REVIEW OF PRACTICES TO IMPLEMENT COST-EFFECTIVE ROADWAY SAFETY INFRASTRUCTURE IMPROVEMENTS TO REDUCE THE NUMBER AND SEVERITY OF CRASHES INVOLVING COMMERCIAL MOTOR VEHICLES

Report to:

Committee on Transportation and Infrastructure of the House of Representatives

Committee on Environment and Public Works of the Senate

Submitted by:

U.S. Department of Transportation

Federal Highway Administration

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
CMV	Commercial Motor Vehicle
State DOT	State departments of transportation
FARS	Fatal Analysis Reporting System
FAST Act	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
HFST	High-Friction Surface Treatment
MCSAP	Motor Carrier Safety Assistance Program
MUTCD	*Manual on Uniform Traffic Control Devices*
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
OS/OW	Oversize/Overweight
PRA	Paperwork Reduction Act
SHSP	Strategic Highway Safety Plan
DOT	U.S. Department of Transportation
VMT	Vehicle Miles Traveled

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Executive Summary

Section 1113(b) of the Fixing America's Surface Transportation (FAST) Act requires the Secretary of Transportation to review, consult, and report best practices associated with implementing commercial motor vehicle (CMV)–related roadway safety infrastructure improvements. Safety is the top priority of the Secretary. According to the Center for Disease Control and Prevention, approximately 93 percent of all transportation-related fatalities are motor vehicle traffic crashes.(1) In 2015, 4,337 persons were killed in crashes involving large trucks or buses, based on data recently released by the National Highway Traffic Safety Administrations (NHTSA) Fatal Analysis Reporting System (FARS). This is 12 percent of all motor vehicle traffic fatalities. Due to the substantial weight differences between CMVs and smaller vehicles, these crashes often result in fatalities. Of those who died in 2015 as a result of crashes involving large trucks and buses, the recently released data indicates only 716 (16.5 percent) were occupants of the large vehicles, the remainder being occupants of other vehicles or pedestrians. Also of interest, from 2014 to 2015 there was a 4.1 percent increase in fatal crashes involving large trucks.(2) Fatal truck crashes also have a significant economic cost, estimated to be more than $20 billion each year.(3)

However, CMV safety has improved in the last 30 to 40 years, both in absolute and relative terms. Fatalities in large truck crashes peaked in 1979 and have generally trended downward since then. The highest 5-year averages were just over 6,000 per year and have averaged around 3,900 in recent years, representing approximately a 35 percent reduction.(4) At the peak levels of large truck crashes, the fatality rate for large truck crashes was almost double the rate for passenger vehicles (a rate of 6.15 fatalities in large truck crashes per 100 million vehicle miles traveled [VMT] by large trucks compared to 3.22 fatalities in passenger vehicle crashes per 100 million VMT by passenger vehicles). (4) In recent years, these fatality rates are much closer. The lowest rate for large trucks was 1.17 in 2009, although that has continued to fluctuate, resulting in the current rate of 1.40 in 2014 when the passenger vehicle fatality rate was at a low of 1.05.(4) This represents a measure of success for transportation safety professionals.

Improving CMV safety is also a goal of the National Multimodal Freight Policy. Trucks are a vital part of the multimodal freight system. The 11 million registered large trucks (single unit and tractor-trailer combinations) move the majority of freight shipments nationwide—69.6 percent of U.S. freight shipments by tonnage and 63.3 percent of shipments by value.(5)

CMV Safety Improvements

Continued improvements in CMV safety outcomes can be achieved through joint efforts between the Federal Motor Carrier Safety Administration (FMCSA), which enforces safety regulations for commercial carriers, and the Federal Highway Administration (FHWA), which oversees the infrastructure on which these vehicles travel. State and local agencies also play a key role because they maintain and operate that infrastructure. This report to Congress offers safety improvements (mainly infrastructure) to reduce both the number and severity of highway crashes; some are specifically designed for CMVs, and many address larger target crash types, which include CMVs as one of the vehicle types involved. This report groups the treatments reviewed into three primary categories:

- Infrastructure safety. These improvements are most directly connected to the roadway infrastructure, including those that affect the roadway geometry, surfaces, or immediate roadside.

- Communication infrastructure. These devices, either along the roadside or on the roadway, seek to communicate information to help CMV and other drivers safely navigate the roadway network. This includes warnings of traffic blockages (recurring congestion or incidents) that may increase safety risks for CMVs.

- Innovative CMV safety practices. These practices to improve CMV safety include roadside intelligent transportation systems that increase compliance with safety regulations and provide for better separation of the larger and smaller vehicles to decrease the risks.

The safety improvements discussed in this report were selected from a review of literature and consultation with transportation practitioners. While the treatments included have all provided safety benefits to agencies that have used them and some are proven to reduce certain types of crashes, it is difficult to designate any particular improvement as a best practice since the benefits vary greatly depending on the highway system where it is applied (e.g., urban Interstate or rural two-lane road) and in some cases the specific location (e.g., intersection within a sharp curve with steep roadside slopes). The application of a given safety practice or crash countermeasure may require engineering studies or other analysis that is tailored to the roadway location. Therefore, some of these treatments may only make sense at very specific locations, whereas other treatments must be implemented over large portions of the highway network to achieve significant safety benefits. Within the report, each practice is assigned a readiness criteria of proven, tried, or experimental and the cost assessment is relative among the practices presented, using a five-part scale—high, moderate to high, moderate, low to moderate, and low cost.

Infrastructure Safety

Roadway Measures

The following safety features are applied to the roadway structure or immediately adjacent to it to mitigate safety risks for all vehicles, including CMVs:

- High-friction surface treatments (HFST) provide a highly durable aggregate locked firmly in place with a polymer binder that greatly increases friction in critical locations.
- Cross-slope break limits reduce the risk of rollovers for large vehicles on the outside of superelevated curves.
- Locations where water tends to pool may require additional drainage structures to remove precipitation or snowmelt.
- Higher-performance barriers can be more effective at containing or redirecting large vehicles.
- Rumble strips near the center line or edge of a lane can alert drivers that their vehicles are drifting from the travel lane, providing an opportunity for safe recovery. Onboard lane departure systems, or virtual rumble strips, perform a similar function.

Adding Lanes and Ramps

The following safety improvements expand the roadway footprint to mitigate the risks of CMV interactions with other vehicles in certain circumstances:

- Escape ramps provide drivers of large vehicles the opportunity to bring a runaway truck or bus to a safe stop by dissipating their energy.
- Climbing lanes and alternate passing lanes can decrease head-on collisions due to risky passing maneuvers in areas with limited sight distance.
- Interchange bypass lanes can separate large vehicles around or through a major interchange area, creating safer, easier merging lanes for CMVs.
- Exclusive truck roadways with various permutations have been studied to offer motor carriers the operational benefits of increased productivity, greater reliability, and safety benefits.

Communication Infrastructure

Signs and Signals

These safety treatments involve roadside communication of particular safety risks or operational conditions of concern to CMV drivers:

- Static warning signs alert drivers to a range of roadway conditions.
- Updating signs to *Manual on Uniform Traffic Control Devices* (MUTCD) standards to improve retroreflectivity and more uniformly apply curve signing.
- Dynamic warning devices display driver messages based on a broad range of vehicle behavior (speed, weight, and height) in advance of high-risk areas for CMVs and can be more effective than static signing to reduce crashes.
- Detection-control systems for traffic signals, which measure the speed and length of vehicles approaching an intersection to determine the best time to end the green phase, are particularly beneficial for large vehicles that take longer to come to a stop.

Pavement Markings

These safety-related communication treatments involve markings on the pavement because drivers regularly watch the pavement ahead for lane directions and possible obstructions:

- Horizontal signing can clarify lane assignments or simply provide emphasis to the driver about a roadway condition.
- Wider edge lines have been shown to reduce crashes on two-lane roads.
- Contrast markings improve lane marking visibility on concrete pavements, with possible benefits for fatigued CMV drivers.

Incident Warnings

This final class of safety communication treatments addresses CMV safety in higher-risk environments that may be sporadic or temporary, risks associated with aggregate traffic patterns that change, or weather-related conditions that pose risks to CMV operations:

- Queue detection warning systems in work zones monitor and detect queue buildup at critical transition points and display real-time warnings to upstream motorists.

- Work zone and incident electronic notification systems implement an in-cab alert system that notifies the CMV driver of an active work zone, traffic congestion, or an incident ahead.
- Visibility and wind detection systems alert drivers to infrequent but high risk driving conditions due to weather that can have serious crash consequences.

Innovative CMV Safety Practices

Compliance with Safety Rules

The following countermeasures are associated with roadside equipment that aids in inspection and enforcement activities or safety rules compliance:

- Parking systems provide information on available parking spaces to help commercial motor vehicle drivers comply with mandatory rest rules.
- Infrared braking detection systems have been tested that use roadside detection devices to identify overheating brakes. The devices have also been used to screen for other potential safety risks.
- Electronic screening deployed in advance of State roadside safety inspection facilities can electronically identify a CMV; verify its size, weight, and credentials information; and review the carrier's past safety performance, all while the vehicle is in motion.
- Virtual weigh stations can effectively target enforcement resources using unstaffed and remotely monitored roadside enforcement facilities.

Truck Separation Measures

States are experimenting with the use of regulatory measures to separate truck movements from the rest of traffic. The following two practices involve this kind of vehicle separation:

- Oversize/overweight (OS/OW) corridors can help manage common problems associated with OS/OW vehicle movements through regulatory authority and infrastructure improvements.
- Lane restrictions separate slow-moving trucks from faster-moving vehicles to improve traffic operations and to improve safety.

Gaps and Challenges

The future of CMV crash countermeasures may also be affected by a number of unpredictable trends:

- How freight and passenger economics and traffic will interact.
- How infrastructure design and safety treatments may evolve.
- How transportation technology may change CMV safety.

Future freight planning and highway safety planning, at the national and State level, will need to respond to these trends.

Future research can be considered by the transportation safety community to address issues as the FAST Act is implemented:

- Concerns about growing traffic levels of CMVs and passenger vehicles may lead to efforts to separate or segregate passenger vehicle and truck traffic. These infrastructure improvements could be balanced against changes in vehicle technology that add vehicle-based capabilities in both passenger vehicles and CMVs to keep both sets of drivers from human errors causing vehicle-to-vehicle crashes.

- As States designate highway freight networks as part of mandated State freight planning, linking State Strategic Highway Safety Plans (SHSP) to these corridors could help inform data-driven safety planning at the State level.

- The CMV safety improvements in this report are responsive to the current CMV fleet (even with regional size and weight variations authorized in current law). Statutory changes to size and weight restrictions may alter CMV safety outcomes and require different types of improvements or adjustment of existing countermeasures.

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Chapter One. Introduction

Section 1113(b) of the FAST Act requires the Secretary of Transportation to conduct a review of best practices with respect to roadway safety infrastructure improvements that are cost-effective and reduce the number and severity of crashes involving CMVs. Section 1113(b) states:

> (b) COMMERCIAL MOTER VEHICLE SAFETY BEST PRACTICES.
>
> (1) REVIEW.—The Secretary shall conduct a review of best practices with respect to the implementation of roadway safety infrastructure improvements that—
>
> (A) are cost effective; and
>
> (B) reduce the number or severity of accidents involving commercial motor vehicles.
>
> (2) CONSULTATION.—In conducting the review under paragraph (1), the Secretary shall consult with State transportation departments and units of local government.
>
> (3) REPORT.—Not later than 1 year after the date of enactment of this Act, the Secretary shall submit to the Committee on Transportation and Infrastructure of the House of Representatives and the Committee on Environment and Public Works of the Senate a report describing the results of the review conducted under paragraph (1).

