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Highway/Heavy Vehicle Interaction: A Synthesis of Safety Practice

Programs of the Federal Motor Carrier Safety Administration (FMCSA) encompass a range of issues and disciplines, all related to motor carrier and bus safety and security. FMCSA's Office of Research and Analysis, which includes the Research, Technology, and Analysis Divisions, defines a "research program" as any systematic study directed toward fuller scientific discovery, knowledge, or understanding that will improve safety, and reduce the number and severity of commercial motor vehicle crashes. Similarly, a "technology program" is a program that adopts, develops, tests, and/or deploys innovative driver and/or vehicle best safety practices and technologies that will improve safety and reduce the number and severity of commercial motor vehicle crashes. An "analysis program" is defined as economic and environmental analyses done for the agency's rulemakings, as well as program effectiveness studies, state-reported data quality initiatives, and special crash and other motor carrier safety performance-related analyses. A “large truck” is any truck with a Gross Vehicle Weight rating or Gross Combination Weight rating of 10,001 pounds or greater.

Currently, FMCSA's Analysis, Research and Technology Divisions are conducting programs in order to produce safer drivers, improve safety of commercial motor vehicles, produce safer carriers, advance safety through information-based initiatives, and improve security through safety initiatives. The study described in this Tech Brief was designed and developed to support the strategic objective to improve the safety of commercial motor vehicles. The primary goals of this initiative are to improve truck and motorcoach performance through vehicle-based safety technologies and infrastructure.

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Background

Highway features and improvements have a very large effect on the safety of heavy vehicle operations. This synthesis is a comprehensive literature review that looks at the safety interactions of commercial trucks and buses with these highway features, and identifies highway upgrades that can be made to improve the safety of heavy vehicle operations. Information is also based on surveys of State departments of transportation and the trucking industry. The following factors are addressed:

- Physical and performance characteristics of heavy vehicles that interact with highways
- Geometric design criteria based on vehicle characteristics
- Traffic control devices and traffic regulations
- Intelligent transportation systems (ITS) and their use to communicate more effectively with heavy vehicle drivers and provide real-time information concerning safe vehicle operation

The specific issues considered in regards to these factors are those that have a direct relationship to interactions between heavy vehicles and roadway features, roadside design features, traffic control devices, or traffic regulations, and those that have a direct relationship to safety.

Trucks and buses are larger, heavier, and less maneuverable than passenger cars and make up an increasingly larger proportion of the traffic on U.S. highways. For example, on many rural interstate highways, commercial trucks and buses now make up more than one-third of the traffic stream. Many of the established criteria for highway design and operation used by highway agencies are based on interactions between highway features and the vehicles that use the highways. For most of these criteria, the larger and heavier vehicles have more critical interactions with highway features than the smaller passenger vehicles. Safe design and operation of highway facilities requires that these interactions be understood and incorporated in the formulation of highway agency policies and in the planning of safety improvements that highway agencies make to the highway system.

Definitions

For the purposes of this synthesis, heavy vehicles include single-unit trucks and other motor vehicles with gross vehicle weight ratings in excess of 4,550 kg (10,000 lb). Commercial buses are those that are designed and used to transport 15 or more passengers (including the driver). Intercity and charter buses are considered; school buses and local transit buses are not addressed, although many of the issues discussed may also apply to these vehicles.

The American Association of State Highway and Transportation Officials' (AASHTO) *Policy on Geometric Design of Highways and Streets*, commonly called the AASHTO Green Book, identifies configurations used as design vehicles. These findings are based on a comparison of the AASHTO Green Book with the current literature review and surveys.

Physical and Performance Characteristics

A wide variety of heavy vehicle types operate on U.S. highways, and each type has unique characteristics that interact with highway features. The understanding of these interactions is important to the safe operation of the highway transportation system. The physical and performance characteristics of heavy vehicles that interact with highways include vehicle types and configurations, weights and dimensions, turning radius, offtracking and swept path width, trailer swingout, braking distance, driver eye height, truck acceleration characteristics, rearward amplification, suspension characteristics, load transfer ratio, and rollover threshold.

