Chapter 5

Technologies To Improve Motor Carrier Safety

Photo credit: Ohio State Highway Patrol

Most States have poorly designed highway segments where accidents are frequent; this one is known as Dead Man's Curve.

CONTENTS

Boxes

Figures

Chapter 5

Technologies To Improve Motor Carrier Safety

Accident analyses and equipment research demonstrate that appropriate road design and vehicle technologies can help prevent highway accidents and reduce fatalities and injuries. Moreover, recent research shows that some aspects of highway design make driving today's heavy vehicles safely very difficult. Although new technologies cannot eliminate the effects of poor road conditions or unsafe driving, they can reduce the likelihood that a roadway mishap will result in a catastrophe.

This chapter examines the relationship between the vehicle, the driver, and the roadway environment, and describes the impact of highway design characteristics, vehicle equipment, and safety technologies on vehicle performance. As motor carriers of passengers, intercity buses operate under many of the same rules and regulations as the trucking industry. Certain aspects of truck safety are directly applicable to bus safety. Critical items such as brakes, tires, and lights are important for the safety of bus passengers and the motoring public and must be monitored by bus operators. Thus, although bus safety issues are not addressed separately in this chapter, many technology issues are applicable to that industry as well.

THE MOTOR CARRIER OPERATING ENVIRONMENT

Today's highway environment is substantially different than that of 10 years ago. The increase in automobile ownership, dispersed patterns of work and residence, and the speed and convenience of truck transportation have increased the use of the Nation's roads, Traffic on many highways in and around major metropolitan areas is already at or above design capacity, and road congestion is a fact of daily life for millions of Americans. The volume of automobile traffic, combined with large numbers of heavy trucks, has made accidents more likely simply by increasing the opportunities for accidents and exposing drivers to stressful driving conditions.

The impact of heavy traffic volume on safety is compounded by the fact that in recent years, passenger cars have become smaller and lighter while commercial trucks and some buses have become longer, heavier, and wider.[1] Combination trucks with 48-foot single trailers or twin 28-foot trailers are permitted on Interstate highways in all States under the Surface Transportation Assistance Act of 1982 (STAA). Segments of the motor carrier industry have mounted intense efforts to expand the network of roads and access points available to these vehicles. However, large portions of the Nation's highway system, particularly State roads, were designed primarily for automobiles, not for vehicles with the size and operating characteristics of heavy trucks. Moreover, the geometric design policy by which virtually all highway design is guided in the United States provides for only a slim margin of safety for large trucks.[2]

The STAA also created the National Truck Network, which includes the Interstate system and designated Federal-Aid Primary routes. The States must allow the heavy vehicles reasonable access between the National Truck Network and terminals and facilities for food, fuel, repairs, and rest. The American Association of State Highway and Transportation Officials (AASHTO), which establishes design guidelines for highways, ". . . has not adopted a design vehicle that reflects the STAA semitrailer combination."[3] Thus, only portions of the Interstate system and the National Truck Network were designed and constructed to accommodate the larger STAA vehicles.

[1] Patricia F. Waller, "Heavy Truck Safety in a Changing Highway Transportation Environment" presented at the annual meeting of the American Society of Mechanical Engineers, Phoenix, AZ, Nov. 16-17, 1982, pp. 42-43.

[2] Robert Ervin et al., *Impact of Specific Geometric Features on Truck Operations and Safety at Interchanges* (Washington, DC: Federal Highway Administration, August 1985), p. 1.

[3] Federal Highway Administration, *Guide for Monitoring and Enhancing Safety on the National Truck Network* (Washington, DC: U.S. Department of Transportation, October 1986).

HIGHWAY DESIGN

Highway designs are". . . developed after considering such factors as traffic volumes, vehicle mix, accident history, turning maneuvers and frequency, economics, and speed."[4] In principle, the design of a highway facility is determined by ". . . the largest design vehicle likely to use that facility with considerable frequency or a design vehicle with special characteristics that must be taken into account."[5]

Highway features affect at least four major safety factors including:

- the ability of a driver to maintain vehicle control and identify hazards;
- the number and type of opportunities for conflicts between vehicles;
- the consequences of an out-of-control vehicle leaving the travel lane; and
- the behavior and attentiveness of the driver, particularly the choice of travel speed.

However, the contributions of even the best highway design to safe vehicle operation can be counterbalanced by variables such as weather, lighting, and traffic.[6] This section examines the interaction between road design geometry and heavy trucks, highlighting potential low-cost countermeasures to dangerous roadway situations.

Road Geometry

AASHTO design standards guide the construction and reconstruction of highways across the country. In most cases, these guidelines were formulated for the passenger car, the dominant vehicle on the road.[7] Stopping sight distances on hillcrests, for example, were based on the locked-wheel performance of passenger car tires, and the passing sight distance standards for passing lanes were based on car acceleration capabilities.[8] AASHTO standards for the Interstate highway system can accommodate STAA trucks. However, States are free to choose the design vehicle for highways within their borders, and in fact, used standards for smaller vehicles for many of the segments of the Nation's road network that are heavily used by trucks.[9] Thus, despite design efforts aimed at minimizing safety hazards, certain features of the highway system are contributing causes for accidents involving heavy vehicles.

Highway standards are evolutionary, and change occurs very slowly. Moreover, the relationship between safety and highway design features is still poorly understood, because statistical correlations have not been determined.[10] Even after new standards are developed, existing roads may not adequately accommodate heavy trucks. Recently released AASHTO highway design standards do not provide fully for the largest trucks authorized by the STAA, for example, since 102-inch semitrailers require wider lane widths than the new standards provide on curves. *l In addition, automobiles need longer passing sight distances and more time to overtake longer tractor-trailer combinations. To make matters even more confusing, the current design manual offers 14 different design vehicles from which States may choose.[12]

Seven areas of AASHTO's "Policy on Geometric Design of Highways and Streets" pose concerns for truck operations, including:[13]

- sight distance and no-passing zones,
- grades and climbing lanes,
- intersection design and operation!

'Ibid., p. 16.

[5]American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets* (Washington, DC: 1984), pp. 19-20.

Transportation Research Board, *Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation,* Special Report (Washington, DC: National Research Council,1987), p. 77.

'Robert Ervin et. al., "Truck Control Problems Posed by the Design of Highway Ramps," *Vehicle High way Infrastructure: Safety Compatibility, P-194* (Warrendale, PA: Society of Automotive Engineers, Inc., February 1987), p. 29.

[8]P.S. Fancher, "Sight Distance Problems Related to Large Trucks," Symposium on Geometric Design *for Large Trucks,* Transportation Research Record 1052 (Washington, DC: Transportation Research Board, National Research Council, 1986), pp. 29-30.

Transportation Research Board, Twin Trailer *Trucks: Effects on Highways and Highway Safety,* Special Report 211 (Washington, DC: National Research Council, 1986), p. 179.

[10]Transportation Research Board, op. cit., footnote 6.

[11]Transportation Research Board, op. cit., footnote 9, p. 180.

[12]Larry King, Office of Engineering, Geometric and Roadside Design Branch, Federal Highway Administration, personal communication, May 10, 1988.

[13]J.W. Hall, "Introduction," *Symposium on Geometric Design for Large Trucks,* op. cit., footnote 8, p. 1.

- interchange and ramp design,
- roadside design and traffic barriers,
- traffic control device usage, and
- safety.

For example, one basic AASHTO design vehicle–tractor and an approximately 40-foot trailer—was intended to serve as the model for designing rural, two-lane intersections. However, this vehicle was subsequently widely used for designing intersections in urban areas across the country. Tractors with 48-foot or longer trailers making turns in such intersections override all available clearance space between travel lane edge and road edge.[14]

Intersections are potentially dangerous in other ways as well. In a turn, the wheels on the rear axle of a vehicle follow a track inside the path of the wheels on the front axle—a phenomenon called off-tracking. Tractor-trailers making turns begin to off-track inwardly at slow speeds and trailers often encroach on intersecting traffic lanes, striking other vehicles (see figure 5-1). Low-speed off-tracking can be reduced or eliminated by mechanisms that steer the wheels of each axle, an expensive alternative generally reserved for specialized equipment. Current intersection designs do not satisfactorily accommodate the effects of low-speed off-tracking, especially for the 48-foot semitrailers that are now basic equipment.[15]

Highway interchange ramps, even those on many Interstate highways, are especially hazardous locations for trucks.[16] AASHTO geometric design standards for ramps are based almost exclusively on passenger car dimensions.[17] While negotiating curves at high speeds, commercial vehicles exhibit outward off-tracking-each outside wheel of an axle travels a path outside the path of the preceding outside wheel. The outside wheels on a trailer may strike a curb or other object close to the roadway, damaging the curb or object or, worse, causing rollover.

The National Highway Traffic Safety Administration (NHTSA) reports that high-speed off-tracking is common, an important safety issue as the population of multiple-trailer combination vehicles increases.[18] No studies have been conducted regarding combination vehicle configuration and accidents due to off-tracking.

