriers are required to enter into a Memorandum of Understanding (MoU) with MTO signifying that the carrier accepts responsibilities as outlined in the program conditions. All approved carriers must maintain a satisfactory Carrier Safety Rating, not just in their LCV operations but in all their operations.

Strict guidelines detailing the vehicle configuration, dimensions and weight allowances are specified in the permit conditions. LCVs cannot be heavier than single tractor-trailers (i.e., 63,500 kg = 140K lb). LCVs are required to have special equipment including horsepower minimums, on-board speed recording devices, anti-lock braking systems (ABS), additional lighting, rear signage and electronic stability control (ESC).

LCV permits have specific and detailed operating restrictions that outline where and when participants may operate these vehicles. Permit conditions outline that LCVs may only operate on approved routes, must not detour off approved routes for any reason, including for road closures, and must not operate on any routes on the evening preceding and the last evening of long weekends.

LCVs must not exceed a speed of 90 km/h, and must not travel in the Greater Toronto Area during morning and afternoon rush hours. They are not permitted to carry livestock or dangerous goods requiring a placard. LCVs must not operate during the winter months of December, January and February and must not operate during inclement weather, poor visibility or poor road conditions.

<u>Details of Ontario LCV Program</u>

Carrier Qualifications

In Ontario, carriers must have at least five years trucking experience, maintain a ‘satisfactory’ Carrier Safety Rating and have at least $5 million liability insurance. Participating carriers are expected to enter into a Memorandum of Understanding (MOU) with MTO signifying that the carrier accepts all responsibilities as outlined in the program conditions document. As well, the carrier must have resources to acquire specialized equipment, train instructors and drivers and engage engineering consultants to assess proposed routes.

If the carrier fails to meet or maintain the high standards set out in the program conditions, they are denied entry into the program or, if they have already been issued permits, those permits are automatically revoked. The potential loss of LCV permits provides a significant incentive for these carriers to ensure all of their operations meet high safety standards.

Driver Qualifications

Drivers must have an OTA-issued LCV Driver Certificate based on a valid Class A driver's license with Z (air brake) endorsement, or equivalent from another jurisdiction, and a minimum of five years provable tractor-trailer driving experience. Drivers must not have had more than two moving violations within the past year, or more than three moving violations in the past two years, and no driving-related criminal code convictions within the past three years.

Each driver must successfully complete the OTA LCV Driver Training Program. This program includes classroom, yard and on-road training and evaluation, including at least 1,000 km of practical LCV experience with a trainer. Alternatively, the driver may have successfully completed an approved Canadian Trucking Alliance (CTA) LCV driver training program in another province or have a Quebec "T" license endorsement issued prior to June 1, 2009, including at least 1,000 km of LCV experience.

LCV instructors may be employed by carriers as 'in-house' driver-trainers or may be attached to an appropriate training organization. The instructors must be qualified LCV drivers themselves and possess an up-to-date OTA-issued LCV Instructor Certificate, which allows them to train Ontario LCV drivers. In addition, LCV instructors must have at least 10,000 kilometers of LCV driving experience. Instruction may only be given to drivers of carriers possessing valid LCV operating permits on approved routes and equipment.

Route Conditions

LCVs are only allowed to operate on designated, approved routes in Ontario. This consists of the primary highway network, rest/emergency stops and origin/destination locations.

The primary LCV highway network consists of 400-series (and similar) highways individually authorized for general LCV travel. Highways must be multilane with controlled access. MTO required the OTA to undertake a full assessment of the highway network to ensure the highways could accommodate LCVs. This included engineering assessments for all the highway-to-highway ramps to identify those ramps that could accommodate LCVs. Some ramps were found to be unacceptable for LCV operations. These are excluded from the primary LCV highway network.

Origin/Destination locations must generally be within km of a primary highway. All off-highway travel to or from any LCV origin or destination location requires a full engineering assessment of the route prior to approval. Carriers are responsible for conducting an engineering assessment of the access route and obtaining any municipal approvals for travel on municipal roads.