This report provides a description of noteworthy practices that the review determined to be effective, lists the comparative cost-effectiveness along with their expected influence on reducing the number and severity of crashes involving these heavy vehicles. Most State departments of transportation (State DOT) have already adopted a variety of strategies and safety treatments to reduce the number and severity of CMV-involved crashes and their associated costs. Twenty-nine States have at least one emphasis area in their SHSP that is related to heavy vehicles or CMVs.

The FHWA and State and local agencies that plan, design, build, maintain, and operate the Nation's network of roadways realize that moving toward zero deaths and serious injuries requires a data-driven focus. Infrastructure improvements need to be made at both the system level and for specific locations where crashes are concentrated. This applies both in the broad sense and when focusing on specific crash types such as those involving CMVs. The infrastructure is vast and diverse, and safety issues exist both in high-speed free-flowing conditions and in places and times where the network is congested.

The review documented in this report includes a review of the literature and consultation with State transportation practitioners regarding their experience related to CMV safety. Reviewers considered the entire spectrum of safety measures including those specifically used for CMVs, which tend to be much larger and operate differently than the rest of the fleet, as well as those aimed at the larger mix of vehicles. Each type of improvement may have either wide application or specific, targeted uses. Since the infrastructure includes not just roads and bridges, but also the roadside environment and devices and equipment that play a significant role in communicating with drivers and their vehicles, the safety improvements and practices described in this report cover this wide range of topics. The review also recognized that to achieve a zero deaths goal requires embracing the role of enforcement, education, and emergency medical services along with engineering, and therefore includes discussion of infrastructure components related to enforcing safety regulations.

Before detailing the roadway safety infrastructure improvements found in the review to reduce CMV-involved crashes, this first chapter provides the context for how improved CMV safety could contribute to the economic vitality of the United States.

How CMV Safety Is Improving and Benefits the Economy

The national Federal highway program safety performance goal established by Congress in 23 USC 150 seeks to achieve a significant reduction in traffic fatalities and serious injuries on all public roads. In addition, the National Multimodal Freight Policy set by Congress in 49 U.S.C. 70101 establishes 10 goals, including two directly associated with safety. It seeks to expand the effectiveness, safety, and resilience of a national multimodal freight network that supports the economic competitiveness of the United States. The safety of that freight network and the use of technology to improve its safety are expected to contribute to the economic vitality of the nation.

Economic Importance of CMVs

As a measure of the connection of the national freight network to the economy, total business logistics transportation costs represented almost 5 percent of the nominal gross domestic product of the United States in 2015, according to the Council of Supply Chain Management Professionals.(6) Motor carriers (trucks) accounted for 65 percent of that total business logistics transportation cost—almost 11 million registered large trucks (single unit and tractor-trailer combinations). Trucks not only represent the majority of business logistics transportation spending, but they also account for the majority of freight shipments nationwide—69.6 percent of U.S. freight shipments by tonnage and 63.3 percent of shipments by value.(7)

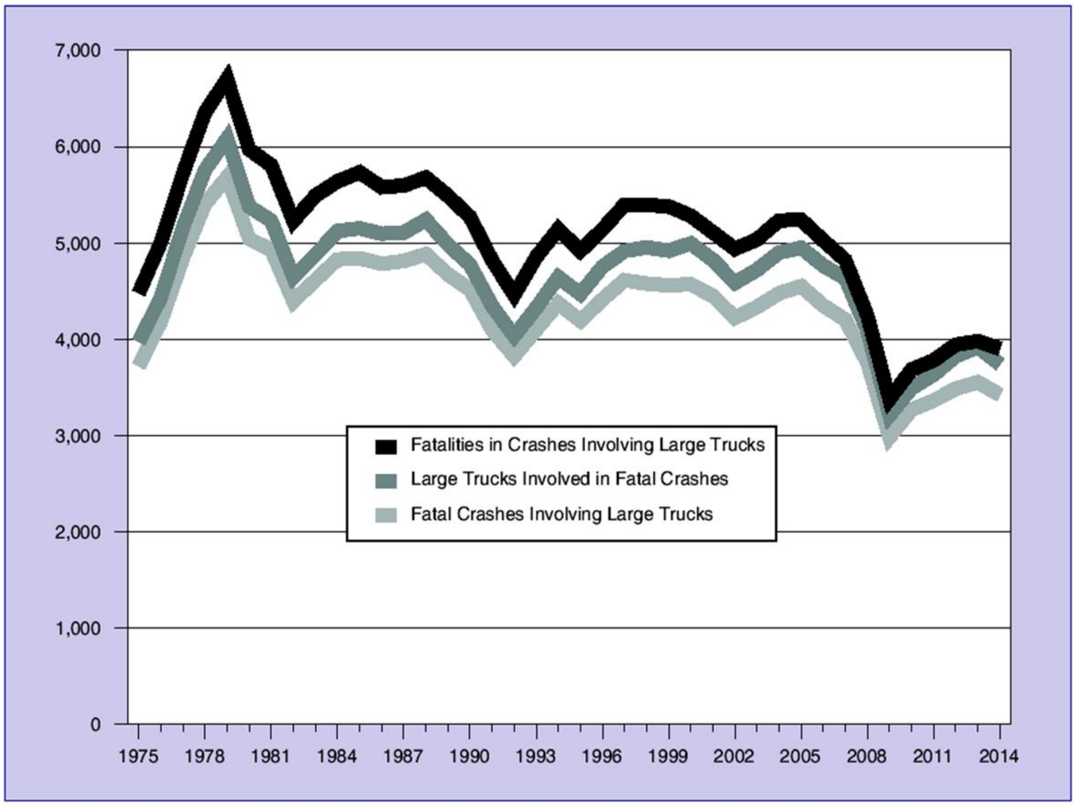
CMV Safety Trends

National crash data cannot accurately track crashes involving CMVs. Therefore, the data reported include the best estimates available, which are based on large trucks and in some cases also buses. A large truck is defined as a truck with a gross vehicle weight rating greater than 10,000 pounds. A bus is defined as any motor vehicle designed primarily to transport nine or more persons.

Large trucks and buses accounted for 4,337 traffic deaths in 2015 according to recently released data in NHTSA's FARS. That is 12 percent of all traffic fatalities in the United States. Due to the extreme weight differences between larger and smaller vehicles, crashes involving CMVs often result in fatalities. In the 40 years data for crashes involving large trucks have been reported, only 16 percent of those fatalities (on average) were occupants of the large truck, a trend that continues over the most recent decade.(4) Similarly, the recently released FARS data indicates 716 of those killed in crashes involving large trucks and buses in 2015 were occupants of the large vehicle, the remainder being occupants of smaller vehicles or pedestrians. The NHTSA reports a 4.1 percent increase in fatal crashes involving large trucks from 2014 to 2015, although the total fatality rate increased 7.2 percent in that same timeframe.(2) Fatal truck crashes also have a significant economic cost estimated to be more than $20 billion each year. The cost associated with the loss of quality of life due to these crashes is approximately $13.1 billion each year.(3)

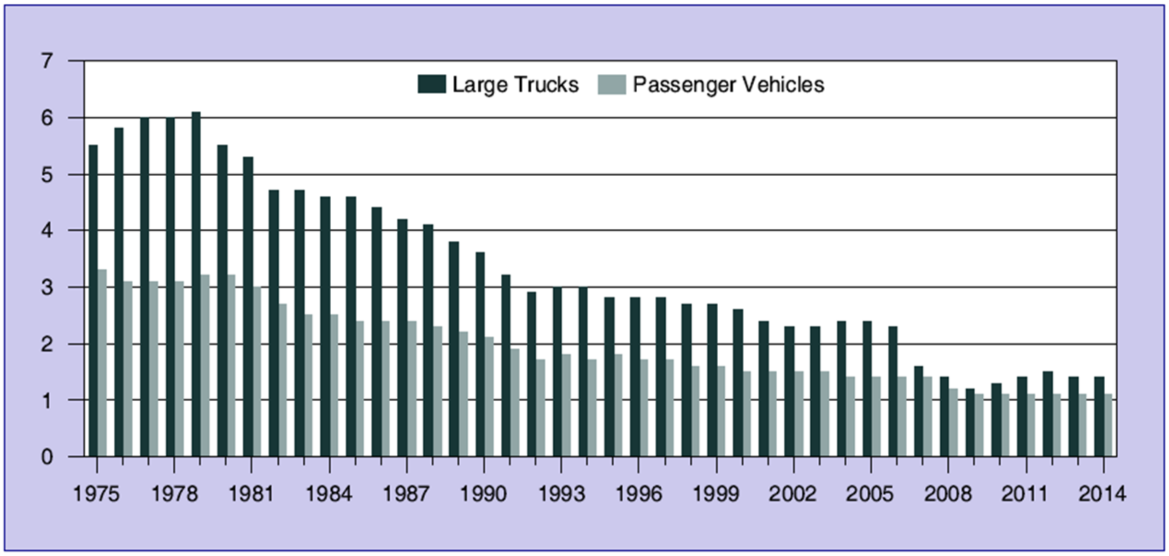
However, large truck safety has improved in the last 30 to 40 years, both in absolute and relative terms. The overall trends in large truck crash fatalities are shown in figure 1. While the crashes and fatalities fluctuate with traffic volumes, the trend line clearly indicates an overall downward movement. Considering 5-year averages to smooth out the trend line, the highest fatalities averaged just over 6,000 per year around 1980 and have averaged around 3,900 in recent years, representing approximately a 35 percent reduction.(4)

Passenger vehicles are more numerous than large trucks in terms of registered vehicles (240 million compared to 11 million, respectively) and in terms of vehicle miles traveled (VMT) (2.7 trillion compared to 279.1 billion, respectively). But large trucks travel more miles per vehicle than passenger vehicles (65,897 miles per combination truck, 13,123 miles per single-unit truck, and 11,287 miles per passenger vehicle).(5) Passenger vehicle and large truck crashes can be compared by considering the relative crash rates; figure 2 shows the rates for crash fatalities for passenger vehicles and large trucks over time.



Source: FMCSA. *Large Truck and Bus Crash Facts 2014*.(4)

Figure 1. Graph. Trend line for fatal crashes involving large trucks, 1975–2014.



Source: FMCSA. *Large Truck and Bus Crash Facts 2014*.(4)

Figure 2. Graph. Fatalities in Crashes Involving Large Trucks and Passenger Vehicles per 100 million Vehicle Miles Traveled by Vehicle Type, 1975–2014.

At the peak levels of large truck crashes, the fatality rate for large truck crashes was almost double the rate for passenger vehicles (a rate of 6.15 fatalities in large truck crashes per 100 million VMT by large trucks compared to 3.22 fatalities in passenger vehicle crashes per 100 million VMT by passenger vehicles). In recent years, these fatality rates have been much closer. The lowest rate for large trucks was 1.17 in 2009, although that has continued to fluctuate, resulting in a rate of 1.40 in 2014 when the passenger vehicle fatality rate was at a low of 1.05.(4) This represents a measure of success for transportation safety professionals.