Particular ramp design parameters make it all too easy for a truck driver to lose control of his vehicle. A truck entering a curving highway entrance or exit ramp at high speed must slow down rapidly on a curving roadway, placing a truck at immediate risk for a jackknife or rollover accident.[19] Compound curves, where the degree of curvature varies throughout the curve, present particularly difficult challenges.[20] Drivers often do not understand the dynamic characteristics of the vehicle and the interaction with the changing highway geometry. They thus do not adequately adjust their speed for the situation and are consequently moving too fast

Photo credit: Michael Hines, OTA staff

Large trucks can be hazardous to other vehicles at intersections because the trailers cannot make sharp turns.

[14]Robert Ervin, acting director, University of Michigan Transportation Research Institute, persona] communication, Jan. 13, 1988.

[15]John W. Hutchinson et al., "Highway Factors in Truck Wrecks," *Proceedings, Symposium on Accommodation of Trucks on the Highway: Safety in Design* (Nashville, TN: American Society of Civil Engineers, May 11, 1988).

[16]Snehamay Khasnabis, "Operational and Safety Problems of Trucks in No-Passing Zones on Two-Lane Rural Highway s," *Symposium on Geometric Design for Large Trucks,* op. cit., footnote 8, p. 38; and Federal Highway Administration, *Longer Combination Vehicle Operations in Western States* (Washington, DC: U.S. Department of Transportation, October 1986), p. III-7.

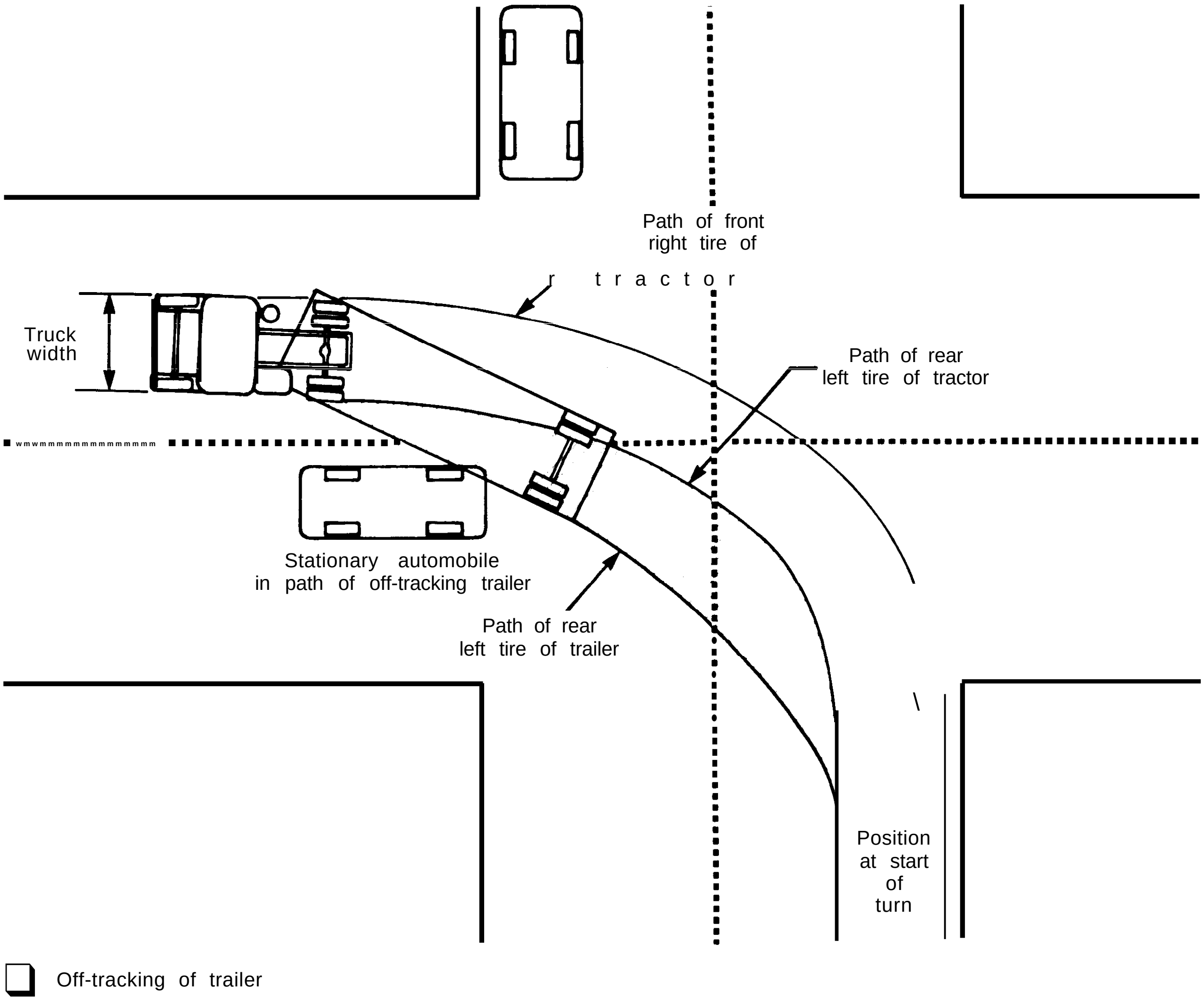
[17]Ervin et al., op. cit., footnote 7, p. 29.

[18]National Highway Traffic Safety Administration, *Heavy Truck Safety Study*, prepared in response to the Motor Carrier Safety Act of 1984 (Washington, DC: U.S. Department of Transportation, January 1987), p. 132.

[19]Ervin et al., op. cit., footnote 2, p. 118.

[20]Justin True, Federal Highway Administration, personal communication, Oct. 21, 1987.

Figure 5-1.—Typical Low-Speed inward Off-Tracking Problem at an Intersection



Off-tracking at intersections presents dangers to other drivers because of the wide path covered by the turning tractor-trailer.

SOURCE: Office of Technology Assessment modification of National Highway Traffic Safety Administration and Federal Highway Administration diagrams.

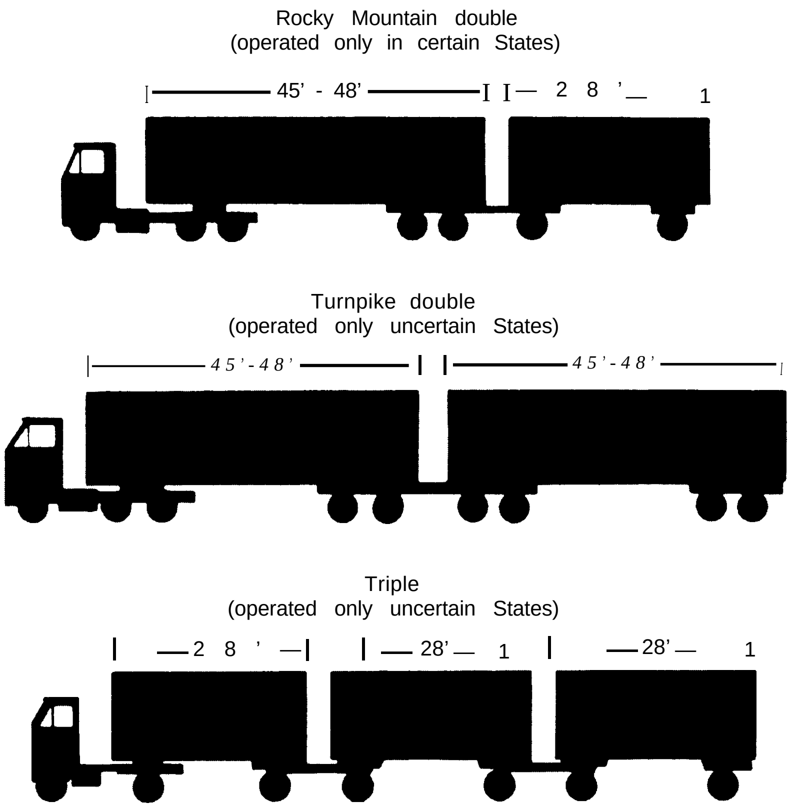
for each succeeding section of the curve. Speed advisory signs compound the problem by giving speeds appropriate for cars not trucks.

Requirements of Longer Vehicles

Drivers of longer combination vehicles (LCVs)–Rocky Mountain Doubles, turnpike doubles, and triples (see figure 5-2)—also confront major driving challenges due to highway design. LCV dimensions "... greatly exceed the dimensions of vehicles that even Interstate highways were designed to accommodate."[21] Problems include off-tracking at intersections, difficulty staying within travel lanes on tight curves, and the increased distance that other vehicles must travel to pass an LCV on two-lane roads.[22] In metropolitan areas, LCVs' greater overall trailer length and inherent handling characteristics further complicate safe operations. Urban freeways also have more crowded travel lanes, reducing distances between vehicles and increasing the need

[21] Federal Highway *Administration,* op. cit., footnote 16, p. V-8.
[22] Ibid., p. III-8.

Figure 5-2.—Longer Combination Vehicles



Lengths shown are typical; shorter or longer lengths are possible depending on carriers' needs and State laws.