5.3 OECD Moving Freight in Better Trucks

The International Transport Forum at the OECD produced two reports (Woodrooffe, Glaeser *et al*. 2010; Organisation for Economic Co-operation and Development 2011) dealing with the analysis of more productive vehicles. The purpose of the reports was to "identify potential improvements in terms of more effective safety and environmental regulation for trucks, backed by better systems of enforcement, and to identify opportunities for greater efficiency and higher productivity." The two topic areas most relevant to this desk scan are heavy truck safety and the evaluation of truck performance.

First, the studies noted that there was a need for additional research in several safety areas. These areas include the potential aggravation of the consequences of accidents when higher capacity vehicles are involved and possible countermeasures to mitigate these consequences, and the effect of vehicle length on the risk of overtaking and on visibility reduction for other road users.

The studies also commented that government intervention in trucking and associated activities is extensive. It includes regulation of vehicle weights and dimensions, technical characteristics of vehicles, vehicle access to the road network, driver licensing and behavior and the practices of transport operators. In some instances, trucking regulation is fragmented (between jurisdictions), prescriptive, and possibly slow to respond to changing technology, industry needs and community expectations. The study concludes that these issues undermine regulatory effectiveness.

The studies found that in Canada and Australia in particular, the current trends in trucking enforcement include:

- Electronic detection of non-compliance;
- Use of information technology to gather and apply information on patterns of behavior, to enable the focusing of enforcement resources on high-risk drivers and operators;
- Use of accreditation and safety ratings schemes to encourage the application of safety
- Management systems; and
- Imposition of legal requirements on off-road parties with control over truck operations.

It was concluded that, in general, regulatory enforcement can benefit from the same advances in technology and management as general transport operations, using vehicle positioning systems, weigh-in-motion systems, on-board monitoring systems and detection and measurement equipment at the roadside and embedded in the roadway, *e.g.*, advanced weigh-in-motion systems. The safety benefits of many of these regulatory approaches have yet to be quantified.

Most requirements relating to vehicle weights and dimensions are prescriptive. They have evolved over a long period and with significant regional differences, including within federal jurisdictions. Canada pioneered the use of performance standards for trucks in the 1980s. There is some evidence that this approach has benefitted Canada, but it yet to be proven that a similar approach would be workable in the U.S.

The study notes that lack of detailed data makes it difficult to assess crash risk on an individual truck basis. A study by TRL in the U.K. (Knight, Newton *et al*. 2008) assessed the various consequences of allowing different types of larger trucks than the current limits; the authors found likely increases in crash risks per vehicle km, but decreased crash risks per unit of goods moved.

Studies of experiences in Canada (Barton and Tardif 2003; Woodrooffe, Anderson *et al*. 2004; Montufar, Regehr *et al*. 2007; Regehr, Montufar *et al*. 2009) found that accident involvement of higher productivity vehicles per kilometer are significantly less than those of single trailer trucks in general operations. The 2009 study found, however, that the relatively superior safety performance of LCVs in Alberta might result in part from the stringent conditions placed on LCV operation through the design and enforcement of special permits. Principal among these is the requirement for experienced, specially qualified drivers for LCV movements. These studies included findings that support the *potential* for LCVs to be able to retain or enhance safety, but more definitive experience and analysis is needed.

The OECD study further concludes that computer simulations show major variations in truck performance, with some Higher Capacity Vehicles (HCVs) performing better than today's workhorse trucks. A comparative analysis of the dynamic stability, geometric performance, payload efficiency and infrastructure impact of 39 workhorse and higher capacity vehicles, using computer simulation, revealed major differences between these vehicles. The analysis indicates that, on key performance measures, higher capacity vehicles perform often better than the workhorse vehicles used to transport the majority of road freight around the world today. The data obtained from the vehicle simulations and the comparison of vehicle performance against the selected measures highlighted areas for improvement as well as good practice

In summary, the CTSW Study safety team believes that the Canadian experience offers generally positive indications of the feasibility of LCV operations, but much more needs to be known about safety performance. The project plan proposed by the team is directed at improving our understanding based on a combination of crash analysis, vehicle stability and control assessments, vehicle simulations and analysis of enforcement efforts.