A variety of factors in large truck fatal crashes compared to all motor vehicle crashes and VMT in 2014 reveal considerations that may impact the effectiveness of crash countermeasures:

- While 72 percent of fatal crashes involving large trucks were linked to a collision with another vehicle, that number is only 37 percent of fatal crashes for all vehicle types.
- Only 10 percent of large truck fatal crashes involved collisions with fixed objects, compared to 33 percent of fatal crashes for all vehicle types. This may be due to less frequent roadway departures, resulting in fewer impacts with fixed objects. It may also be due to the greater mass of large trucks, resulting in a more survivable crash than similar collisions involving lighter passenger vehicles.
- One in four of these crashes occur on the Interstate, split almost evenly between rural and urban portions. The urban Interstate System represents less than 20,000 miles of the total U.S. roadway network and carries 21 percent of the large truck VMT, indicating this system should be a focus. However, lower-cost solutions must also be considered for systems beyond the Interstate to address the other 74 percent of fatal crashes involving large trucks.

- While 61 percent of fatal crashes involving large trucks occurred on rural roads, only 47 percent of large truck VMT is on rural roads. Rural roads are also overrepresented for passenger vehicle crashes, so both countermeasures that work for all vehicles and those that are specific to larger vehicles should be considered on the rural systems.

- The nighttime crash rate for all motor vehicles is estimated to be three times that of the daytime rate—approximately half the crashes but only about one-quarter of the travel. The difference is not as significant for trucks; only 37 percent of fatal crashes involving large trucks occurred during nighttime hours. The large truck nighttime fatality rate can also be considered in light of the different time of day travel patterns for long-distance truck traffic through urban areas and local truck trips. Local truck trips follow daytime travel patterns for passenger vehicles, albeit with more midday travel, while long-distance truck travel is more evenly distributed over time.

- Only 2 percent of all fatal crashes occurred in work zones, while 5 percent of fatal crashes involving large trucks occurred in a work zone. While only 11 percent of all fatal crashes involved at least one truck, 30 percent of fatal work zone crashes involved at least one truck. (4,8,9,10)

How This Report Is Organized

A large number of safety infrastructure treatments and practices were reviewed to determine those best suited to reducing the number and severity of crashes involving CMVs. In this report, the infrastructure is considered to extend beyond the roadway itself to include shoulders, slopes, and roadside appurtenances. This report presents information on CMV safety improvements and practices in three categories in the following chapters:

- Chapter Two. Infrastructure Safety. These improvements are most directly connected to roadway infrastructure—those that affect the roadway or roadside itself and those that add some form of CMV-related safety or capacity.

- Chapter Three. Communication Infrastructure. These devices, either along the roadside or on the roadway itself, seek to communicate information to help CMV and other drivers safely navigate the roadway network. This also includes warnings of traffic blockages (recurring congestion or incidents) that may increase safety risks for CMVs.

- Chapter Four. Innovative CMV Safety Practices. These practices to improve CMV safety include roadside intelligent transportation systems that increase compliance with safety regulations and provide for better separation of the larger and smaller vehicles to reduce crash risks.

The final chapter identifies gaps in the current crash countermeasures, and describes changing conditions and technologies that might affect CMV traffic levels, safety risks, and mitigations against those risks.

Informed by the literature review and in consultation with a team of practitioners, this report addresses the documentation of the "cost effectiveness and expected influence on reducing the number and severity of crashes" involving these heavy vehicles, as required in section 1113 of the FAST Act. However, the effectiveness varies significantly depending on the location where it is applied, and costs can also vary somewhat. The CMV safety measures are described in chapters two, three, and four, and the report includes an assessment of the overall safety effectiveness of each countermeasure using the three-part readiness criteria similar to that outlined in *National Cooperative Highway Research Program* (*NCHRP) Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 13: A Guide for Reducing Collisions Involving Heavy Trucks*. The three-part readiness criteria are:

- Proven: Those strategies that have been used in one or more locations and for which properly designed evaluations have been conducted that show them to be effective. Evaluations may include simulation and testing or involve statistical crash data analysis.
- Tried: Those strategies that have been implemented in a number of locations, but have not been rigorously evaluated.
- Experimental/promising: Those strategies that have been suggested and that at least one agency has considered sufficiently promising to try on a small scale in at least one location.[11]

These criteria identify the extent to which the countermeasures are being used and have been demonstrated and evaluated to be effective. The report also summarizes a general assessment of the costs of implementing the treatment in order to address the requirement for cost-effectiveness evaluation. This cost assessment is relative among the practices presented, using a five-part scale—high, moderate to high, moderate, low to moderate, and low cost.

Chapter Two. Infrastructure Safety

The focus of this chapter is on safety improvements to the most permanent infrastructure features. Although traffic safety analysts and highway designers generally think in terms of the roadway (travel lanes) separately from the roadside (shoulders and beyond), this chapter considers the roadway in a more generic sense. The roadway in this context is the land and improved surface over which vehicles travel, including the paved surface—lanes and shoulders—and extending to the drainage structures and safety hardware. This definition also includes all the materials and structures that support the paved surface and prolong its operating life.

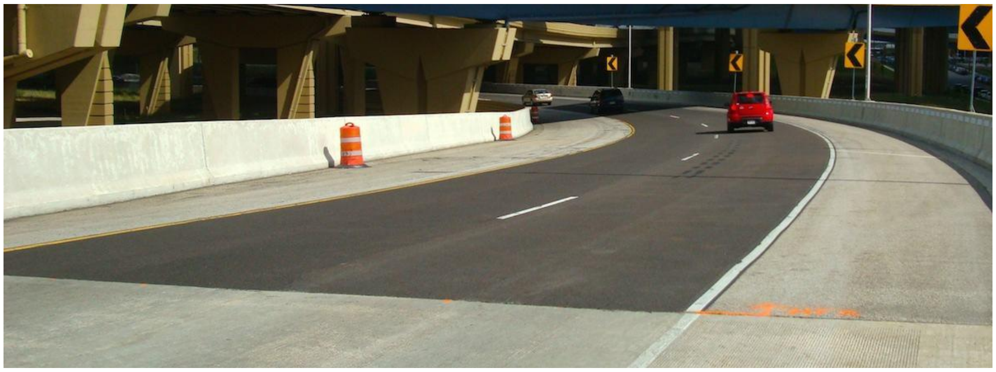
This chapter includes safety improvements specific to this broad definition of the roadway, focusing on the surfaces and hardware that may contribute to a crash or reduce its severity, rather than traffic control devices that communicate visual information to the driver, which are covered in the next chapter. This chapter also includes treatments that provide additional roadway capacity or operational safety benefits.

Roadway Measures

Highway professionals apply guidelines and engineering judgment to design roadways that maximize the effectiveness and safety of the interactions between vehicles and the roadway and between drivers and the roadway. This complicated balance considers the roadway's function (traffic volume, vehicle mix, and design speed) and geometrics (curvature, grades, lane, and shoulder width). Design elements are added to mitigate safety risks due to roadway design constraints (geography, right of way availability, construction, and operating costs). In some cases, crashes may occur or persist at certain roadway locations due to the geometrics of the road and the actual vehicle volumes and traffic mix. The following safety practices mitigate safety risks for all vehicles, including CMVs.

High-Friction Surface Treatments (HFST)

Horizontal curves and roadway sections involving speed transitions can present challenges for drivers to negotiate, and repeated traffic can reduce the friction of the pavement precisely at the locations where it is most needed for vehicle control and braking.[12,13] Wet driving conditions can increase the risks of crashes with reduced-friction pavements. These challenges are compounded for CMVs, which are heavier and have higher centers of gravity. While traditional friction surface layers can address this issue for long segments of roadways, HFSTs are appropriate for critical locations with parameters known for these types of crashes, such as intersections, curves, and ramps, as shown in figure 3. The HFSTs can be a cost-effective alternative to changing the curvature or correcting superelevation of the roadway and do not induce increased speeds as these more traditional countermeasures do. The HFSTs have a proven life-cycle cost benefit.[13,14]



Source: The Transtec Group. *Pavement Treatment Reduces Crashes*.[15]

Figure 3. Photo. High-friction surface treatment on a ramp in Wisconsin.

The HFSTs involve the application of a thin layer of durable, very high-friction aggregate onto a bed of specially engineered resin or polymer binder. The binder locks the aggregates firmly in place, creating a durable surface that greatly increases friction in locations where the demand is high such as horizontal curves, intersections, ramps, steep grades, or combinations of these. The treatment is typically applied in short lengths and can be installed by machine or by hand with short cure times and minimal effects on traffic. The HFST applications have been tested to provide improved friction over a 10-year period, so the relatively higher cost of HFSTs (compared to other friction surface treatments) is offset by the small amount of material needed for the focused application and its demonstrated effects on crash reduction. The HFST technical assistance to States is available through the FHWA Every Day Counts initiative.[14] The FHWA is working with State organizations and industry through the American Traffic Safety Services Association High Friction Surfacing Council to revise the American Association of State Highway and Transportation Officials (AASHTO) provisional specification and encourage use of HFST. Application of this countermeasure at interchange ramps has demonstrated excellent reduction in large truck crashes in Illinois and California.

COST-EFFECTIVENESS ASSESSMENT: HFSTs are assessed as proven and low to moderate cost.

Cross-Slope Breaks

Another issue with curves is the design of the slopes to help drivers comfortably and safely negotiate the curve. Design guidelines provide standards to transition from the normal pavement crown to a superelevated section near the beginning of a curve and back to the normal crown near the end. The shoulder cross-slope may not follow the superelevation, depending on drainage and other design considerations. This break in the cross-slope can be an issue for vehicle stability, particularly for vehicles with a high center of gravity such as CMVs. The difference between the cross-slope of the shoulder and the cross-slope of the adjacent travel lane is called the roll-over, shown in figure 4.[16] American Association of State Highway and Transportation Officials (AASHTO) design guidelines call for a maximum roll-over of no greater than 8 percent.[17,18] Use of a rounded shoulder may alleviate some of the concern associated with large cross-slope breaks.

Source: Stein, W., and Neuman, T. *Mitigation Strategies for Design Exceptions*.[17]

Figure 4. Photo with illustration. Cross-slope break on a superelevated curve.

In response to recommendations from a National Transportation Safety Board (NTSB) report regarding a cargo tank rollover crash in 2009, FHWA issued a memorandum reminding agencies of these design considerations and encouraged geometric improvements at identified or probable problem locations rather than system-wide as these crashes are relatively rare.[19,20,21] Education on this topic may be helpful for construction and maintenance personnel who need to be aware why this detail is important to construct correctly and maintain during pavement overlays.

COST-EFFECTIVENESS ASSESSMENT: Cross-slope breaks are assessed as tried and moderate cost.

Enhanced Drainage

Roadways are engineered to allow precipitation to drain away from the pavement surface, with standards and guidelines for the pavement cross slopes. Drainage is necessary not only to remove water from the surface and reduce its effects on safe vehicle handling (hydroplaning and loss of friction), but to drain away water from the roadway structure to reduce the degradation of the pavement subsurface and grading, which can lead to pavement failures. Wet roadway surfaces pose problems for heavier CMVs that are more difficult to maneuver in adverse weather (which can result in overcorrections and pose risks to other vehicles on the roadway).

In urban sections, water often drains into storm sewers and off bridge structures; in rural roadways with more right of way, water drains off shoulders and away from roadways into ditches designed to move the water. In order to maintain proper drainage and prevent water pooling, drainage structures need to be calibrated to local weather conditions (frequency and intensity of rain events and consideration of melting snow), and shoulders and drainage ditches and culverts require maintenance to properly channel water away from the roadway.[22,23]

Areas most prone to water pooling are the inside of curves and tunnel entrances and other restricted areas. In these locations, road owners use slot drains to capture the water and prevent continual freeze-thaw cycles that can damage the pavement and result in icy driving conditions. These enhanced drainage treatments involve higher costs due to the infrastructure intervention involved but can be beneficial in certain locations with observed drainage issues and crash frequencies.