SOURCE: Office of Technology Assessment, 1988; based on American Trucking Association, Inc

for rapid steering movements.[23] Abrupt turning movements by the driver, such as changing lanes to reach an exit or to avoid slow traffic ahead, create special dangers from rearward amplification and swaying of the rear trailer.

States that permit LCVs provide for these large vehicles in several ways to keep them off highways that cannot accommodate them. The most common method is to construct large truck parking or exchange lots at intervals on turnpikes and Interstate highways. Carriers that use turnpike doubles or triples use these lots as assembly and break up points for the LCVs. Tractors haul single trailers from origins off the Interstate to the lot where the trailers are hitched in tandem to a single tractor for the long haul to a destination lot. There the trailers are broken apart and either hitched to another tandem for a further leg or attached to an individual tractor and hauled to the final destination.

A segment of the trucking industry is pushing for increased productivity through expanded use of LCVs. However, safety problems and pavement deterioration at the edge of the roadway caused by off-tracking are likely to result if large numbers of LCVs use inadequate road segments for increased off-highway access.[24] Although research is currently underway to identify major shortcomings in road design, immediate, wholesale reconstruction of the road network is not feasible. Since many longer trucks are here to stay, some form of interim safety countermeasures are prudent public investments.

Countermeasures include selective improvements at high-risk locations, determined by traffic volume

[23] Ibid., p. 111-7.

[24] Ibid., p. 111-16.

and accident analysis and aimed at reducing accident frequency and severity. Highway safety can be improved during reconstruction by correcting deficiencies in:[25]

- lane and shoulder widths,
- roadsides and sideslopes,
- bridge entrance widths,
- road horizontal alignments,
- sight distances,
- intersections,
- pavement edge drops,
- pavement surface conditions,
- posted speeds for ramps and curves, and
- sign design, height, and location.

Warning signs that communicate timely and specific safe speed information for trucks on highway entrance or exit ramps are relatively inexpensive countermeasures. Outer curb removal on interchange ramp curves can reduce trailer rollovers. Other safety efforts, such as runaway truck escape ramps, grade-climbing lanes, and better pavement markings can also reduce hazards inherent in truck operations. These vary in cost and scope and illustrate actions that State and local governments can undertake.

Some State highway departments have begun to address the special problems of large, heavy trucks in mixed traffic. The California Department of Transportation adapted a computer model to compare data representing the geometry of State roads against the operating parameters of large trucks. The model identified portions of the State road network where STAA trucks would have difficulty negotiating the existing road geometry safely. California chose to use special signs to designate the highways where STAA trucks could travel.[26] The trucking industry found the designated network overly restrictive; efforts to effect a compromise are under way.

Other jurisdictions are considering constructing exclusive truck-use lanes on congested highways in urban areas. The State of Texas has undertaken a feasibility study for such lanes focused on the I-35 corridor between Dallas and San Antonio. The study showed that present volumes on 90 percent of the corridor did not warrant exclusive truck-use lanes. The researchers used a computer program to evaluate the study corridor and obtain information on volume-to-capacity ratios and effective median width. Congested segments of the corridor near urban areas contained insufficient roadway median space for truck lanes. However, one of the six design options, elevated truck lanes, was suitable for some segments of the corridor.[27]

[25]Transportation Research Board, op. cit., footnote 6, pp. 105-106.

[26]John Van Berkel, chief, Truck Operations Branch, California Department of Transportation, personal communication, Nov. 12, 1987.

[27]Dan R. Middleton et al., "Moving Analysis Program to Evaluate Geometric and Operational Feasibilities of Exclusive Truck Facilities," *Geometric Design and Operational Effects,* Transportation Research Record 1122 (Washington, DC: Transportation Research Board, 1987), pp. 132 and 141.

VEHICLE TECHNOLOGIES

Accident data analyses suggest that improvements in several areas of equipment design and maintenance could enhance heavy vehicle safety. The braking system is foremost among these safety technologies, and brake systems are especially problematic for tractor-trailer combinations. Such issues as handling and steering, occupant protection, visibility and lighting, and splash and spray control also are important for buses and combination and straight trucks. Current technologies are discussed in the following sections. The truck of the future is likely to incorporate advanced electronics, such as monitors for vehicle operation, vehicle controls, drivetrain controls, information displays, electrical systems, comfort and convenience features, and driver performance aids.[28] However, until these technologies are proven and cost-effective, they will not be readily adopted by the industry.

Truck Brake Systems

U.S. Department of Transportation (DOT) inspection data show that the most frequent violation on trucks pulled out of service is poorly maintained or misadjusted brakes. Moreover, OTA found wide-

[28]*Automotive* News, "Heavy-Duty Electrucks," Nov. 24, 1986, p. D14.

spread misunderstanding particularly among owner-operators, about the proper installation and maintenance of brakes. Three basic air brake foundation brake designs are currently fitted to heavy trucks (see figure 5-3): cam brakes, wedge brakes, and disc brakes, Over 90 percent of heavy-duty, air braked vehicles use an S-cam drum brake, which is operated via a push rod from a diaphragm air chamber (see figure 5-4). The wedge drum brake has built-in automatic adjusters.

The disc brake provides improved resistance to fade, comes equipped with automatic slack adjusters, and operates more effectively at high temperatures than drum brakes.[29] Disc brakes on trucks presently cost more ($250-$500 per axle) than drum brakes and account for less than 3 percent of the truck brake market.[30] Early problems with truck disc brakes included premature pad wear and rotor failure due to cracking, conditions resulting from design problems and incompatibilities between disc and drum systems.[31] Although many operators of fleets comprised of straight trucks are long-time disc brake users, compatibility problems need to be resolved before disc brakes can be widely used on tractor-trailers. Correct driving practices are also a key issue.

Brake System Performance

Brake performance is generally evaluated in two dimensions–stopping distance and stability. The ability of truck braking systems to perform according to these criteria has been tested by NHTSA using driver-modulated stops (driver applies brakes to just below wheel lockup and modifies the pressure until the vehicle comes to a complete stop). As figure 5-5 shows, all trucks, regardless of configuration and load, take longer to stop from a speed of 60 miles per hour (mph) than passenger cars and buses. Loaded tractor-trailers perform relatively well, better than empty vehicles, particularly bobtail tractors, since brake systems are typically optimized for loaded conditions. Very short wheelbase bobtail tractors require as much as 500 feet to stop, almost three times more than a passenger car.

Truck brakes must be sized to handle vehicle loaded weights that can be up to three times greater than vehicle empty weights. For large combination vehicles, the relationship between a trailer's brakes and those of the tractor are critical; incompatible systems create unbalanced braking and excessive wear.[32]

Tractors and trailers are manufactured separately by different companies in separate industry segments. Broad ranges of performance exist for tractors, trailers, and other components, and some of the ranges may be incompatible with other parts of the vehicle system.[33] Current NHTSA requirements for air brake systems (tractor-trailers have air brakes on each axle) require brake actuation in 0.45 seconds for tractors and 0.30 seconds for trailers.[34] However, many safety experts and industry representatives believe that tractor-trailers should have more evenly matched or synchronized brake actuation times and antilock systems to help maintain stability and control.

The effectiveness of truck brakes is determined by many elements within the braking system. They include brake system capacity, brake force distribution, application timing, limiting valves, linings, and maintenance and adjustment.

Brake System Capacity

Truck brakes rely on friction and brake lining material to provide sufficient torque to slow and stop a vehicle weighing as much as 80,000 pounds within a reasonable distance. Repeated or continuous brake use (such as on long or steep hills) generates high temperatures that cause the brake linings to lose effectiveness either from fading or disintegration.[35] Thus, on a 60 percent grade, an 80,000-pound tractor-trailer requires 167 times more braking power than a 3,000-pound passenger car, even

[29] Chris Shapeley, "A Comparison of Car and Truck Safety," Proceedings, Symposium on Accommodation *of* Trucks *on the Highway: Safety in Design*, op. cit., footnote I 5.

[30] *Fleet Owner*, "Fleets Hold Back From the Next Brake," July 1983.

[31] Ian Jones, "Truck Air Brakes—Current Standards and Performance, " presented at the 28th Annual Conference of the American Association for Automotive Medicine, Denver, CO, October 1984, p. 12.