5.4 Netherlands

This report documents the safety outcome of a pilot study of longer and heavier vehicles (Aarts and Honer 2010). The Netherlands introduced an initial trial of Longer Heavier Vehicles (LHVs) between 2001 and 2004. The authorization of LHVs was extended in a second trial period between 2004 and 2006. After a transitional period a large-scale trial was commenced on 1 November 2007. This was the first time that LHVs were introduced on such a large scale. Approximately 118 LHV companies participated during the course of this study and the trial period lasted until November 2012.

LHVs operating in the Netherlands must not transport livestock or hazardous materials and are equipped with the following extra hardware:

- A mirror kit in accordance with the latest European regulations;
- Advanced braking systems;
- An axle load measuring system;
- Side protection between the wheels;
- Side markings to ensure better visibility in the dark; and
- A sign on the back showing the contour of the combination and stating the length in meters.

The handling of the combination and the detailed operation of the vehicles are also subject to further requirements.

In addition to equipment requirements, with regard to road safety, in order to drive an LHV the driver must comply with the following three conditions;

- The driver must have at least five years of experience driving an articulated vehicle;
- The driver must possess a specific LHV certificate; and
- In the three years prior to participation in the trial, the driver may not have been disqualified from driving, have had his/her driving license revoked or been required to surrender his/her license due to an offence or crime.

The objective of this research was to make clear whether the current deployment of LHVs causes any issues in relation to road traffic safety, traffic flow and road design. The intent of the safety analysis is to gain preliminary insight into possible issues concerning LHVs in relation to traffic safety, road design and traffic flow. This insight was obtained through technical analysis of LHV accident records.

The following steps were used in the safety analysis.

1. Ascertaining accidents involving LHVs.
2. Individual (case-by-case) analysis of the crash.

3. Comparison of crash characteristics.

Each identified incident was thoroughly examined on a case-by-case basis addressing the following categories:

- Description of location;
- Description of circumstances;
- Description of accident;
- Significance of LHV characteristics; and
- Accident proneness of location.

With respect to safety the study produced the following conclusions.
Between 2007 and mid 2009 eleven accidents involving LHVs were recorded. All eleven accidents had resulted in material damage only (MDO).

Not all accidents that happen are recorded by police. Considering the high registration level of accidents involving fatalities and casualties requiring hospital treatment, there is little chance for any LHV accident involving casualties to have occurred.

Based on the accident analyses it cannot be concluded that LHVs are at a higher risk of accidents than regular trucks.

One matter of interest is the side visibility and perception of the vehicle combination. LHV drivers have the impression that other road users, upon passing or overtaking, discover too late that they are driving next to a longer vehicle. This poses a heightened safety risk in the following situations:

1. Short slip roads and slip roads that do not continue into a hard shoulder; and
2. Busy motorways with a high concentration of entry and exit lanes.

Poor weather conditions (wind and slippery roads) in combinations with limited axle pressure because of a light or small vehicle load may also bring about increased traffic safety risks for LHVs.

It is suspected that LHVs at threat of overturning are more difficult to correct than regular trucks.

Interactions with slow traffic will always bring about an increased risk to traffic safety; this is no different for LHVs than it is for regular trucks. The vast majority of potentially treacherous situations that were reported happened on the strategic road network, however. Moreover, drivers indicated they encountered little slow traffic on their routes. The designation of LHV routes may as such be deemed successful.

Current vehicle requirements appear to work well in practice, too:

- At regular police checks LHVs distinguish themselves in a positive sense; vehicle equipment is generally in good order;
- Brake power and visibility from within the an LHV (blind spot issue) is no different from regular goods vehicles or, according to drivers and experts, sometimes even better; and
- Splash guards and anti-spray mud flaps appear to work well in practice.

LHV drivers tend to cherish a great sense of responsibility and anticipate other traffic with great awareness. Separate LHV training and driver requirements contribute greatly to this. LHVs appear to adhere to the routes designated for use by these vehicles.

5.5 European Modular System

In the European Union, political initiatives regarding road transport are proposed by the European Commission and decided upon by the Council of Ministers in agreement with the European Parliament. Current policies build on the White Paper “European transport policy for 2010: Time to Decide” and a mid-term review of this White Paper “Keep Europe Moving – Sustainable Mobility for our Continent”. The 27 nations of the Union are responsible for domestic policies related to truck regulation but are required to allow trucks that meet European Union standards access to their road networks.