COST-EFFECTIVENESS ASSESSMENT: Enhanced drainage is assessed as tried and moderate cost.

Higher-Performance Barriers

Longitudinal barriers along the roadside or median are designed to contain and redirect vehicles in a controlled manner. These barriers are used where leaving the roadway will likely result in a more severe crash. They keep vehicles from crossing into oncoming traffic, prevent vehicles from rolling over on steep slopes, keep vehicles on bridges and ramps and protect traffic under those structures, and prevent vehicles from hitting roadside objects. Since 1993, these barriers and all other roadside hardware have been tested for effectiveness under *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*, which specifies a range of test levels for roadside hardware for certain vehicles at certain speeds.(24) AASHTO's new *Manual for Assessing Safety Hardware* updates these tests to accommodate changes in the vehicle fleet.(25)

The first three test levels, TL-1, TL-2, and TL-3, require successful tests of a small car and a pickup truck at speeds of 31 mph, 43 mph, and 62 mph, respectively. Where a greater percentage of large vehicles are present or the risk of penetration through the barrier has higher consequences, agencies may choose to use barriers that have been crash-tested with larger vehicles. The TL-4 adds a single-unit truck at 56 mph to the TL-3 requirements; TL-5 substitutes a tractor/van trailer for the single-unit truck; TL-6 substitutes a tractor-tank trailer. TL-3 has typically been used for roadways posted above 45 mph for many years, although not all older systems have yet been replaced.

Higher-performance barriers (those at TL-4 or higher) are more likely to contain a large vehicle effectively. Each successive test level requires more substantial and typically taller structures. Highway and bridge designers should consider overall CMV volumes, vehicle mix, and the nature of the risk associated with different roadway corridors and bridges to determine where the additional cost is justified. Barriers that can contain CMVs under the test criteria may also be so rigid as to pose increased crash severity risk for the larger number of passenger vehicles compared to more flexible systems typically associated with the lower crash-testing levels, so this balance must be kept in mind. The costs of higher-performance barriers can vary based on a number of factors. For example, modifying existing barriers is typically not cost-effective and may actually cost more than installing new barrier because the existing barrier often needs to be removed or modified to add strength with reinforcing steel between the existing and new concrete. Another example is where concrete barrier is needed in a median to limit deflection into an opposing travel lane; this is significantly more expensive than a flexible or semi-rigid barrier. However, if new concrete barriers are to be installed, which is common on urban freeways, much of the cost for the new barrier is in the mobilization of equipment, drainage and storm water management, and building the foundation. In these cases strong consideration should be given toTL-5 barriers, since the additional cost is incremental and occupant risk is virtually unchanged while the barrier serves a greater percentage of the CMV fleet (Figure 5). The TL-6 structures are significantly more expensive and will likely be limited to certain high-risk locations.

Source: FHWA.

Figure 5. Photo. TL-5 concrete median barrier.

COST-EFFECTIVENESS ASSESSMENT: Higher-performance barriers are assessed as proven and moderate to high cost.

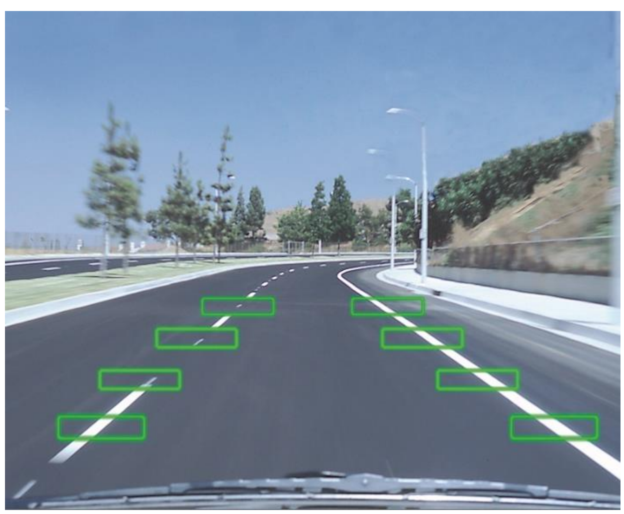
Rumble Strips and Lane Departure Warning Systems

Rumble strips are a series of milled or raised elements applied at center lines, edge lines, or shoulders (Figure 6) to alert drivers who are leaving their travel lane. They are primarily intended to address crashes caused by driver inattention and fatigue. The CMV drivers are susceptible to fatigue-related safety risks, given the longer hours of operation or longer distances of travel and the financial pressures to maximize driving time allowed by hours of service regulations. Rumble strips are proven to significantly reduce fatal and injury head-on collisions and single-vehicle run-off-the-road crashes.(26,27,28) Analysis results indicate approximately 40 percent reduction in single-vehicle run-off-the-road crashes involving heavy vehicles (i.e., trucks) on rural freeways.(26) Since drowsy and distracted drivers can drift from their lane at any location, this crash countermeasure is applied systemically rather than at specific locations.

Source: Hughes, W., Jagannathan, R. and Gross, F., 2008. *Two Low-Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways*. [29]

Figure 6. Photo. Milled shoulder rumble strip.

Recent research has demonstrated the benefits of onboard lane departure systems (Figure 7), or virtual rumble strips. These systems can detect lane departures and offer driver feedback through steering wheel vibration, lights or audio warnings, and even steering correction. Driver simulation studies indicate that virtual rumble strips may be more effective than physical pavement rumble strips for providing safety feedback to sleepy CMV drivers.[30] Lane departure systems are being implemented in more new vehicles as a safety option and are a necessary precursor to more advanced driver-assisted and automated vehicle operations. Truck manufacturers are offering more lane departure systems to motor carriers and are developing the systems as part of a suite of services to offer broader driver assistance as a pathway to more autonomous CMV operations. Continued use of physical rumble strips will be necessary until most of the vehicle fleet has lane departure warning systems.



Source: Halvorson, B. *IIHS: Avoidance Systems Could Cut Fatal Crashes by One-Third. The Car Connection*. Photo ©2016 Nissan.[31]

Figure 7. Photo with illustration. Lane departure warning system (virtual rumble strip).

COST-EFFECTIVENESS ASSESSMENT: Rumble strips and lane departure warning systems are assessed as proven and low cost.

Adding Lanes and Ramps

Given their size and weight, CMVs present different operational characteristics over the road than passenger vehicles and light-duty trucks: they require longer distances to brake, accelerate more slowly, and negotiate steeper grades more slowly. These differences can lead to operational conflicts between passenger vehicles and CMVs and can cause automobile drivers to perform risky maneuvers to avoid slower CMVs. In some cases, geography and topography result in roadway segments with long, steep grades, which cause CMVs to slow significantly on uphill sections and can lead to unsafe acceleration and braking on downhill sections. The following safety improvements are related to expanding the roadway infrastructure to mitigate the risks of CMV interactions with other vehicles in such circumstances.

Escape Ramps

Downhill grades, even designed according to AASHTO guidelines, can pose operational risks for CMV drivers. Downhill operations require drivers to observe proper braking procedures (to avoid degrading braking system performance) and proper brake maintenance more than in ascents. If extended downhill grades are accompanied by sharp curves and switchbacks, more frequent braking may accelerate braking system failures. The CMVs with failed or degraded braking systems can pose serious crash risks to CMV drivers and to other traffic.

Since the 1950s, States have built escape ramps—exclusive facilities to control runaway vehicles by diverting them from the main traffic lanes and dissipating their energy through gravitational deceleration, rolling resistance (gravel beds), or both.(32) The escape ramps (Figure 8) require extra right of way and must be constructed to fit within the downhill slopes of the roadway.(33,34)

Source: FHWA. Designing for Transportation Management and Operations: A Primer.(35)

Figure 8. Photo. Truck escape ramp.

The CMV safety professionals are also mitigating these downhill risks by changing commercial driver's license training curricula to instruct drivers on braking procedures that control vehicle speeds while allowing braking system components to dissipate energy and maintain functionality. The CMV safety enforcement agencies also pay attention to braking system components in roadside safety inspections to encourage motor carriers and drivers to pay attention to signs of braking system problems.

COST-EFFECTIVENESS ASSESSMENT: Escape ramps are assessed as proven and high cost.

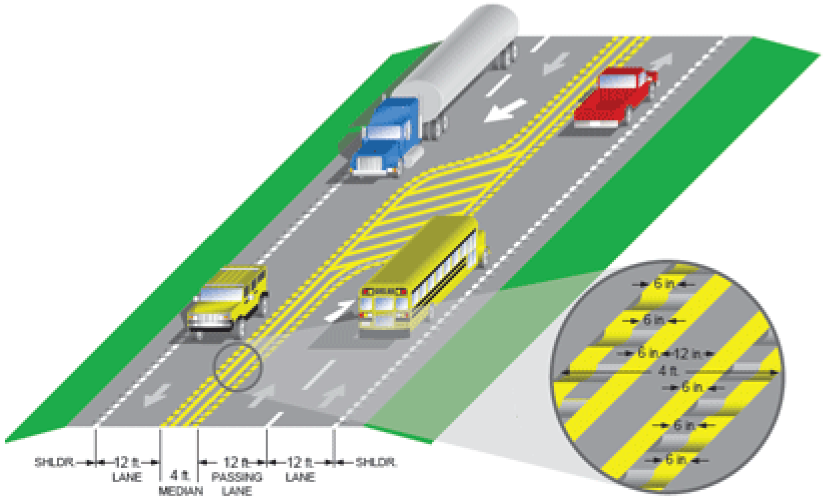
Climbing Lanes and Alternate Passing Lanes

Large vehicles can present problems for other traffic on hilly terrain and may lead to risky passing behavior with limited sight distances. Climbing lanes provide additional capacity on uphill grades to allow faster traffic to pass slower traffic without the increased risk of making the passing maneuver in the opposing traffic lane. Highway professionals use climbing lanes (Figure 9) of varying lengths and spacing, depending on the truck volumes, overall traffic levels, shoulder widths, and right of way availability.(27,36)

Source: New York State Thruway Authority and Canal Corporation. *Highway Improvements Report: Tappan Zee Bridge/I-287 Corridor Project.*(37)

Figure 9. Photo with illustration. Climbing lane on I-81 in Virginia.

Alternate passing lanes have three lanes of traffic (two directions of travel), shown in figure 10. The center lane alternates as a passing lane in one travel direction. The center and right lanes merge back into one lane, and then the center lane serves as a passing lane for traffic in the opposite direction. The alternate passing lanes in Missouri, sometimes called a shared four-lane road, feature wider than normal center striping with two sets of rumble stripes within 4-foot medians and a series of signs accompanying the beginning and ending of the lanes. This design provides increased capacity and improved safety at significantly less cost than providing four lanes in each direction.