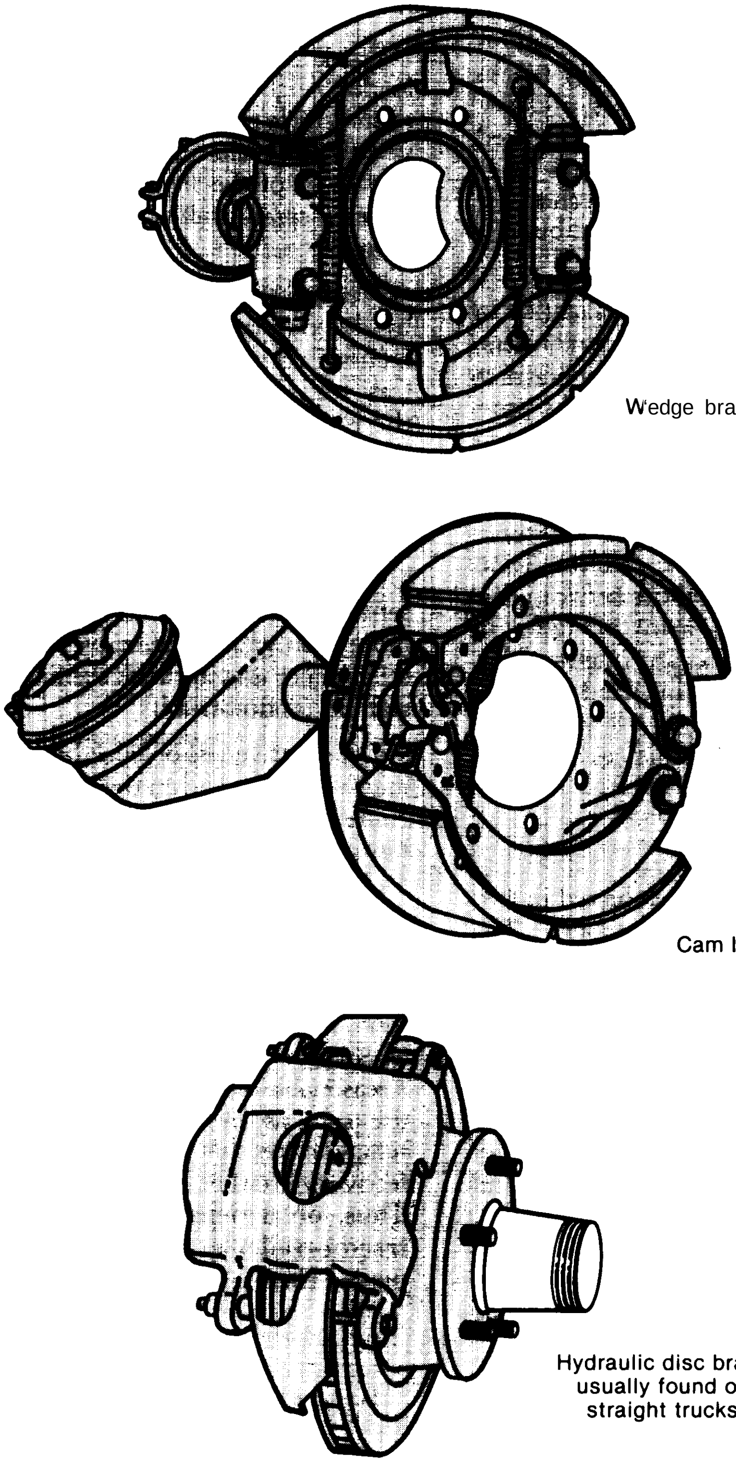
[32] Insurance Institute for Highway Safety, *Big Trucks* (Washington, DC: 1985), p. 12.

[33] National Highway Traffic Safety Administration, op. cit., footnote 18, p. 57.

[34] 49 CFR 571.121.

[35] National Highway Traffic Safety Administration, op. cit., footnote 18, p. 59.

Figure 5.3.—Types of Brakes for Medium and Heavy Trucks



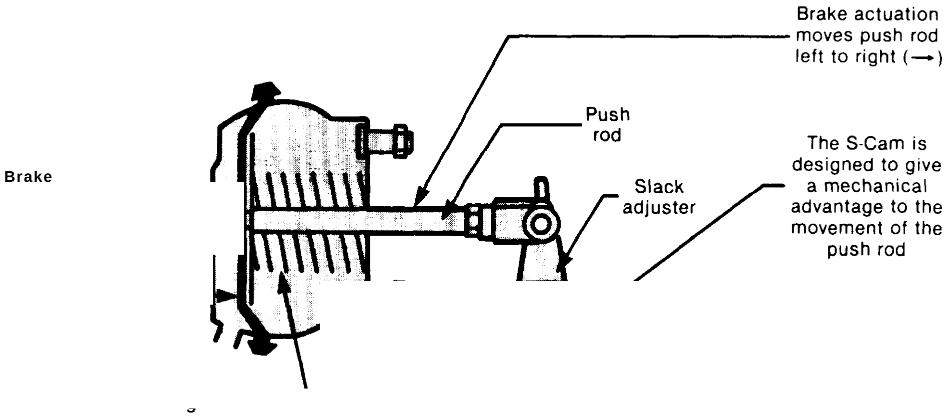
Wedge brake

Cam brake

Hydraulic disc brake
usually found on
straight trucks

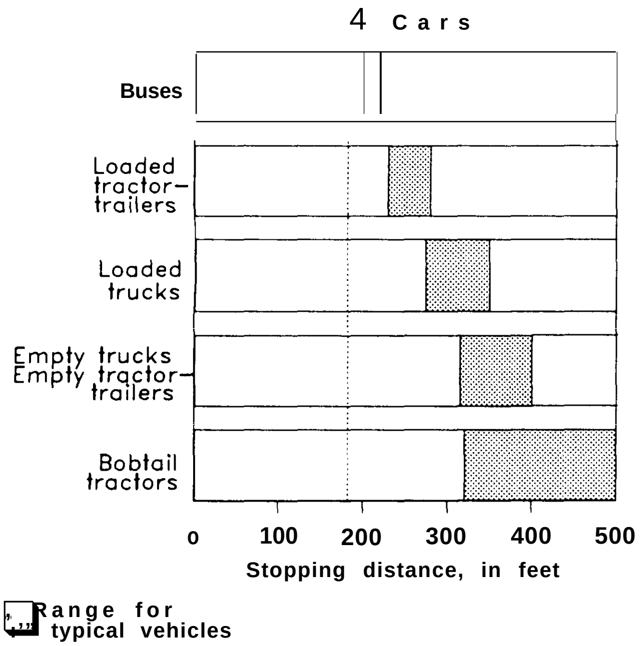
SOURCE: Insurance Institute for Highway Safety and G. DeClaire, Vice President of Research and Engineering, Rockwell International Corp.

Figure 5.4.—Cam Brake Assembly



SOURCE, Off Ice of Technology Assessment modification of National Highway Traffic Safety Administration diagram

Figure 5-5.—Stable Stopping Distances of Heavy Air Braked Vehicles From 60 mph on Dry Road



SOURCE: Office of Technology Assessment, 1988; based on National Highway Traffic Safety Administration data, 1987

though the tractor-trailer weighs only 27 times more. (See figure 5-6.)[36]

To achieve better fuel efficiency, truck manufacturers have worked to reduce vehicle rolling resistance and improve aerodynamics. However, this puts greater stress on truck braking systems. Current truck brakes do not have sufficient heat capacity for all braking requirements, and brake thermal loads may increase in the future. Brake retarders could be useful in lessening thermal loads on brakes, especially in hilly and mountainous terrain. (See box 5-A.)

Brake Force Distribution

Ideally, distribution of braking energy among the truck's axles matches the load placed on it. However, in normal truck operations, load size and weight distribution vary by shipment, and nothing in current brake systems modulates brake force distribution in reaction to changes in loading. In general, if the braking forces on the tractor and trailer are poorly matched to the way the load being carried

[36] Ibid., p. 61.

Photo credit: *Tse-Sung Wu, OTA staff*

A driver demonstrates how to connect brakes when attaching a trailer to a cab.

is distributed, the brake components can overheat leading to fading, disintegration, or even fire in very extreme cases. Until new brake technologies become standard equipment on new vehicles, achieving brake force distribution and balance compatible with each of the ways in which trucks can be loaded and operated will be difficult.[37]

One method of redistributing brake force as loading changes is a load proportioning valve. The simplest load proportioning device is one that senses whether there is a connection between a tractor and trailer. If the tractor is operated without a trailer, braking effort is shifted to the steering axle from the drive axle. The proportioning valves can reduce the stopping distance for a bobtail tractor moving at 60 mph from 500 feet to about 300 feet. Domestic manufacturers offer this relatively simple and inexpensive ($50) device[38] as standard equipment on some models and as optional equipment. The device cannot discriminate between a loaded and an empty trailer and benefits only a bobtail tractor.

More sophisticated load proportioning devices are widely used on heavy vehicles in Europe, in part because European Community regulations for truck brakes cannot be met without such a system. These devices continuously monitor the load on each axle by measuring the deflection of the suspension system.