The literature review led to the recognition of various factors that are affected by or affect physical and performance characteristics:

- The dimensions of heavy vehicles, particularly the spacing between axles and hitch points and the front and rear overhang distances, are primary determinants of the vehicle turning radius, offtracking, and swept path width. These vehicle performance measures are, in turn, key factors in the design of various highway features to accommodate heavy vehicles.

- Antilock brakes are now required by Federal regulation for all newly manufactured heavy vehicles. The antilock brakes used on heavy vehicles must meet a specific performance standard. Braking capabilities of trucks have improved to the point that the braking distances of passenger cars and trucks on wet pavements, where braking distance is most critical to safety, are now nearly equal.

- Heavy vehicle drivers sit higher than passenger car drivers and, thus, have greater eye heights. As a result, truck and bus drivers can see farther than passenger car drivers when approaching vertical sight restrictions, such as hillcrests. This may permit truck and bus drivers to see traffic conditions or objects in the road sooner and, therefore, begin braking sooner. There is no comparable advantage for truck and bus drivers at horizontal sight restrictions.

- Because of their lower acceleration rates and greater length, heavy vehicles take longer than passenger cars to accelerate and clear specific conflict zones, such as intersections and railroad-highway grade crossings. Heavy vehicle speed maintenance capabilities on upgrades are a function of the vehicle's weight-to-power ratio and the length and steepness of the grade.

- In trucks with more than one trailer, the second or third trailer may experience higher lateral acceleration than the first trailer in lane change or avoidance maneuvers. The maximum desirable lateral displacement of a trailer due to this rearward amplification is 0.8 m (2.7 ft).

- Vehicle characteristics related to the dynamic stability of trucks, as represented by load-transfer ratio and rollover threshold, include dynamic inter-axle load transfer, height of roll center, roll stiffness, roll steer coefficient, compliance steer coefficient, center-of-gravity height, overall weight, and longitudinal and lateral weight distribution.

Highway Geometric Design

Many highway geometric design criteria are based on vehicle characteristics. In many cases, the characteristics of trucks and buses are the most critical in defining these design criteria or assessing their appropriateness. Highway geometric design features whose design is based on consideration of vehicle characteristics include sight distance, upgrades, downgrades, acceleration lanes, horizontal curves, intersection design, interchange ramps, and roadside features.

The literature provided several confirmations, including:

- The current sight distance criteria used in highway geometric design, including stopping, passing, intersection, and railroad-highway grade crossing sight distance, can reasonably accommodate the current heavy vehicle fleet.

- Where long, steep upgrades reduce truck speeds by 16 kph (10 mph) or more, the provision of truck climbing lanes should be considered. The AASHTO Green Book presents criteria for determining where truck climbing lanes are warranted and economically justified.

- Long, steep downgrades present a safety concern for heavy vehicles. If the vehicle service brakes are used too often in descending the grade, they may overheat and lose their ability to decelerate the vehicle. Because of these risks, highway agencies provide warning signs and roadside brake check areas at the top of some downgrades and provide emergency escape ramps for out-of-control vehicles in the middle or lower portion of some downgrades.

- Acceleration lanes are provided at entrance ramps to major highways to provide a location for vehicles to increase their speed before entering the highway. The AASHTO Green Book criteria for the length of acceleration lanes appear adequate to accommodate average trucks but may not accommodate the lowest performance trucks.

- Horizontal curves designed in accordance with AASHTO Green Book criteria allow heavy vehicles to operate at the design speed of the curve with a substantial margin of safety against skidding or rolling over. Skidding or rollover should occur only when a heavy vehicle substantially exceeds the design speed of the curve.

- Heavy vehicles are a key consideration in the design of intersections. Intersection features that must consider the presence, frequency, and characteristics of heavy vehicles include curb return radii for right turns, storage lengths for left-turn lanes, median widths on divided highways, and the offset between opposing left-turn lanes.