Source: Missouri Department of Transportation. *Shared Four Lane Brochure*.(38)

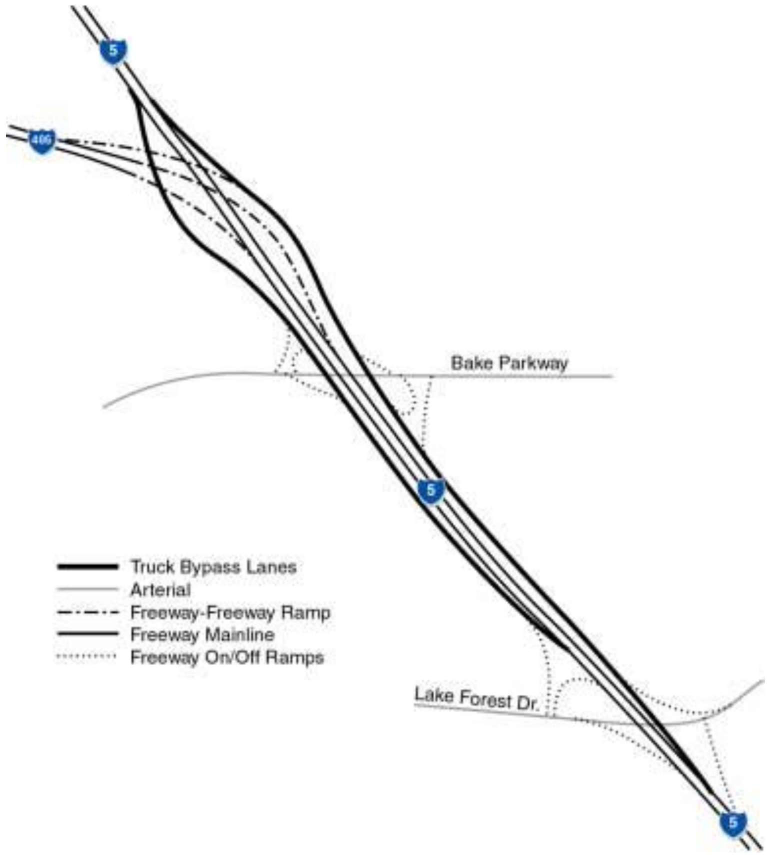
Figure 10. Illustration. Alternate Passing Lane.

Newer CMVs are being manufactured with engines with better weight-to-horsepower ratios, allowing CMVs more power to negotiate moderate changes in highway grades. Since climbing and alternate passing lanes involve more paved roadway surface, their cost can limit their cost-effectiveness to being applied in limited, targeted instances.

COST-EFFECTIVENESS ASSESSMENT: Climbing lanes and alternate passing lanes are assessed as proven and high cost.

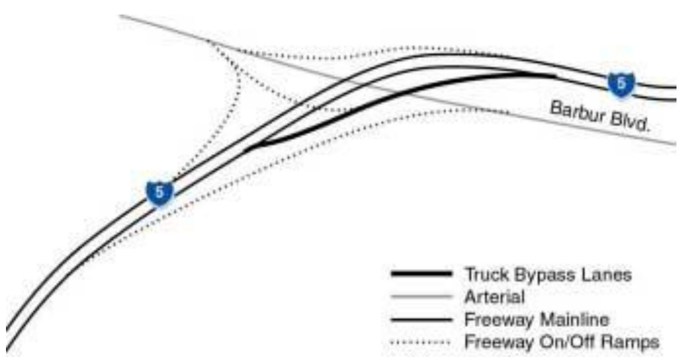
Interchange Bypasses

Some freeway interchanges (freeway to freeway [Figure 11] and freeway to arterial [Figure 12]) are situated in regions with steep grades, affecting the ability of CMVs to travel fast enough through the interchange to merge with other high-speed traffic. Interchange bypasses are facilities that separate large vehicles around or through a major interchange area, allowing CMVs to negotiate grades and creating safer, easier merging lanes onto major roadways.(36)



Source: Douglas, J.G. Handbook for Planning Truck Facilities on Urban Highways.(39)

Figure 11. Map. Interchange bypass at I-5/I-405 in Orange County, California.



Source: Douglas, J.G. Handbook for Planning Truck Facilities on Urban Highways.(3936)

Figure 12. Map. Interchange bypass at Tigard interchange in Oregon.

These separate roadway facilities can offer operational benefits and avoid multivehicle collisions involving slower-moving CMVs. This high-cost countermeasure may have applicability for certain interchanges with high truck volumes and unique topography. The cost is dependent on many factors such as the number of additional lanes, complexity and length, right of way costs, and environmental clearances.

COST-EFFECTIVENESS ASSESSMENT: Interchange bypasses are assessed as tried and high cost.

Exclusive Truck Roadways

The New Jersey Turnpike implemented a dual-dual facility, with an inner and outer roadway in each direction. The inner roadway is reserved for passenger vehicles, while the outer roadway is open to all vehicle types. In this 35-mile segment, 23 miles has three lanes in each direction for both the interior and exterior roadways, while another 12 miles has two lanes on the exterior roadway and three lanes on the interior roadway. Each roadway has 12-foot lanes and shoulders, and the inner and outer roadways are barrier separated, as shown in figure 13.

Source: Collier, T., Goodin, G. *Managed lanes: A cross-cutting study*.(40)

Figure 13. Photo. Dual-dual section of the New Jersey Turnpike.

States have been studying the application of exclusive truck roadways with various permutations: tolled truck-only lanes and truck-only lanes that allow longer combination vehicles or vehicles exceeding Federal weight limits. These facilities are expected to offer motor carriers operational benefits of increased productivity and greater travel time reliability, and to potentially offer safety benefits.(36,41,42) However, there are no domestic examples of exclusive truck-only freeways to test for safety benefits, which would likely differ from the New Jersey dual-dual section by assigning the inner roadway exclusively to trucks rather than passenger vehicles. Some studies have used micro-simulations of truck and truck-auto operations to estimate the safety effects of the absence of truck-auto interactions, while others have used statistical tools to estimate the safety benefits.

Motor carriers and truck drivers are less supportive of tolled truck-only facilities, and not all motor carriers are interested in truck-only lanes that allow longer or heavier vehicles because some carriers would have to purchase new equipment to take advantage of the productivity gains. Increasing freight demand in the long term may create an environment in which highway professionals and motor carriers expand their interest in exclusive truck roadways to move more freight with less congestion. New research techniques are being investigated to estimate the safety benefits from these new facilities.

COST-EFFECTIVENESS ASSESSMENT: Exclusive truck roadways are assessed as experimental/promising and high cost.

Chapter Three. Communication Infrastructure

Highway professionals use all available guidelines and principles to design roadways to maximize their functionality and safety. Yet traffic control devices are needed to delineate the alignment, assign right of way, and communicate regulations, warnings, and other information to drivers so they can navigate safely and efficiently, both day and night. More advanced communication tools are also becoming more available to augment traditional devices or to inform drivers of temporary or infrequent safety risks, such as work zones, congestion, and weather. As connected and automated vehicles become a larger portion of the fleet, the infrastructure is likely to change to communicate not only visually with the driver but also electronically with the vehicle.

The CMV drivers require special safety messages about the roadway: critical geometrics like bridge and tunnel clearances may interfere with oversize loads; curves, intersections, and grades require adjustments in speed, braking, or engine power. Operating characteristics of CMVs—longer braking distances, more gradual acceleration, and higher centers of gravity—make CMVs more susceptible to these variations in the roadway environment, both those that are normal and the unexpected (e.g., changes in weather that diminish visibility or risk rollovers, or sudden congestion in work zones). The following safety practices are particularly applicable for CMV safety.

Signs and Signals

Roadside signs convey a variety of messages to drivers—regulatory signs inform of the laws and regulations on the road and at intersections; warning signs inform of safety risks; guide signs aid wayfinding and direction; and service signs inform of nearby food, gas, lodging, or parking areas. The MUTCD provides the national standard for size, shape, color, and application of all traffic control devices, including signs and signals (discussed in this section) and pavement markings (discussed in the next section). Uniformity is a key factor in communicating so that drivers can quickly assess information through common sign formats, colors, and designs. The devices included in this section are placed on the roadside.

Static Warning Signs

Diamond-shaped yellow signs with black symbols or legends warn drivers of a range of roadway conditions that may be unexpected; Figure 14 shows an example. These signs are installed when circumstances warrant (according to engineering studies and judgment) and stay in place as long as the roadway conditions are in effect. Static signs are used regularly because they are a cost-effective means of conveying needed information to drivers to allow them to safely negotiate an unfamiliar roadway.[27] Signs that are particularly beneficial for safety of CMVs and preservation of the infrastructure include:

- Signs to warn of limited clearance at bridges (often resulting from pavement overlays), which may vary by lane.
- Signs to warn of truck rollover potential due to geometric conditions for vehicles with a high center of gravity.
- Vertical grade signs and plaques that warn of long and steep grades.
- Curve and ramp warning signs, particularly those with advisory speed plaques.

- STOP ahead, YIELD ahead, or SIGNAL ahead warning signs that provide the additional time needed for larger vehicles to begin slowing before the intersection control device itself comes into view.

Source: FHWA, MUTCD, Figure 2C-1[43]

Figure 14. Graphic. Truck rollover warning sign.

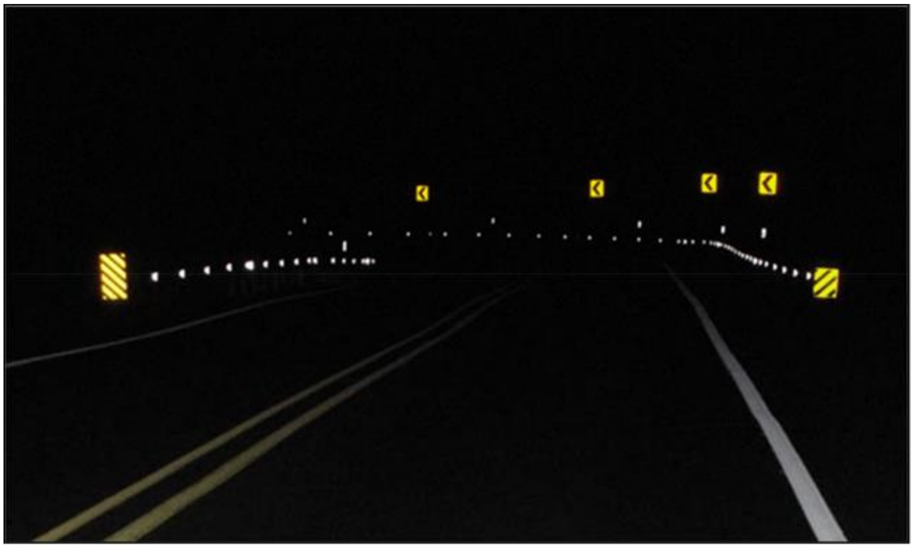
Static warning signs run a risk of losing effectiveness for frequent travelers on a roadway because drivers may grow accustomed to signs as background scenery. This can be a risk for CMV drivers following regular urban or intercity routes. Sometimes, these static signs can be increased in size to increase their conspicuity. In corridors with significant truck traffic, placing a duplicate sign on the left side of the road can also provide drivers of passenger vehicles a better opportunity to see signs that may otherwise be blocked by large vehicles in the right lanes. Static signs, both in standard and larger format sizes, have proven to be a cost-effective method of communicating roadway conditions to CMV and other drivers.

COST-EFFECTIVENESS ASSESSMENT: Static warning signs are assessed as proven (static) or experimental/promising (oversized static), and low cost.

Updating Signs to MUTCD Standards

The FHWA oversees a process for updating the MUTCD on a periodic basis to better reflect the most current knowledge on good practice, based primarily on research and in-service evaluations. Most updates to the MUTCD do not have a specific time frame but rather are to be completed through a systematic approach or when the existing device is replaced because it is no longer serviceable. Because it may take a long time for updates to be seen across the entire roadway network, when there is a sufficient safety implication to justify it, FHWA specifies a timetable for compliance with the new standards and provisions. Two such changes have implications for CMV safety.

A rulemaking in 2007 established minimum maintained standards for retroreflectivity of traffic signs. Retroreflectivity of traffic signs is crucial to drivers' ability to see the signs at night, especially in areas without continuous roadway lighting. Because the angle from the vehicle headlamps to the sign and back to the driver's eye is greater for large vehicles, signs are less visible at night to drivers of these vehicles, making adequate retroreflectivity even more critical. As more signs with deteriorated retroreflectivity are replaced in response to the standards, CMV drivers should be better able to see traffic signs at night (Figure 15).