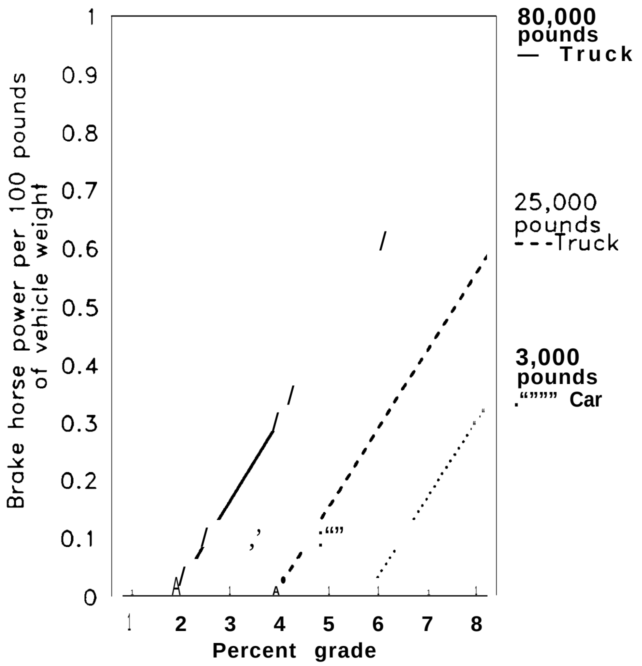
Brake Application and Release Timing

Brake application and release times need to be as quick as practical. Although long release times do not affect stopping distance, they do make it difficult to release the vehicle's brakes quickly in the

[37] Ibid., p. 91.

[38] Ibid., p. 91.

Figure 5-6.—Braking Power Necessary To Maintain 55 mph v. Percent Grade



SOURCE: Office of Technology Assessment, 1988; based on National Highway Traffic Safety Administration data, 1987,

event that the driver overbrakes and locks the wheels. The longer the trailer wheels remain locked, the more likely that trailer swing or jackknife can occur.

Current Federal Motor Vehicle Safety Standard (FMVSS) regulations specify that tractor brakes may take no longer than 0.45 seconds to actuate once the pedal is pushed, but give no minimum time. Consequently, tractor manufacturers have designed their brake systems for the worst case—the longest wheelbase tractor with the slowest actuation times.[39] However, the actuation times may be much less than the maximum, and the tractor brakes may actuate so quickly that the trailer cannot respond effectively. Trailer manufacturers have been unable to design an air brake system that will actuate at the same time as that of the tractor. (See figure 5-7.) Requiring a minimum actuation time as well as a maximum could ensure that tractor brakes do not actuate too quickly—prior to the trailer brakes—putting the combination out of balance. One industry group holds that a minimum brake actuation time for tractors should be set at 0.30 seconds,[40] and trailer brakes should also actuate and release within a certain time.

NHTSA has addressed several of these problems through a notice of proposed rulemaking[41] The goal is a more effective timing balance without an increase in complexity of the system. The notice proposes changing the existing brake application and release timing requirements for trucks, tractors, and trailers, and establishing new timing requirements for the control-line coupling between lead and trailing units.

Box 5-A.—Brake Retarders

A brake retarder is an auxiliary braking device that can help a truck maintain a steady, controlled speed on grades without the service brakes and slow down before it enters interchange ramps or turns. Retarders can reduce brake wear and fade and the potential for brake failure in emergencies.[1]

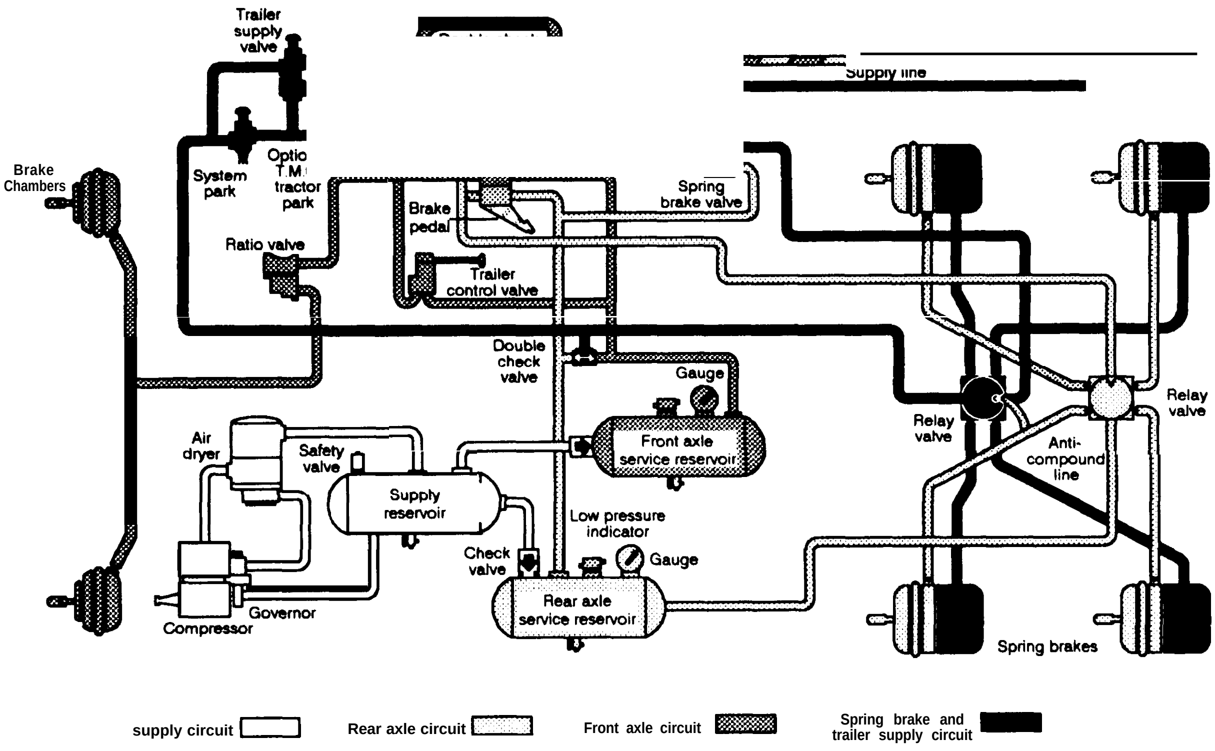
There are four main types of retarders: engine, exhaust, hydraulic, and electric. Each functions differently, but all reduce truck speed through means other than service brakes. An engine retarder operates by changing valve timing and causing the engine to compress air on the compression stroke during otherwise normal engine functioning. Absorbed energy is then released from the engine by the opening of the exhaust valve at the end of the compression stroke.[2]

Retarders can reduce brake maintenance costs in many heavy vehicle operations, especially those in mountainous areas. One truckload sector carrier experimented with retarders on several trucks, and found that trucks without retarders had substantially greater brake wear.[3] However, training is recommended for drivers, because retarders can cause the drive axle to lock if brakes are applied too quickly, especially on wet pavement.

[1]National Highway Traffic Safety Administration, *A Professional Truck Driver's Guide On the Use of Retarders* (Washington, DC: U.S. Government Printing Office, January 1985), pp. 2-3.
[2]Ibid., p. 5.
[3]Paul Richards, "Retarders Giving Brakes a Chance," *Commercial Carrier Journal*, December 1987, p. 64.

[39]Larry Strawhorn, American Trucking Associations, personal communication, Mar. 4, 1987.

[40]American Trucking Associations, Comments on NHTSA Docket No. 85-07, Notice 1, 50 *Federal Register* 20113 (Dec. 30, 1985).
[41]Docket No. 85-07, Notice 1, Air Brake Systems, 50 *Federal Register* 20113 (May 14, 1985).