European Modular System is a concept of allowing combinations of existing loading units (modules) into longer and sometimes heavier vehicle combinations to be used on some parts of the road network. The typical modules are 20 and 40 foot cargo containers making this vehicle highly compatible with intermodal freight movement. Because of transport challenges facing Sweden and Finland, vehicle weights were significantly higher than those in most European countries. Therefore it was impractical for Sweden and Finland to apply the EU rules on weights and dimensions as they would have reduced vehicle productivity. In order to find a solution that would enable foreign transporters to compete on equal terms in Sweden and Finland, a compromise was reached to allow increased vehicle length and weight all over the EU on the condition that the existing standardized EU modules were used. This is the so-called European Modular System.

Legislation that limits the maximum size and weight of trucks (Directive 96/53/EC) together with provisions for Combined Transport operations (Directive 92/106/EEC) were re-evaluated with the view to making more efficient use of infrastructure capacity and distribution logistics. This includes potential wider use of European Modular System vehicle combinations 25.25 meters long (82.84 feet). These vehicles are in regular use in Sweden and Finland, with trials underway in some other member states (Netherlands, Denmark and some northern German States). In April 2013, Directive 96/53/EC was amended and provided a mechanism to facilitate wider use of EMS vehicles among cooperating countries.

Key elements of the policy on which regulatory decisions are based in the EU are:

- The principle of co-modality (the efficient use of different modes on their own and in combination) has been adopted as the approach to achieve optimal and sustainable utilization of resources;
- European-wide standardization of various conditions of road freight transport, such as driving licensing, working conditions and easing of administrative burdens;
- Establishment of national electronic registers for infringements of Community legislation for road freight transport and interconnection of these registers so as to obtain harmonization of sanctions for such infringements;
- A directive on road charging for heavy vehicles that seeks to prevent discrimination, or charging monopoly rents, by requiring charges to be based on road expenditure but which allows nations to charge some of the external costs associated with road transport in congested and polluted areas; and
- A target to produce 20% less CO_2 by 2020 for the EU as a whole, across all sectors of the economy, compared to a 1990 baseline.

5.6 Sweden

The following is a reproduction of the summary of research focusing on the operations and safety of long combinations vehicles published by VTI, the Swedish National Road and Transport Research Institute (Hjort and Sandin 2012).

Longer and heavier vehicles on the roads could result in large transport and economic benefits. In an on-going VTI project, denoted Sammodalitetsprojektet, an economic estimate is made of the effects of allowing longer and heavier trucks in Sweden. A central part of that project is traffic safety analysis and risk assessment of longer and heavier vehicles. This review concerns potential traffic safety effects from the introduction of longer and heavier trucks than those currently allowed in Sweden.

For this purpose, a summary of results from accident studies, literature summaries and in-depth studies of fatal accidents involving heavy trucks done in the past few years was made. In addition, a focus group study with truck drivers was conducted to pick up the traffic safety problems with road transports involving the heavy trucks available today. Results from a parallel VTI study concerning overtaking of longer trucks have also been included in order to give an overall picture of the possible traffic safety effects associated with the introduction of longer and heavier trucks in Sweden.

In summary, the literature shows that it is very complex to estimate how the traffic safety in general would be affected by the introduction of longer and heavier vehicles. Some studies indicate a slightly increased risk of accidents per vehicle mile, and that the increase depends on the vehicle combination in nature. Other studies show that the difference in accident rates in comparison to conventional vehicles is small, at least for larger and safer roads. Several studies make the case that if the number of accidents per unit of transported goods is counted, there is an expected crash risk reduction with longer and heavier vehicles. Potential adverse traffic safety effects per vehicle kilometer could thus be offset by the fact that fewer vehicles are needed to transport a given amount of goods. Some studies conclude that the longer and heavier vehicles may even have a positive net effect on traffic safety. In order to estimate the overall impact on traffic safety of an introduction of longer and heavier vehicles, it is important to take into account whether the traffic volume of heavy transport will change due to the new conditions. Will, for example, the amount of transported goods increase as a direct consequence of the introduction of these vehicles? On which roads will the transports take place? How will the freight be divided across different transport modes if longer and heavier vehicles are introduced on a larger scale? For maintaining or achieving a net positive effect on road safety, it is essential that the longer and heavier vehicles do not significantly increase the risk of any aspect of traffic safety. Based on the investigations that have been completed in this report, the following elements were found to be beneficial to completing the work required in the Study –