Source: FHWA, *Low-Cost Treatments for Horizontal Curve Safety*.(44)

Figure 15. Photo. Retroreflective chevrons.

A more recent change to the MUTCD focuses on use of warning signs for horizontal curves. The 2009 MUTCD established new standards and guidance to improve the consistent use of advance warning signs, advisory speed plaques, and chevrons at horizontal curves. The changes, encompassing sections 2C.06 through 2C.08, also encourage methods for setting advisory speeds that are more comparable to design practices than many agencies have used in the past. Highway agencies determine advisory speeds for horizontal curves to maintain necessary side friction for safety of negotiating the curve and for driver comfort. Depending on the difference between posted and advisory speeds, MUTCD table 2C-5 establishes the signs that are required, recommended, or optional. Updating the sign infrastructure to these new standards will provide a consistent message to drivers as they drive on highways operated by different agencies and may help address the more than one-quarter of all fatal crashes that are associated with horizontal curves.(44) The CMV risks at horizontal curves are greater than the passenger vehicle risk due to their mass and high center of gravity.

COST-EFFECTIVENESS ASSESSMENT: Updating signs to MUTCD standards is assessed as proven and moderate cost.

Dynamic Warning Devices

To improve the chances of drivers noticing important signs, highway agencies sometimes use dynamic signs with flashing lights or beacons to capture driver attention. A variation on this uses detection systems to monitor traffic and flash or provide other specific information that relates to the roadway or traffic condition of concern when triggered. One example is height detection equipment in advance of bridges with clearance restrictions. Another is dynamic speed display signs, which combine speed detection systems displaying the vehicle’s actual speed along with a static sign with the regulatory speed limit or advisory speed (Figure 16).

Source: FHWA, Low-Cost Treatments for Horizontal Curve Safety. Chapter 4.(44)

Figure 16. Photo. Dynamic speed signs.

Some dynamic signs only flash or display a message if the speed detection unit indicates the vehicle is approaching over a set speed. For example, sequential flashing chevrons provide more active warning to drivers who need to slow down to safely negotiate the curve. Unfortunately, reductions in speeds found with these devices often do not last after drivers become accustomed to them, and a reduction in crashes has been difficult to determine. The ability of various size vehicles to safely negotiate a curve with the same geometrics and pavement friction complicate the research efforts. However, since larger CMVs are more sensitive to these factors, the devices are likely more beneficial for these vehicles.

Another type of dynamic sign displays a driver message based on a broader range of vehicle behavior (speed, weight, or height) in advance of high risk areas for CMVs—tight curves, restricted clearances, load-zoned bridges, or signalized intersections (Figure 17). These dynamic systems can reduce rollover or run-off-the-road crashes by reducing speeds at curves and can reduce congestion-related crashes when oversize vehicles cannot move beyond restricted bridge or tunnel clearances. (See references 44, 45, 46, 47, 48, 49, and 50) These signs may need further improvements to guard against frequent traveler inattention.

Source: FHWA

Figure 17. Photo. Dynamic warning sign showing activated truck rollover warning system.

COST-EFFECTIVENESS ASSESSMENT: Dynamic warning devices are assessed as proven and low to moderate cost.

Detection-Control Systems for Traffic Signals

Because CMVs are more difficult than smaller vehicles to stop due to their weight, they can pose risks at signalized intersections. A traffic signal control system has been designed and tested that continually monitors vehicles approaching an intersection to determine the best time to end the green phase for the major road, allowing all vehicles, but especially CMVs, a better opportunity to proceed safely through the intersection rather than run a light or stop suddenly and risk a crash.[51] The system measures vehicle speed, vehicle length, and the lane that each vehicle occupies and predicts their arrival based on detection at 1,000 feet from the intersection. Research findings based on full-scale testing in several States indicate significant improvements in metrics related to safety such as red-light running, vehicles caught in the dilemma zone, and maximum green light timing cycles automatically ending a green phase regardless of the vehicles in the intersection. This countermeasure may be effective for signalized intersections along arterials that are part of State-designated priority freight corridors.

COST-EFFECTIVENESS ASSESSMENT: Detection-control systems for traffic signals are assessed as proven and moderate to high cost.

Pavement Markings

Another set of safety-related communication treatments involves markings on the pavement because drivers regularly watch the pavement ahead for lane directions and possible obstructions. The primary function of markings such as lane lines, center lines, and edge lines is to assign space on the paved roadway to vehicles traveling in the same or opposing directions, but these markings also provide the driver information on alignment changes and passing opportunities and regulations. Other markings provide additional information such as the location of turn lanes or marked pedestrian crossings.

The retroreflectivity of pavement markings is critical to nighttime drivers because the pavement can be difficult to see more than a short distance ahead with headlamps alone. Unlike the situation with signs, drivers of CMVs are actually better able to see retroreflective markings than drivers of smaller vehicles. This is because the markings are on the pavement in front of the driver whereas signs are off to the side and several feet above the pavement. Larger vehicles are equipped with higher-intensity headlamps that are mounted higher than those on automobiles, which is more important in this situation. However, increasing the retroreflectivity of pavement markings will aid in the visibility of the markings during nighttime hours for all drivers.[52,53] The following treatments also offer proactive communications to drivers, including CMV drivers, to allow more fluid, more predictable auto-truck interactions along the road.

Horizontal Signing

Horizontal signing refers to messages typically communicated by signs on the roadside or overhead being placed on the pavement in addition to the sign. (Figure 18). It can include route numbers, stop and yield markings, traffic or parking prohibitions, bus lane markings, or school zone markings. Supplementing signage with markings is helpful to all drivers. One case that is particularly beneficial for larger vehicles is route signing at interchanges because it may reduce risky behavior by passenger vehicle drivers. These passenger vehicle drivers may make last-minute lane changes, often immediately in front of a CMV that has intentionally left a larger gap to enable the longer stopping distance needed. Research has shown the kinds of horizontal signage that most effectively communicate to drivers, but more research may be needed to demonstrate that such signs have a positive impact on CMV crashes. (54,55,56)

Source: Virginia Department of Transportation. *Use of Horizontal Pavement Markings*.(57)

Figure 18. Photo. Route shield pavement marking in Virginia.

COST-EFFECTIVENESS ASSESSMENT: Horizontal signing is assessed as tried and low cost.

Wider Edge Lines

Wider edge lines are any marking along the outside pavement edge over the 4-inch minimum MUTCD standard (Figure 19). Studies have shown that 6-inch edge lines more effectively communicate usable lane widths along two-lane roads.(58,59,60) Many of these studies examine general driver behavior but do not examine the effects of wider edge lines on CMV crashes. However, fatal crashes involving large trucks occur more frequently on rural roadways than urban, so this treatment may have some applicability for CMV safety. Wider edge lines have a proven safety benefit and are a cost-effective crash countermeasure. They have also been found to improve operational metrics such as encroachment and driver eye glance when compared to pavement marking brightness.

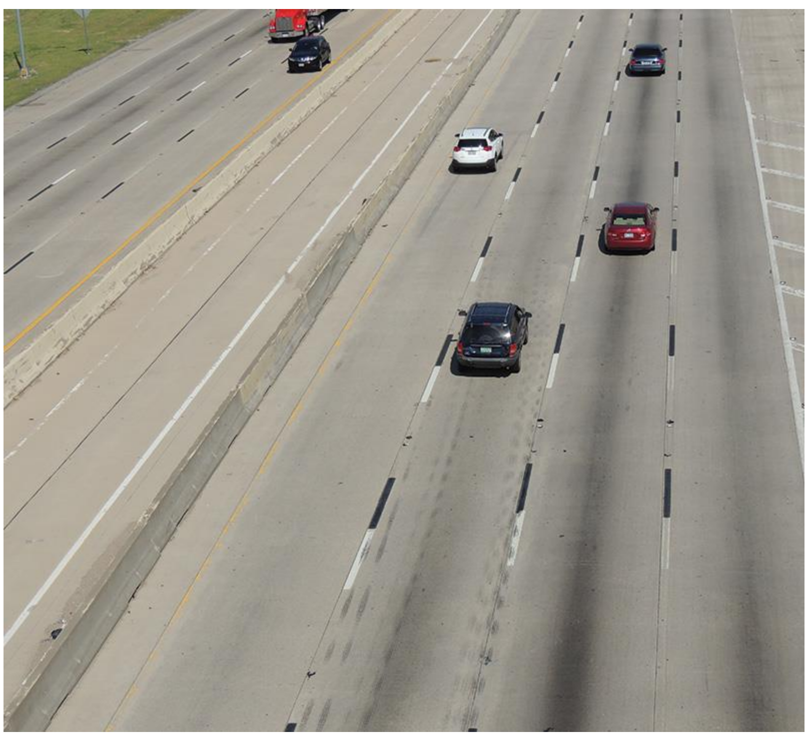
COST-EFFECTIVENESS ASSESSMENT: Wider edge lines are assessed as proven and low cost.

Source: Carlson, P. and Wagner, J. *An Evaluation of the Effectiveness of Wider Edge Line Pavement Markings.*(58)

Figure 19. Photo. Wider edge line marking.

Contrast Markings

On concrete surfaces, pavement markings may blend with the concrete color during the daylight. To improve lane marking visibility, black contrast marking material is applied adjacent to the retroreflective white or yellow line, or beneath the standard marking with a larger footprint, as shown in Figure 20. This type of pavement marking increases the conspicuity of longitudinal pavement markings, with possible benefits for fatigued CMV drivers.(61,62)



Source: Brewer, M., Murillo, D., and Pate, A. Handbook for Designing Roadways for the Aging Population. (63)

Figure 20. Photo. Contrast marking.

COST-EFFECTIVENESS ASSESSMENT: Contrast markings are assessed as tried and low cost.

Incident Warnings

This final class of safety communication treatments addresses CMV safety in higher-risk environments that may be non-recurring or temporary. Risks are associated with changes in lane alignment or configuration, aggregate traffic patterns that change, or weather-related conditions that pose risks to CMV operations. Two are focused on operational safety issues within work zones because these are related to construction that provides for the upkeep of the infrastructure. As mentioned in chapter one, nearly a third of all work zone traffic fatal crashes involve at least one truck. The FHWA has been leading a joint effort with other USDOT agencies over the last several years to improve large truck safety in work zones. The final countermeasure included in this section relates to weather conditions that can pose CMV safety challenges on certain segments of the infrastructure.

Queue Detection Warning in Work Zones

This system uses vehicle speed monitoring to detect queue buildup at critical transition points in work zones and displays real-time warnings to upstream motorists using portable changeable message signs. Drum-mounted radar systems can be deployed at the beginning of work-zone-related constrictions or alignment changes, and can be moved as work zones change during different project phases (Figure 21). This system offers promise for CMV drivers in work zones because 30 percent of work zone crashes are related to large trucks. Displaying queue detection to drivers can help CMVs begin to slow down in advance, reducing the risk of not being able to stop before they reach the queued traffic. This is one of several strategies that can be found on the "Large Trucks in Work Zones" Web page at the National Work Zone Safety Information Clearinghouse (https://www.workzonesafety.org/work_zone_topics/heavy-vehicles/).

Source: Brydia B. *Getting information to drivers to improve awareness, safety*.(64)

Figure 21. Photo. Dynamic queue detection warning sign in a work zone.

COST-EFFECTIVENESS ASSESSMENT: Queue detection warning in work zones is assessed as proven and moderate to high cost.