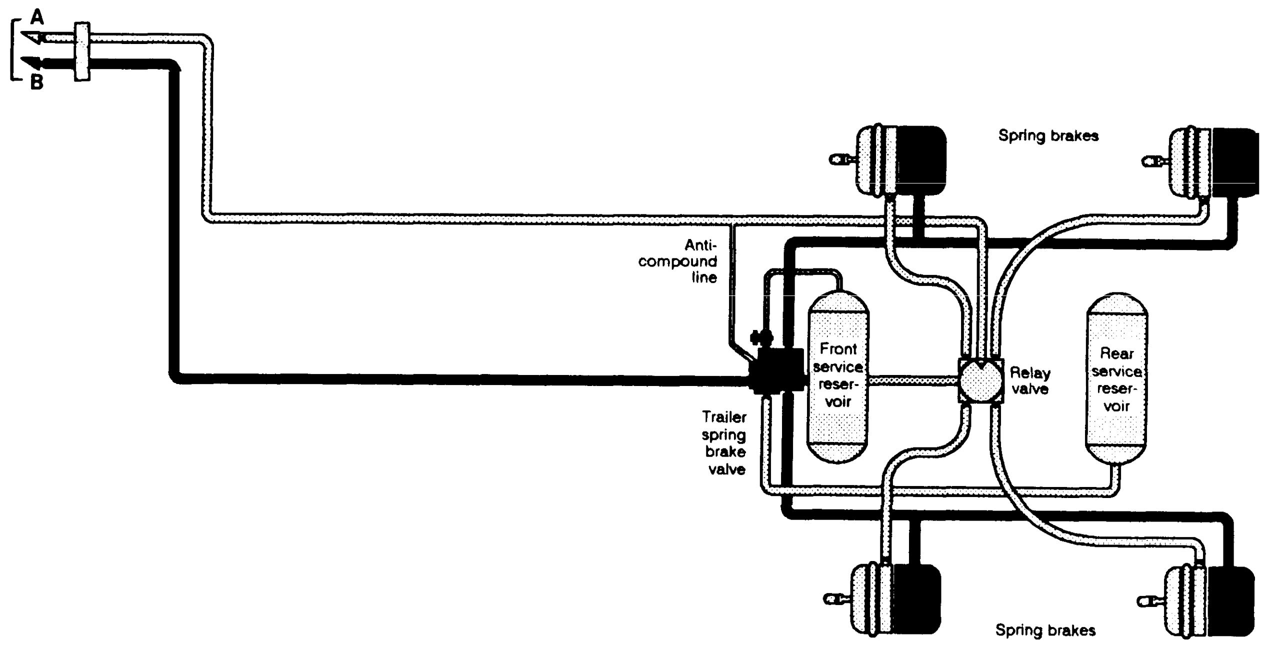


Antilock Brakes

Antilock brakes can prevent the wheels from locking and reduce the potential for directional instabilities that often lead to jackknifing and overturning. An antilock system consists of devices attached to each truck axle that sense when a wheel begins to lock and momentarily release the brakes. As early as 19'77, a NHTSA study comparing trucks fitted with antilock systems with those without, found that jackknifing accidents were reduced by 29 percent. Second-generation antilock systems are now being developed using recent advances in microprocessor technology. Although no widespread domestic production of antilock systems exists at this time, at least one domestic manufacturer is already installing a European antilock system on U.S. vehicles.

Antilock technology has progressed sufficiently so that many safety advocates are calling for a regulation requiring antilock brakes on all new equipment. Brake and tractor manufacturers have developed tractor-only, tandem-axle systems that they believe will be compatible with U.S. industry operations. However, the lesson of FMVSS 121 (see box 5-B) is that the reliability of antilock system technology must be proven before antilock brakes can be mandated. In cooperation with antilock suppliers, truck manufacturers, and motor carriers, NHTSA is testing equipment with antilock systems to acquire performance, reliability, maintainability, and cost data.

Trailer System



Automatic Limiting Valves

An automatic brake pressure limiting valve (ALV) is used by some operators to reduce brake application pressure to the front axles of combination-unit trucks under all but panic stops. Steering wheel pull during braking is related to poor front brake adjustment and maintenance. Brake experts and manufacturers contend that ALVs may cover up front brake maintenance problems, degrade stopping capability when the vehicle is operating empty or on slippery roadways, and burden other brakes on downhill grades. Proponents among carriers hold that limiting valves on standard front brakes keep the front axle from locking or the vehicle from pulling to one side during a sudden brake application under emergency stopping conditions.[42]

Brake Maintenance and Adjustment

Appropriate brake adjustment is essential for adequate braking for current systems. NHTSA tests conducted on brakes at different adjustment levels show that stopping distance increases as brake adjustment deteriorates (see figure 5-8). Adjustment of S-cam drum brakes is especially critical because

[42] Larry Strawhorn, American Trucking Associations, quoted in Paul Richards, "Point/Counterpoint: Front Brake Limiting Valves, " *Commercial Carrier Journal,* December 1987, p. 59.

Box 5-B.—Rulemaking History

Approximately 20 years ago, the National Highway Traffic Safety Administration (NHTSA) began its rulemaking effort to set standards for air brake systems.[1] Although antilock devices were not explicitly required in its proposed standard, NHTSA established criteria for them and maintained that their performance was reliable.[2] However, truck manufacturers claimed that existing antilock technology was unreliable and that these devices on the steering axle, in combination with strong front-wheel brakes, constituted a safety hazard. NHTSA asserted that problems with the antilock devices were caused by component variability and large compliance margins.

Subsequently, a lawsuit over Federal Motor Vehicle Safety Standard (FMVSS) 121 was brought by truck manufacturers and the American Trucking Associations against NHTSA, contending that no need had been demonstrated for the stopping distance standard, compliance was costly, and the standard's requirements were beyond the reach of current technology. Although the court found that NHTSA was justified in promulgating an air brake system standard, it invalidated the road test portions of FMVSS 121. This sequence of events had far-reaching effects on many aspects of vehicle design, performance, and operation, and has contributed to industry reluctance to implement antilock systems.

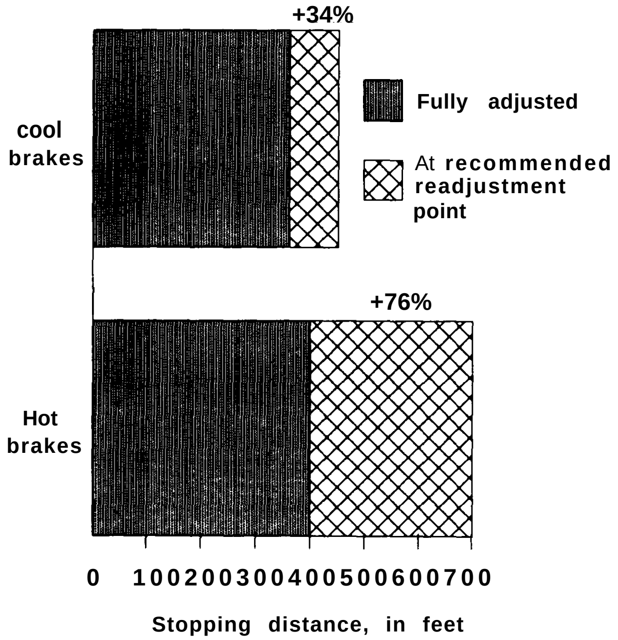
Despite recent advancements in antilock technology, revised brake standards have not yet been issued by NHTSA, although a new rulemaking effort was announced in 1979.[3] Before any formal regulatory action will be taken, NHTSA intends to complete both test-track and on-the-road evaluations of both European and American antilock brake systems.[4] Tests are scheduled to begin in fall 1988 and to be completed within 2 years.

[1]Comments were initially requested in 1967. See 32 *Federal Register* 14279 (Oct. 14, 1967).
[2]See 36 *Federal Register* 3917 (1971), 37 *Federal Register* 12496 (1972), and 37 *Federal Register* 3907 (1972).
[3]44 *Federal Register* 9783 (Feb. 15, 1979).
[4]Robert Clarke, National Highway Traffic Safety Administration, personal communication, Feb. 29, 1988.

drivers cannot sense brake adjustment when brake systems depends on compressed air for actuation.

Steering axle brakes are often poorly maintained–only half of trucks randomly inspected had operative front-wheel brakes. Those that were in operative had missing parts or were so out of adjustment that the brakes did not function, and, in some cases, drivers had detached the front-wheel brakes.[43]

Figure 5-8.–Stopping Distance of Fully Loaded Truck at Two Brake Adjustment Leveis



SOURCE: Office of Technology Assessment, 1986; based on National Highway Traffic Safety Administration data, 1987.

Most truck brakes must be adjusted manually, and this requires regular maintenance. However, automatic slack adjusters can take up the slack created by normal wear of the brake shoes. Although early models had problems with overadjustment, causing the brake to overheat and wear excessively, these problems have been overcome.[44] Approximately 20 percent of heavy vehicles are presently using automatic slack adjusters at a cost of $100-$150 per axle,[45] and three tractor manufacturers have announced plans to make these standard equipment within the next year.

Even poorly performing automatic adjusters, when properly installed, are improvements over manual brake adjustment. Their potential safety benefits underscore the need to establish a performance test

[43]Studies by Cunagin (1986), Kirkpatrick (1986), and Smith (1986) as cited in National Highway Traffic Safety Administration, op. cit., footnote 18, p. 72,
[44]Jones, op. cit., footnote 31, p. 13.
[45]National Highway Traffic Safety Administration, op. cit., footnote 18, p. 74.

and acceptable performance limits for brake adjustment systems. Such systems could be enhanced by diagnostic devices to indicate when routine brake adjustment maintenance is needed.

Brake Linings

Brake linings are essential components in providing sufficient braking force. Although Federal regulations specify minimum performance requirements for brakes on newly manufactured trucks, no standards exist for brake linings or replacement linings. In practice, heavy truck operators often do not or cannot obtain linings that match the performance of those that came as original equipment on the vehicle, This is due in part to the difficulty in identifying linings—lining codes are hard to read and interpret, and the code is destroyed as the lining wears out. Moreover brake linings vary widely from manufacturer to manufacturer, from formulation to formulation supplied by a single manufacturer, and even within a given formulation from batch to batch."

Although equipment as fundamental as brake linings needs quality control and reliability, no immediate solution is available. The Society of Automotive Engineers is currently developing an improved method of rating brake linings, but the time to develop a rating scheme is lengthy, and the precision of the scheme is hard to predict.