- Longer and heavier vehicles should mainly operate on main roads where it is possible to overtake heavy vehicles without fear of oncoming traffic. Longer and heavier vehicles should operate as little as possible in urban areas.
- Longer and heavier vehicles shall be constructed for good stability, and be equipped with Electronic Brake Systems (EBS), which apply different amount of brake force between the wheels to avoid wheel lock.
- Longer and heavier vehicles put greater demand on tires, brakes and especially maintenance and inspection. In that statistics from Svensk Bilprovning show deficiencies in the brake system of heavy trucks (29%) and heavy trailers (45%), it is of the utmost importance that the braking system on conventional as well as longer and heavier vehicles is checked regularly. In general, the legislation should be reviewed to see if an increased responsibility could be put on vehicle owners regarding control of brakes for all heavy vehicles.
- Driver fatigue is a significant causal factor in single-vehicle accidents involving heavy vehicles. Drive and rest times may be harder to keep with the extra-long vehicles if rest areas, which are already today overcrowded along certain roads, are not extended.
- The signs of the transition distance on 2+1 roads should be reviewed to possibly reduce the risk of dangerous situations and emergencies caused by overtaking of heavy vehicles, regardless of length. (Note: A “2+1” road is a three lane road consisting of two lanes in one direction and one lane in the other, alternating every few kilometres, and separated usually with a steel cable barrier.)

- The design or the visibility of the sign that warns of "long load" could possibly be improved in order to reduce the risk of critical situations when overtaking of heavier and longer vehicles on both 2 +1 roads and two-lane roads.
- In the literature, accident risk is usually estimated as an average over all accident categories. In order to identify in better detail which traffic situations may be affected by longer and heavier vehicles, additional studies should be carried out to estimate the risk of accidents per accident category.
- In the literature it is often mentioned that longer and heavier vehicles are likely to have a negative impact at intersections caused by the length of the vehicle and/or slower acceleration. Studies need to be conducted to determine whether this is the case.
- Frontal Collisions with oncoming vehicles when overtaking on two-lane roads results in fatal and serious injuries with significant social costs. Additional field studies on two-lane roads are therefore necessary to determine whether there is a higher risk to overtake a 30 m-long vehicle compared to overtaking a conventional heavy truck.

The following is a reproduction of the summary of research focusing on overtaking safety of long combinations vehicles published by VTI, the Swedish National Road and Transport Research Institute Summary of report (Andersson 2011).

The purpose of this report is to investigate if the introduction of extra-long and heavy vehicles has an effect on traffic safety on Swedish roads, especially in relation to overtaking. Traffic safety effects will be measured by road user behaviors in terms of speed and accelerations and time slots. Road user experiences and heavy truck drivers' experiences will also be studied. The traffic conflict technique (Almqvist, 2006; Ekman, 1996; Hydén, 1987; Svensson, 1998) presents how time-to-collision and speed are related to accidents and near accidents. The traffic conflict technique will be used as a starting point for the discussion on how the introduction of extra-long trucks might affect traffic safety.

The report presents four empirical studies: a focus group interview study with heavy truck drivers, an interview study with extra-long truck drivers, a simulator study and a field study. The simulator study and the field study focuses on overtaking.

The purpose of the focus group interview is to investigate if the heavy truck drivers (that do not drive the extra-long trucks) might have an opinion on how extra-long vehicles could have an impact on traffic safety. The purpose of the interview of extra-long truck drivers is to grasp the experiences they have of the extra-long trucks. Truck drivers that do not drive the extra-long trucks believe that the introduction of extra-long trucks will create a number of traffic safety problems especially in terms of conflict with ordinary road users. The drivers of extra-long trucks do not experience the problems that ordinary truck drivers predict. The problems they experience can be taken care of with more planning (thinking ahead). They also believe that the traffic sign on the back of the extra-long vehicle has a positive effect. The truck company, working environment and truck equipment are other important aspects mentioned by the extra-long truck drivers [sic].