Work Zone and Incident Electronic Notification Systems

With the exception of very small owner-operators, most commercial motor carriers communicate to truck drivers through dispatchers, who assign loads and monitor truck location and condition. Larger motor carriers also connect to CMVs through satellite or wireless networks that provide real-time tracking of vehicles and shipments, engine diagnostics and fuel use, hours of service logging, and driver communication. The FMCSA is seeking to take advantage of these CMV driver communication networks to connect to public information about work zone activities. The FMCSA Innovative Technology Deployment grant-funded projects are implementing an in-cab alert system that will notify the CMV driver of an active work zone, traffic congestion, or an incident ahead. The alert system must be able to be broadcast through the CMVs' transponders, electronic onboard systems, cell phones, or motor carrier routing and dispatching systems. These notification systems will alert CMV drivers of work zone delays with sufficient advance notice to allow dispatchers to suggest alternate routes.

COST-EFFECTIVENESS ASSESSMENT: Work zone and incident electronic notification systems are assessed as experimental/promising and moderate to high cost.

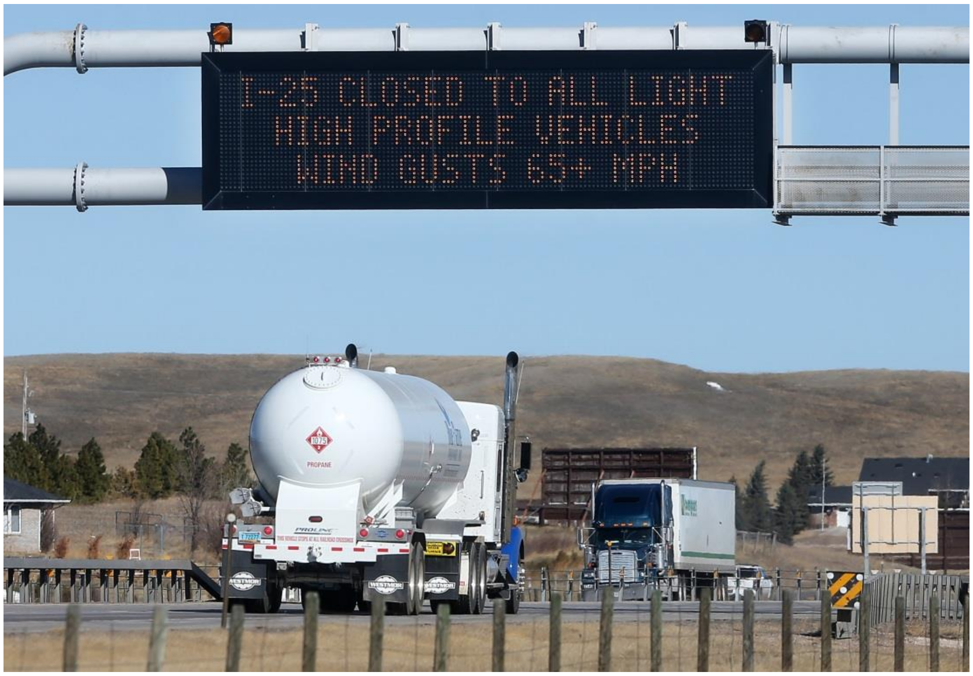
Visibility and Wind Detection Systems

Limited visibility due to fog, dust, or smoke can lead to infrequent but high-consequence crashes, sometimes involving multiple vehicles, including CMVs. High winds affect large vehicle dynamics, especially tractor-trailer combinations. Road Weather Information Systems are used in locations with frequent weather risks to inform drivers about adverse road conditions during weather events. The message conveyed may be general (Figure 22) or may include specific suggestions such as adjusting behavior (e.g., reduce speed) or vehicle performance (e.g., use tire chains), or it may suggest drivers stop driving or seek alternate routes due to road closures. In some cases, the road closure may be specific to high profile vehicles (Figure 23).[65] Some States combine these weather detection systems with variable speed limits to further reduce risk. These systems monitor weather conditions, either from a central location or with local weather detection measurement devices, and communicate adverse weather conditions through dynamic message signs. These warning systems can provide valuable information to CMV drivers to reduce exposure to weather risks.

COST-EFFECTIVENESS ASSESSMENT: Visibility and wind detection systems are assessed as proven and moderate to high cost.

Source: Elkins, H. B. *Millennium Highway: The New I-26 Virtual Tour.*[66]

Figure 22. Photo. Weather advisory system using a static sign with beacons.



Source: Orr, B. "*Wyoming wind not abnormal but the timing is*." Photo Credit: Blaine McCartney, Wyoming Tribune Eagle[67]

Figure 23. Photo. Weather advisory system with a changeable message sign.

Chapter Four. Innovative CMV Safety Practices

An important aspect of reducing the number of CMV-involved crashes is providing areas for drivers to rest and enforcing regulations designed to ensure CMVs and their drivers are in good condition. Safety infrastructure improvements can assist with making these operations more feasible. This chapter discusses these practices along with practices attempting to provide some separation of large vehicles from the more agile stream of passenger vehicles.

Compliance with Safety Rules

The primary mission of FMCSA is to reduce crashes, injuries, and fatalities involving large trucks and buses. The FMCSA enforces Federal motor carrier safety regulations primarily through the Motor Carrier Safety Assistance Program (MCSAP). The roadside inspection portion of the MCSAP consists of roadside inspections performed by qualified State and local safety inspectors, following guidelines developed by FMCSA and the Commercial Vehicle Safety Alliance. Six levels of inspections include a vehicle component, a driver component, or both. Separately, the traffic enforcement component of MCSAP is composed of two distinct activities: a traffic stop as a result of a moving violation and a subsequent roadside inspection. Infrastructure improvements to provide wider shoulders or specifically designed pullout areas, where roadside inspections can be conducted with less risk of drivers in the adjacent travel lanes intruding into the inspection space, would be beneficial to these important safety activities.

The FMCSA has developed the Roadside Intervention Effectiveness Model to estimate the effects of these safety enforcement programs. The model associates each violation of the Federal Motor Carrier Safety Regulations with a specific crash probability. Using these probabilities, analysts can estimate the number of crashes prevented as a result of correcting these violations. The model estimates that for roadside inspection and traffic enforcement in 2012, these programs saved 472 lives and prevented 8,833 injuries by averting more than 14,424 crashes.(68) The following safety practices are associated with roadside equipment that aids in inspection and enforcement activities or countermeasures that aid in rules compliance.

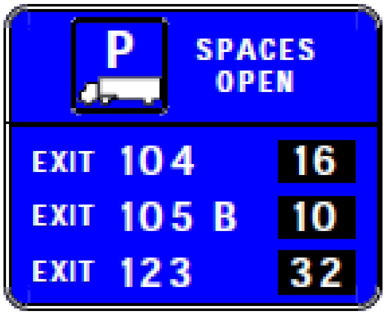
Truck Parking Systems

Like the Federal Railroad Administration for train crews and the Federal Aviation Administration for pilots, FMCSA enforces hours of service regulations for CMV drivers, establishing rest periods, breaks, and the maximum number of hours over a certain period.(69) In order for drivers to comply with the mandatory rest rules, drivers need to find safe, available parking.(70) The challenges of finding available parking can mean that drivers spend more time on the road hunting for parking when they should be resting.

To address this problem, States are using FMCSA and DOT grant programs to implement intelligent transportation systems that monitor truck parking spaces in public rest areas and some private truck stops. These smart systems communicate space availability to CMV drivers either directly through phone messages or via roadside message signs (Figure 24 and Figure 25).(71,72) A variety of technologies are being deployed to monitor space occupancy and availability, but the common element is providing drivers with reliable, timely information. This information should reduce time spent hunting for parking and reduce the safety risks to drivers that park in less safe locations. These intelligent transportation system parking systems can also be accompanied or leveraged by truck parking expansions in public rest areas in order to reduce the number of trucks that park overnight in unsafe areas.

Source: Photo Courtesy HNTB Corporation.[(73)]

Figure 24. Photo. SmartPark in Michigan.



Source: FHWA

Figure 25. Graphic. Current recommended sign design.

COST-EFFECTIVENESS ASSESSMENT: Truck parking systems are assessed as tried and high cost.

Infrared Braking Detection Systems

A number of States have tested infrared screening technology in roadside detection devices that identify overheated and inoperable brakes. The testing also involved screening for additional safety inspections and subsequent checks of credentials and safety compliance. Such screening can help remove unsafe vehicles and drivers from the roadway, gaining safety benefits by preventing crashes caused by malfunctioning or inadequate brakes. In some cases, these detection devices can catch brake problems before the driver is aware of them.

COST-EFFECTIVENESS ASSESSMENT: Infrared braking detection systems are assessed as experimental/promising and moderate to high cost.

Electronic Screening

Electronic screening is a process deployed in advance of State roadside safety inspection facilities that electronically identifies a CMV; verifies its size, weight, and credentials information; and reviews its carrier's past safety performance, all while the vehicle is in motion. The driver receives in-cab signals to pull into the inspection or weigh station or bypass it based on the screening results. Vehicles that are properly credentialed, operated by a motor carrier with a history of safe operations, and within weight are allowed to bypass inspection facilities. Not all sites are instrumented for weight measurements, and random inspections may still be performed for those meeting all the listed criteria.

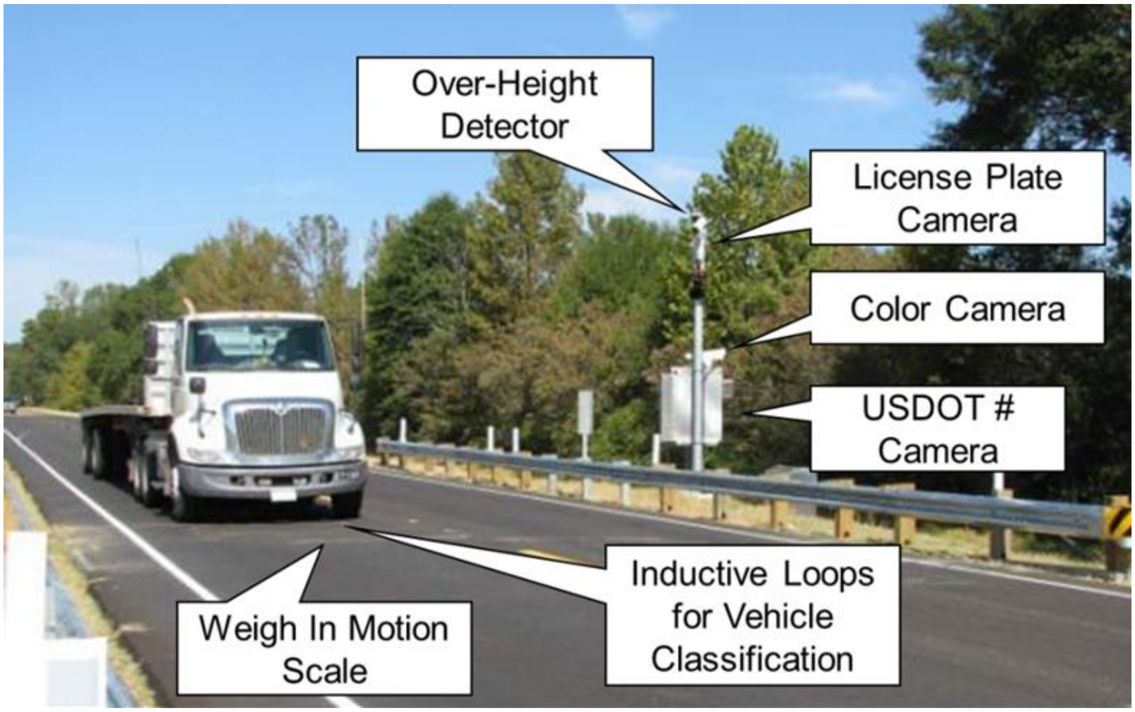
Electronic screening projects are designed to target roadside enforcement services aimed at high-risk motor carriers or vehicles and to reduce operating costs for safe and legal motor carriers. Fixed, virtual, or mobile inspection stations that can provide this functionality are examples of electronic screening implementations. Transponders or other onboard wireless mobile data devices that transmit and receive information between the driver and the inspection site can be used to fulfill the e-screening requirement for Core Compliance with FMCSA's Innovative Technology Deployment program.