Truck Steering and Handling

Heavy truck sizes and physical properties give them distinctly different and unique handling characteristics. Merging and turning actions, steering around corners, and lane changes present problems not found in car driving that increase the potential for truck accidents. Considerable research has been conducted on steering and handling as well as vehicle design and stability. The engineering details, as summarized below, have been well documented recently by NHTSA.[47]

Rollover

A rollover is a major risk in truck driving, especially for tractor-trailers. Truck rollovers occur because as a vehicle moves through a turn, centrifugal force acts to roll the vehicle outward from the turn, causing the vehicle's inside tires to lift from the ground. If the imbalance is too great, the vehicle rolls over. The ratio of the track width to the height of the truck's center of gravity is the basic determinant of the vehicle's stability, although in maneuvers such as lane changes, the dynamics of the vehicle are also important. For example, rollovers can also be caused by rearward amplification through the trailer, caused by inherent properties of the vehicle design. The most effective ways to reduce rollovers would be to lower the center of gravity and to use wider vehicles. Wider (102-inch) vehicles reduce loading heights and permit wider track and suspension spreads. It has been estimated that if both tractor and trailer were 102 inches wide, the incidence of rollovers might be reduced up to 35 percent for combination-unit trucks operating with medium-density freight.[48]

Rearward Amplification

Rearward amplification is manifested as rear trailer side-to-side oscillation. It can be caused by slight steering actions, by changes in road surface, or by wind disturbances. A driver's steering maneuver at the front of the vehicle increases in intensity at the rear of the vehicle or combination. Although the oscillations may not be large enough to cause loss of control, they sometimes result in trailing units encroaching on other traffic lanes and endangering other motorists, or moving off the pavement and striking a curb or roadside obstacle.

Rearward amplification greatly magnifies the effects of a steering action on the rear trailer of doubles units and LCVs. Furthermore, the driver of a multiple-trailer combination has difficulty avoiding a rollover caused by steering actions, because he cannot feel what the rear trailer is doing and because of the delays between steering inputs and responses at the end of the combination "train."[49] A driver's first indication of incipient rollover due to lateral oscillation of a trailer is observation of trailer motion via the rearview mirror,[50] although warning technologies have been developed.[51] Thus, truck-

[46] Ibid, p. 77.
[47] Ibid., pp. 96-154.

[48] Ibid., p. 109.
[49] Ibid., p. 102.
[50] Roundtable discussion, *Proceedings, Symposium on Accommodation of Trucks on rite Highway: Safety in Design*, op. cit., footnote 15.
[51] Edward Domenico, Truck Systems, Inc., personal communication, June 1, 1988.

ing industry pressure to improve productivity and efficiency by using longer and multiple-trailer combination vehicles, makes rearward amplification and stability of rear trailers an issue of considerable concern.

Research has shown that rearward amplification is strongly related to the type of trailer-to-trailer hitching mechanism. The most common mechanism is currently the A-train, a dolly that is connected to the towing unit by a single pintle hitch (see figure 5-9). Although the A-train provides easy maneuverability at low speed, it is less stable at highway speed than a conventional tractor-semitrailer and has comparatively poor rearward amplification performance.

Technical solutions to rearward amplification are under consideration, although current alternatives all have trade-offs in cost, weight, maintenance, and operational difficulties compared with the A-dolly. The most basic innovation to the hitching mechanism has been the introduction of the B-train (see figure 5-9), which greatly reduces rearward amplification. In this design, the pintle hook articulation joint is eliminated and the vertical support and fifth wheel functions of the dolly are incorporated into the rear of the leading trailer. A number of practical problems limit the B-train's use to doubles where the trailers are always used together, are not interchangeable, and do not need to be unloaded from the rear.[52] Some Canadian provinces now give B-train users a 1,000-pound payload advantage.[53] A popular variation, the C-train, is composed of a tractor-semitrailer towing one or more full trailers made of a B-dolly and semitrailer.

Off-Tracking

Off-tracking occurs when the wheels on the rear axle of a vehicle do not follow the same track as the wheels on the front axle. (See the section on "Road Geometry" earlier in this chapter for a more detailed discussion). Off-tracking complicates heavy truck handling and steering for the driver during turning movements and on curved portions of roadways.

[52] National Highway Traffic Safety Administration, op. cit., footnote 18, p. 130.

[53] Ian Jones, Insurance Institute for Highway Safety, personal communication, Apr. 19, 1988.

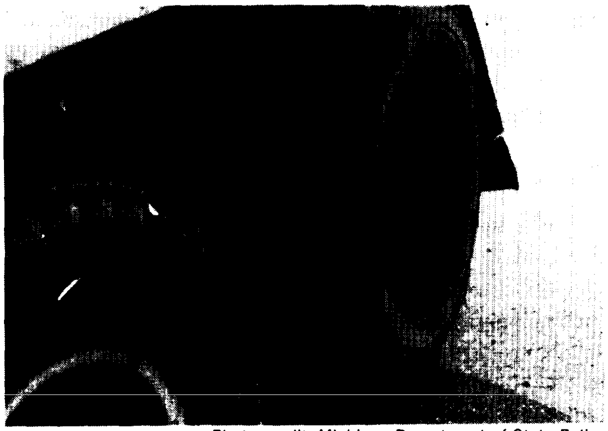


Photo credit: Michigan Department of State Police

Faulty tires and brakes are frequently cited as safety violations during inspections.

Truck Tires

Tire performance affects the stability and control of trucks. Ultimately, tires transmit all the driving and braking torque, and develop the cornering and directional stability essential to the performance of highway vehicles. "Tire manufacturing technology has advanced considerably in the past 10 to 15 years, so that fewer than 5 percent of tire failures are believed to be due to manufacturing or material failures. Accident reconstructions suggest that a tire failure in an accident is more likely to occur than an accident caused by a tire failure.[54] Although metal objects, debris in the roadway, and poor tire maintenance (principally underinflation) are major causes of tire failure, little is known about tire failures that cause accidents.[55]

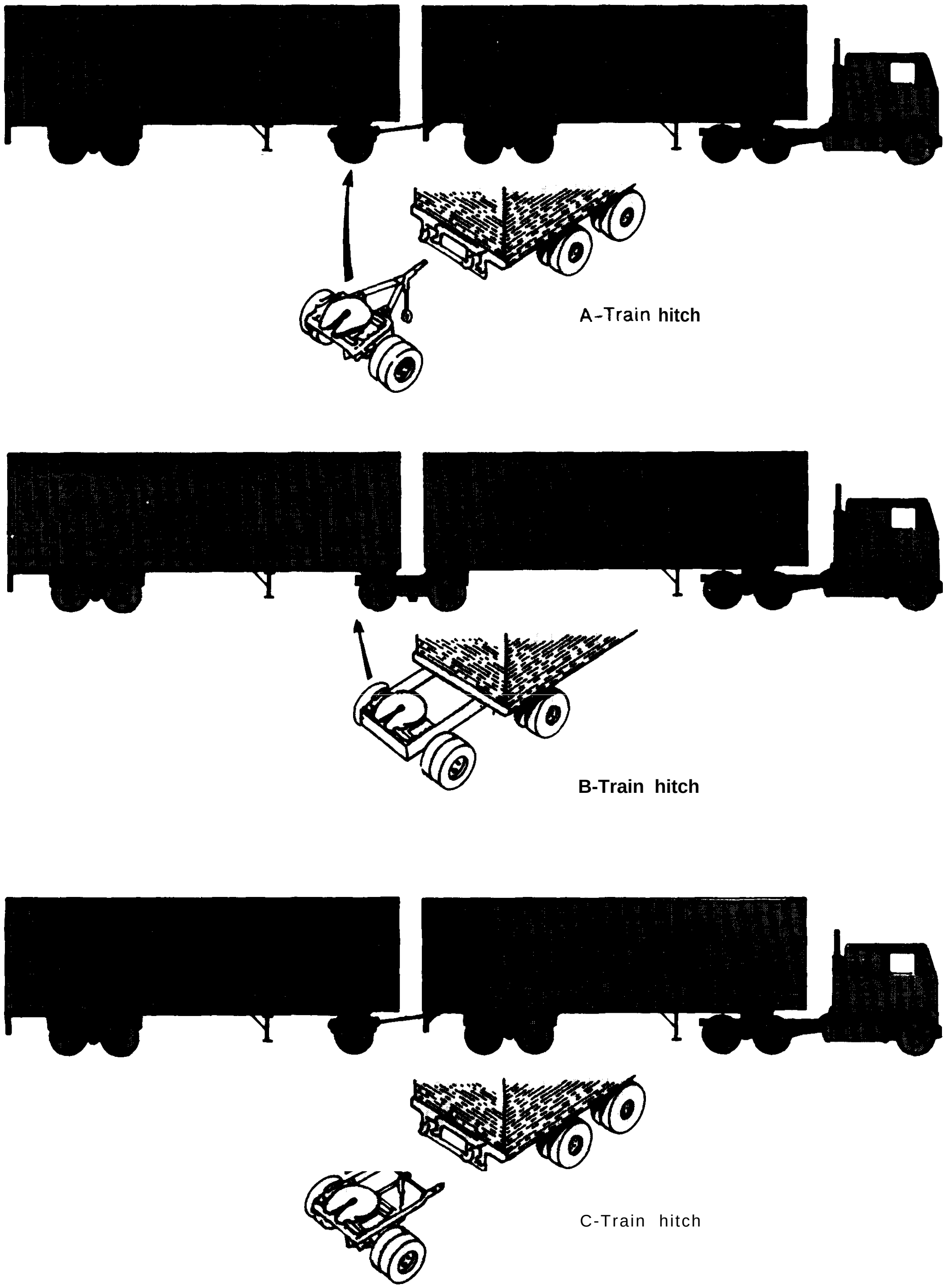
Radial tires have become the standard of the industry although bias-ply tires are used as well. Lifecycle cost analyses have determined that radial tires have longer tread wear, more durable casings, yield greater fuel economy due to lower rolling resistance, and provide better handling. These advantages far outweigh the higher initial costs.[56]

[54] David Williams, Smithers Scientific Services, personal communication, May 17, 1988.