The simulator study investigates over taking situations on a 2+1-road, with extra-long trucks (30 m) and an ordinary truck (18.75 m). The results reveal that the distance from the back of the truck to the point where only one lane exists affects car drivers' decision to overtake, independently of truck length. If the back of the truck is in the same position, the time slot for a safe overtaking was reduced significantly for extra-long trucks compared to ordinary trucks. Overtaking speed was, however, the same (approximately 117 km/h).

The field study also assesses overtaking situations with an extra-long vehicle (30 m; 98.4 feet) (with a license to drive on a specific road) and a reference vehicle (24 m; 78.7 feet), on a 2+1 road and an ordinary two-lane road. Overtaking vehicles were filmed with the purpose to measure overtaking behavior but also in order to be able to contact the road users by telephone. The overtaking personal car drivers did not experience a traffic safety conflict on the road at hand. They did not even remember overtaking an extra-long vehicle. The number of data points was relatively few, especially for the reference vehicle. No significant differences were obtained for overtaking speed or time slots. The overtaking speed was, however, relatively high for both trucks. On the other hand, video analyses revealed a small overrepresentation of critical time slots for critical overtaking of the extra-long trucks on a normal road, but not for the 2+1 road.

The conclusion is that a small tendency exists which points in the direction of enhanced traffic safety problems with the introduction of extra-long trucks. The results should however not be over interpreted since number of data point was few and collected during specific situations during specific conditions. The not so surprisingly conclusion is that more research is needed. Not to be forgotten is the reduction of number of trucks on the road it extra-long trucks are permitted.

6.0 Findings

The following are the particular findings that have emerged from this desk scan.

1. Crash and exposure data to support policy decisions is typically lacking and, with the end of the Vehicle Inventory and Use Survey (VIUS) and Trucks Involved in Fatal Accidents (TIFA) data collections, the trend for the availability of sufficient truck crash data is not favorable.

2. Due to the lack of variables related to truck weight, trailer dimensions and number of axles on many state crash report forms, it is difficult to identify crashes involving some of the specific truck configurations of interest in size and weight studies.
3. Methods being developed to estimate configuration-specific exposure measures from vehicle count, vehicle classification, and WIM data are promising.
4. In the absence of good crash and exposure data, safety studies often rely on measured or simulated vehicle characteristics.
5. Older crash rates studies have shown that roll threshold, rearward amplification, load transfer ratio, braking efficiency, and steering sensitivity are associated with changes in crash risk. Low-speed and high-speed offtracking have not yet been shown to be associated with crash risk.
6. Gross vehicle weight would appear to be associated with higher crash rates based on changes in vehicle operating characteristics and limited crash studies. However, crash studies are greatly hindered by the lack of weight data on state crash report forms.
7. Different studies have found crash rates for doubles were either the same, lower, or slightly higher than rates for singles.
8. Different studies have found crash severity to be lower, higher or about the same for LCVs and tractor semitrailers.
9. Operating environment, including road type and time of day, has a larger effect on crash rates than truck configuration.
10. Studies in Alberta, Canada, of LCVs operating in a permit regime that regulated driver qualifications, vehicle equipment, and with operating restrictions on road types, road condition, urban areas and time, showed good relative safety performance. A study of similar LCVs operating in states of the Western US, which are less strictly regulated, showed higher crash rates for LCVs in comparison with tractor-semitrailers.
11. Time-limited pilot studies in small states do not generate sufficient data to assess safety performance.
12. The recent studies based on observing the effect of larger and heavier trucks on the total system crash rate or the total truck rate were inconclusive.

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7.0 Addendum to the Draft Desk Scan

Truck Crashes Involving Barriers

Following the submission of the initial draft desk scan, team determined the review of two references related to heavy truck crashes and barriers would be beneficial. Provided in this addendum are those reviews. The safety team is aware of the consequences of a heavy truck crash that penetrates a barrier, especially a median barrier, in which the crash results in a collision with an oncoming vehicle. As part of the proposed crash analysis, we will explore differences in the frequencies and rates of multiple collision types, including barrier-related collisions. We will document any differences in these measures between proposed truck configurations and the baseline configurations. The limitation on any collision-type analysis will likely be sample size, e.g., there may be too few truck-involved barrier-related crashes to develop definitive results. More extensive analyses may be conducted with a diagnostic review of crash reports or through the use of finite element analysis. However, pursuit of such options need to be discussed with FHWA in terms of specific objectives, likelihood of success in accomplishing those objectives, cost, and schedule.