- Interchange ramps are designed to provide sufficient width for other vehicles to pass a stalled heavy vehicle. The design and signing of horizontal curves on ramps is important to their safe operation because safety problems may result, as noted above, when heavy vehicles exceed the design speed of a curve. A special truck rollover warning sign for use at such locations has been used by highway agencies.

Traffic Control Devices and Traffic Regulations

Traffic control devices and traffic regulations have an important role in safely accommodating heavy vehicles on the highway and are used by highway agencies for this purpose, especially at locations where safety problems have occurred or are anticipated. Traffic control device strategies that have been used, or are being considered, to better accommodate heavy vehicles on the highway include differential speed limits, road restrictions, exclusive lanes and roadways, signing for long downgrades, signing and marking of interchange ramps, mitigating the restriction of sign visibility, and modifying signal timing to better accommodate heavy vehicles.

Many traffic control devices and regulations have been found to have less safety benefits than anticipated:

- Highway agencies have tried to improve traffic operations and safety by restricting heavy vehicle use of the left lane or restricting heavy vehicles to use only the right lane on major highways. Most evaluations of such lane restrictions have shown no effect on safety, positive or negative. However, a recent test in Houston for an 8-month period in one freeway corridor recognized safety benefits from left-lane restrictions for heavy vehicles.

- Highway agencies have prohibited truck travel on selected highways for a variety of reasons unrelated to safety. Naturally, this eliminates truck-related crashes on the facility in question, but no studies for these sites have examined the safety impact of truck diversion to other routes.

Availability: The synthesis report "Highway/Heavy Vehicle Interaction: A Synthesis of Safety Practice" is available at the Transportation Research Board and can be found at www.trb.org.

Key Words: Bus, CMV, carrier safety, commercial motor vehicle, heavy vehicle, intelligent transportation systems, motorcoach, truck

Web Site: All FMCSA Tech and Analysis Briefs may be accessed at www.fmcsa.dot.gov.

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February 2007
Publication No. FMCSA-MCRRR-07-007

- Some highway agencies have implemented, and others are considering, exclusive truck lanes or exclusive truck roadways on selected facilities. No measures of the safety performance of such facilities are available.
- Heavy vehicles, because of their size, can block the view of highway signs by other motorists. Highway agencies have developed specific methods for dealing with this problem where it occurs, including the use of additional advance warning signs, as well as placement of signs overhead, and on both sides of the road.
- Heavy vehicles are often a consideration in selecting the length of a yellow signal phase and assessing the need for an all-red clearance interval at signalized intersections.

Intelligent Transportation Systems Initiatives

Highway agencies are increasingly using Intelligent Transportation Systems (ITS) initiatives to more effectively communicate with heavy vehicle drivers and provide real-time information concerning safe vehicle operation. The types of ITS systems in current use by highway agencies include warning systems for long downgrades, dynamic curve warning systems, and improved weigh station operations. ITS initiatives related to heavy vehicle safety also include on-board vehicle technology, such as collision avoidance systems for buses.

Recommendations

The synthesis highlighted the following recommendations:

- The marking of passing and no-passing zones on two-lane highways in regards to sight distance criteria in the Manual on Uniform Traffic Control Devices (MUTCD) should be evaluated to ensure that heavy vehicles use them properly.
- Research is needed to determine whether the current AASHTO Green Book criteria for acceleration lane lengths at entrance ramps to major highways leads to poor safety performance, and whether the design criteria for acceleration lane length can be changed in a cost-effective manner.
- Research on sight restrictions and the benefits of providing offset left-turn lanes to remove them has not been documented.
- Highway agencies need better information on the safety effects of differential speed limits.
- Further research based on field trials would be desirable to establish whether lane restrictions have safety benefits.
- Research is needed to provide safety performance measures to assist highway agencies in decisions about whether to reduce traffic congestion by building exclusive truck lanes or roadways.
- New and innovative ITS technologies to improve heavy vehicle safety should be developed, and the safety effectiveness of both existing and new systems should be evaluated and documented.