COST-EFFECTIVENESS ASSESSMENT: Electronic screening is assessed as proven and moderate to high cost.

Virtual Weigh Stations

Unstaffed and remotely monitored roadside enforcement facilities, commonly called virtual weigh stations (shown in Figure 26), are deployed to address some of the limitations in States' traditional roadside enforcement programs.(74) These facilities can screen CMVs on routes that bypass fixed inspection stations, on secondary roadways, and in heavily populated urban or geographically remote locations where it may be difficult to deploy traditional enforcement operations. Data from virtual weigh station sites can effectively target enforcement resources on roadways where overweight trucks and noncompliant carriers are known or suspected to operate. Most States already use weigh-in-motion equipment for FHWA data collection requirements as part of the vehicle classification for Highway Performance Management System sampling.

COST-EFFECTIVENESS ASSESSMENT: Virtual weigh stations are assessed as proven and moderate cost.



Source: FHWA.

Figure 26. Photo. Virtual weigh station.

Truck Separation Measures

The frequency of auto-truck interactions on a roadway can increase the aggregate safety risks of possible multivehicle crashes. States are experimenting with the use of regulatory measures to separate truck movements from the rest of traffic.

Oversize/Overweight Corridors

Some common problems associated with OS/OW vehicle movements, such as restrictive clearances, pavement condition, and vehicle interaction, may be managed through designating certain corridors with high freight volumes as OS/OW corridors through regulatory authority and infrastructure improvements.(75) Some States are experimenting with this around ports, but it is advocated for economic development purposes more than safety. The OS/OW movements in these corridors could be authorized through trip permits or regulatory changes to allow certain vehicle-weight combinations access to the corridor. These corridors could be designed and constructed specifically for OS/OW movements, using strategies such as limiting geometric changes along the road and payment of fees commensurate with the relative adverse effects on pavements and structures.

COST-EFFECTIVENESS ASSESSMENT: OS/OW corridors are assessed as experimental/promising and high cost.

Truck Lane Restrictions

States have established truck lane restrictions to separate slow-moving trucks from faster-moving vehicles. This treatment includes the restriction of trucks from at least one lane (Figure 27). Studies suggest that restricting trucks to fewer lanes in general improves traffic operations and decreases pavement deterioration in the restricted lanes, while other studies show an improvement in safety.(36,76,77) A recent safety evaluation of truck lane restrictions found a 40 percent reduction in truck-related fatal and injury crashes on multilane freeways with traffic volumes below 10,000 vehicles per day, and a 14 percent increase for multilane freeways above that threshold.(77) Commercial operators may perceive this as a negative treatment since restricting trucks to fewer lanes limits their maneuverability. These lane restrictions are imposed as a regulatory measure, limiting truck movement in all lanes and posting associated signage to inform drivers.

Source: Texas A&M Transportation Institute

Figure 27. Graphic. Truck lane restriction in Texas.

COST-EFFECTIVENESS ASSESSMENT: Truck lane restrictions are assessed as proven and low cost.

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Chapter Five. Challenges and Conclusions

Factors Affecting CMV Safety

This report identifies safety infrastructure improvements and practices that are being deployed and show promise for improving CMV safety outcomes. The future of CMV safety may also be affected by a number of unpredictable trends:

- How freight economics and traffic will interact.
- How infrastructure safety improvements and transportation technology may change CMV safety.
- How freight planning and highway safety planning will respond to these trends.

Economic Trends

The following changes in freight demand and in trucking industry capacity are expected in the near term (1 to 3 years):

- VMT increase. As crude oil prices have declined, so too have motor fuel prices. This trend has resulted in VMT increases that resume the growth trends before the Great Recession. This means trucks will be competing with more cars on the road.

- Truck VMT growth. The National Strategic Freight Plan and many State-level freight mobility plans are estimating significant long-term growth in freight demand as the economy and population grow.(7) The DOT estimates that freight tonnage moving on the Nation's transportation network will grow 40 percent in the next three decades, and the value of the freight will almost double.(78) This means more truck traffic can be expected to join the growing numbers of vehicles on the road.

- Constrained trucking industry capacity. The trucking industry has been wary of a significant anticipated truck driver shortage with an estimated need to fill over 2 million jobs between 2012 and 2022, fueled by changing employment demographics.(79) New regulations (hours of service and electronic log books(80)) add a degree of uncertainty to the scope of this short-term issue. In addition, weak freight volumes in the recent past have led to increasing bankruptcies among smaller firms, resulting in reductions in new truck equipment orders.(81) When the economic recovery strengthens, the ability of the motor carrier industry to respond may be limited in the near term. Driver turnover and longer use of older equipment could lead to adverse CMV safety outcomes.

- Persistent traffic congestion. Even before the passage of the FAST Act, many States were taking steps to increase transportation revenues to address network maintenance issues and relieve congestion chokepoints. Even with these new financial resources, States can be expected to struggle with stubborn congestion in urban areas. Much of this congestion will be difficult to resolve with capacity expansion because of available resources, land use conflicts, and environmental issues.

As FHWA works with States to conduct the freight planning required by the FAST Act and updates its own national strategic freight plans, FHWA can help States adopt scenario plans for these and other changes in CMV traffic that will be critical to inform State SHSPs and financially constrained freight project plans.

Changes in highway financing could also affect truck VMT and industry capacity. Many States have been experimenting with road user fees, which are highway funding mechanisms to replace or augment motor fuel taxes and vehicle registration fees. Tests of such systems have been encouraged in previous surface transportation reauthorizations, and section 6020 of the FAST Act also establishes a grant program to assist States in testing user-based alternative revenue mechanisms. Since combination trucks travel more miles per vehicle than autos or single-unit trucks, any user-based fee is likely to charge large trucks more, as is already the case with per-gallon motor fuel taxes. If new user-based alternative funding mechanisms increase the relative share of user fees paid by CMVs, the economics of longer-distance truck trips may change. This could lead to either pressure for longer combination vehicles to gain more productivity from mileage-based fees assessed on the tractor unit or more truck-to-rail diversion of intercity trips. Either of these outcomes could have implications for CMV safety.

Potential Future Safety Practices

This report has described a number of roadway infrastructure safety improvements, but some incremental adjustments could increase their safety benefits. The following examples of possible alterations to current practices could be explored with existing or new technologies:

- Exclusive CMV lanes. This would be a lower-cost variant of the exclusive truck roadway described in chapter two, where the inner lane or lanes would be designated and marked for usage only by CMVs, but not separated with additional space and barrier. Unlike the truck lane restrictions described in chapter four, positioning the large vehicles on the inner lanes reduces the inefficiency and safety issues associated with the interaction of large vehicles with merging vehicles. This kind of separation may be worthwhile in certain corridors, and infrastructure improvements could be balanced against advancement in vehicle technology that reduces human error by drivers of automobiles and CMVs.

- Vehicle-specific adaptable advisory speeds. A variation on dynamic speed advisory signs described in chapter three, this could address the lower speeds that are appropriate for vehicles with higher centers of gravity. This may also potentially improve driver respect for advisory speed signing because many small passenger vehicles can safely negotiate curves at speeds significantly higher than the posted advisory speed if they have adequate tires and the pavement is not wet or icy. Similar applications may be appropriate on ramps.

- Active traffic management strategies. Dynamic lane restrictions, opening shoulders for use as travel lanes, and variable speed limits could be deployed at known bottlenecks to prevent or relieve recurring congestion. These strategies could be activated as part of a roadway segment's congestion management strategy, segregating CMV and auto traffic, opening additional "lanes" and adjusting speed limits to address safety concerns if queues build. When traffic volumes ease in the corridor, the larger vehicles could once again be allowed to use all lanes and shoulder driving would no longer be permitted.

Size-sensitive in-vehicle warnings. Vehicle technologies are currently available that provide proximity alerts. As these systems become even smarter, they may consider additional information about the potential risk by considering the size of other vehicles along with the distance and speed to determine the appropriate safe spacing between vehicles.

Freight and Safety Planning Responses

The subject of CMV safety also raises issues beyond the scope of this report that the transportation safety community can consider as the FAST Act is implemented. Pertinent stakeholders include policy makers, modal administrations in DOT, State infrastructure owners, law enforcement agencies, industry associations, vehicle and traffic safety equipment manufacturers, and transportation research institutions. These safety issues include the following:

- Freight and safety planning integration. Congress has authorized the designation of the Primary Highway Freight System and mandated State freight planning after October 2017 that will identify State-specific highway freight networks. Collection of traffic safety data on these corridors could help inform data-driven safety planning at the State level, such as during the SHSP process. In addition, as States identify projects to improve freight operations on these corridors, they should consider safety outcomes on these freight highway networks.

- Truck size and weight issues. Section 32801 of the Moving Ahead for Progress in the 21st Century Act required DOT to conduct a comprehensive truck size and weight limits study. The April 2016 report addressed five core technical areas and concluded that data gaps and model limitations prevented a conclusive, bottom-line finding. Without this definitive conclusion, certain shippers and motor carriers have advocated adjustments to the Federal truck size and weight limits (e.g., longer combination vehicles within current weight limits and heavier trucks with different axle configurations) in the FAST Act authorization and annual appropriations deliberations. The CMV safety measures in this report are responsive to the current CMV fleet (even with regional size and weight variations authorized in current law). Changes to truck size and weight restrictions may alter CMV safety outcomes and require different practices.

Findings and Conclusions

Infrastructure will always be critical to the safe and efficient operation of the Nation's highway system. The goal of no fatalities cannot be achieved by focusing on infrastructure alone, so Congress requires State SHSPs to address six elements of highway safety as key factors in evaluating highway projects:

- Engineering
- Management
- Operations
- Education
- Enforcement, and
- Emergency services.

States are currently deploying a number of infrastructure safety measures identified with varying degrees of demonstrated effectiveness in addressing CMV safety needs. The safety improvements and practices included are not limited strictly to pavements and bridges but also consider roadside hardware, capacity improvements, signage and markings, better work zones, and ways the infrastructure can support safety enforcement efforts. While standard safety design practices and traffic engineering work well on large portions of the systems, enhanced measures can be used in areas of greater risk. Dynamic signing, higher-performing barriers, and detection systems are examples. Technology is playing a greater part in safety every year as more concepts emerge as practical applications to provide smarter vehicles and smarter infrastructure. The countermeasures described in this report fall within the engineering, management, operations, and enforcement elements.

Each State will continue to identify emphasis areas, strategies, and goals through a collaborative planning process with multiple stakeholders. Beginning in 2017, States will also establish annual targets for fatalities and injuries to measure safety performance. The CMV-related emphasis areas are already included in over half of the State SHSPs. Since 12 percent of all traffic fatalities involve large trucks and buses, State data-driven approaches may focus on many other crash and casualty issues and factors. However, with the vision of zero deaths embraced by FHWA and most State DOTs, CMV safety will continue to be part of reaching this goal.

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