Reference Review 1

Gabauer, D. J., (2012), Real-World Barrier Performance of Longitudinal
Barriers Struck by Large Trucks, TRR 2309, Transportation Research Board, Washington D.C., p127-134.

The authors seek to identify the performance of barriers when impacted by large trucks as measured by various crash databases including the Large Truck Crash Causation Study (LTCCS), Fatality Analysis System (FARS 2000 through 2009) and the General Estimates System (GES for years 2000 through 2009). Among the metrics used are: barrier crash and fatal crash involvement rates and the impact performance of barriers specifically designed for large trucks and those not designed for large trucks. Different search criteria are used in each database to identify the relevant crashes to be used for analysis. The criteria used to identify barrier crashes may be of interest to the team in identifying the sample size of barrier-related events in our data sets. Exposure data were drawn from annual summaries provided by FHWA.

The databases used were adequate for the analyses undertaken by Dr. Gabauer, but contain insufficient detail for use in the current CTSWL study to assess the crash experience of specific vehicle configurations at different weights. The crash data used in this study (with the exception of LTCCS) does not contain vehicle configuration or weight data.

The focus is on barrier performance but vehicle weight and length are not explicitly included in the analysis. Barrier penetration was assessed using a dichotomous variable: 1 if penetrated and 0 if not. LTCCS analyses aggregated vehicle type in two classes: single unit and tractor-trailer. A logistic regression was used with LTCCS data to estimate the proportion of barriers penetrated. Barrier type was the only predictor of stated significance (see **Table 6** in reference). This modeling is described in a summary manner and important measures of model performance such as the receiver operating characteristic curve are not included.

Crash and fatality rates were computed per year for single-unit trucks and tractor semi-trailers and compared with light trucks and vans and cars (and motorcycles). The use of crash rates measured over time, while interesting, does not provide keen insights concerning *vehicle* performance differences, which are of relevance to the CTSW team.

For the purposes of the CTSWL study, the results of this paper are of limited use. The truck descriptions are at a level of aggregation that does not permit identification of even baseline vehicles, let alone future configurations. So the study is useful in general, but does not provide the specificity needed to contribute quantitatively to the CTSWL study.

<u>Reference Review 2</u>

Knipling, RR, P Waller, RC Peck, R Pfefer, TR Neuman, KL Slack, and KK Hardy, (2004), NCHRP 500, volume 13, A Guide for Reducing Collisions Involving Heavy Trucks, Transportation research Board, Washington, D.C.,

The goal of the NCHRP 500 series is to reduce highway deaths. Volume 13 of the series focuses on countermeasures to reduce large truck involvement in these fatalities. To reduce the number of heavy-truck fatality crashes, the study recommends actions including the following:

- Reduce truck driver fatigue
- Strengthen commercial driver’s license (CDL) requirements and enforcement
- Increase public knowledge about sharing the road
- Improve maintenance of heavy trucks
- Identify and correct unsafe roadway and operational characteristics
- Improve and enhance truck safety data
- Promote industry safety initiatives

The focus of the volume is clearly on countermeasures and particularly on countermeasures that have already been implemented. As such, it is not directly related to the safety of larger and heavier vehicles. In a detailed description of the problem, however, truck weight is specifically mentioned in terms of the disparity between the weight of trucks involved in fatal crashes (from one study over half weighed in excess of 60,000lb) and the weight of passenger vehicles (given as typically less than 5,000lb).

A set of strategies (**Objective 12.1E** in the reference) are proposed that seek to identify and correct unsafe roadway infrastructure and operational characteristics These roadways strategies are stated as being focused on impacting the speed of trucks or overcome loss of control due to excessive speed (Page V-38 of report). Barriers, particularly those designed for heavy trucks are specifically mentioned as a countermeasure to reduce heavy vehicle road departures, particularly to the left of the road.