[55] Peggy Fisher, president, Roadway Tire Co., personal communication, May 17, 1988.

[56] Thomas Ford and Joseph Zekoski, "Impact of Truck Tire Selection on Contact Pressures," presented at the Paving and Transportation Conference, Symposium on Pavement Rutting, University of New Mexico, Jan. 4, 1988.

Figure 5-9.-Hitching Mechanisms for Twin-Trailer Trucks



SOURCE: Roads and Transportation Associatlon of Canada, "Canadian Vehicle Weights and Dimensions Study," Technical Steering Committee Report, 1987

Retread tires are used throughout the industry, although no studies have been completed of the extent of their use or their impact on safety. The retread industry has made considerable advances in product reliability in recent years, due to demands from both the trucking and airline industries, and confidence in the product is high.[57] Trucking firms with successful maintenance programs have found retreading to be safe and cost-effective, and some even find it advantageous to do their own retreading.[58]

An industry trend is visible toward use of low profile tires for line-haul trucking.[59] These have a shorter side wall than standard tires, permitting lower trailer floors and greater trailer capacity. Coupled with improved wheel systems, low-profile tires can reduce truck weight, maintenance costs, and recapping costs.[60]

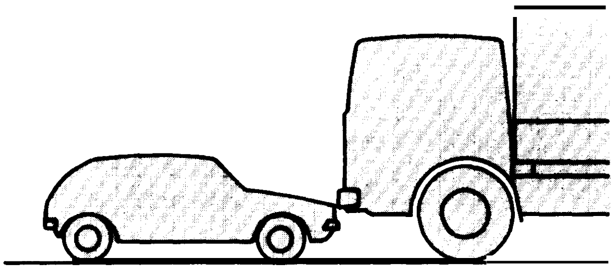
Using a single, wider tire to replace a pair of standard tires to reduce both capital and operating costs is also being considered by industry. Safety concerns include the fact that single tires on trucks running empty have less lateral grip, and the tires can bounce sideways. Moreover, heavily loaded single tires do not spread the loaded weight in the same manner as dual tires and may cause additional damage to the road pavement and the roadbed.[61]

[57] Fisher, op. cit., footnote 55.
[58] Gerald F. Stanley, "The Master of Maintenance," *Commercial Carrier Journal,* May 1988, pp. 73-78.
[59] Ford and Zekoski, op. cit., footnote 56, p. 10.
[60] *Overdrive,* "As the Wheel Turns," September 1987, pp. 14-18.
[61] Asa Sharp, Goodyear Tire Co., personal communication, May 6, 1988.

TRUCKS AND OTHER TRAFFIC

Collisions between heavy trucks and smaller vehicles, primarily cars, inevitably result in more serious consequences to the occupants of the smaller vehicle. A truck can weigh as much as 40 times more than a car, has a much stiffer structure, and stands higher above the ground. Trucks are designed to carry heavy payloads and have large, stiff frames that do not generally deform much in a frontal collision and therefore absorb little of the kinetic energy generated in a crash. Thus, when cars and trucks collide, practically all of the damage occurs to the car.[62]

Figure 5-10.—Typical Car/Truck Front Bumper Height Differential



SOURCE: National Highway Traffic Safety Administration.

Override and Underride

In a car/truck collision, if the truck's bumper or body structure is too high to engage the car's bumper, the car's primary energy absorption capability is not utilized (see figure 5-10). Either the car strikes the truck and slides underneath it (underside), or the truck strikes the car and climbs over it (override).[63]

Rear-end collisions in which passenger vehicles underride the rear ends of trucks or trailers are very likely to cause fatalities. A study of fatal accidents in Texas and Michigan found that underride occurs in more than 90 percent of car/truck rear-end collisions.[64] NHTSA estimates that truck underride accidents account for approximately 300 occupant fatalities per year, or 1 percent of all fatalities.[65]

A Federal standard requiring an underride guard on trucks and trailers in excess of 10,000 pounds was originally proposed by NHTSA in 1969. NHTSA subsequently amended its proposal by requiring

[62] National Highway Traffic Safety Administration, op. cit., footnote 18, p. 138.
[63] Ibid., p. 145.
[64] Insurance Institute for Highway Safety, op. cit., footnote 32, p. 7.
[65] Jeffrey Miller, deputy administrator, National Highway Traffic Safety Administration, testimony before the House Committee on Appropriations, Subcommittee on Transportation and Related Agencies, March 1986, p. 73.

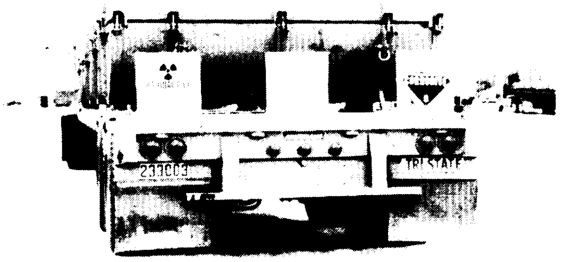


Photo credit: Land Line

Sturdy rear underride guards can prevent a car from sliding under the truck—a frequent cause of fatalities in such accidents.

trucks and trailers to meet a modified strength test with whatever components were in position to contact the test block.[66] However, NHTSA has never issued a final standard. Underride guards for the rear ends of trucks are required by FHWA under Federal Motor Carrier Safety Regulation 393.86, although many safety experts believe the standards specify guards that are not strong or low enough. In the absence of an adequate Federal standard, the Michigan legislature established a standard similar to the modified NHTSA proposal and required rear underride guards for 53-foot trailers in 1986.[67]

NHTSA officials recently stated that alternatives, such as visibility enhancements for the sides and rear ends of trucks, are being tested.[68] These include additional lighting and reflective materials that would help drivers avoid collisions altogether.

Researchers in Germany have sought to design truck front-end protection to reduce override impact. The most effective design was found to be an energy-absorbing bumper mounted low; it absorbed energy, and disengaged and deflected the car after initial impact.[69] Independent tests conducted in Britain showed that a device with certain force and deflection characteristics fitted to the front of trucks, could substantially reduce override and injuries and fatalities.[70]

Splash and Spray Protection

Splash and spray created by a heavy truck on a wet pavement restricts the view for both car and truck drivers. Section 404 of the STAA directed DOT to establish minimum standards for the performance and installation of splash and spray suppression devices for use on truck tractors, semitrailers, and trailers to improve visibility on wet roadways,[71] The Statute required the development of these standards within a year. In 1984, Congress extended the industry compliance deadlines in the 1982 act, because standards had not yet been issued by FHWA and NHTSA.[72]

In 1985, NHTSA published a notice of proposed rulemaking requesting comments on minimum standards and installation requirements for spray suppressant flaps and side skirts.[73] The proposal

[66] The proposed test block was a rectangle 4-inches high and 12-inches wide, and its height was uniformly set with the lower edge 16 inches from the ground. Each truck or trailer had to meet the strength test at all points out to the outermost test points on the vehicle. These changes were made in response to industry concerns about economic and operational difficulties posed by a requirement for a maximum road clearance of 18 inches. 35 *Federal Register 12956* (Aug. 14, 1970).

[67] Robert Ervin, University of Michigan, in U.S. Congress, Office of Technology Assessment, "Transcript of Proceedings—OTA Workshop on Technologies Affecting Truck Safety," unpublished transcript, Mar. 10, 1987, p. 210.

[68] Miller, op. cit., footnote 65; and Diane Steed, administrator, National Highway Traffic Safety Administration, testimony before the House Committee on Appropriations, Subcommittee on Transportation and Related Agencies, March 1986, p. 73.

[69] M. Danner and K. Langwieder, Association of German Automotive Insurers, Department of Automotive Engineering, "Results of an Analysis of Truck Accidents and Possibilities of Reducing Their Consequences Discussed on the Basis of Car-to-Truck Crash Tests," Paper No. 811027, unpublished manuscript, 1984.

[70] S. Penoyre and B. Riley, Transport and Road Research Laboratory, "Desirable Structural Features for the Design of Front and Rear Underrun Bumpers for Heavy Goods Vehicles," Report No. C168/84, unpublished manuscript, 1984.

[71] Section 414 of the Surface Transportation Assistance Act of 1982, Public Law 97-424, 49 U.S.C. 2314. In 1970, the National Highway Traffic Safety Administration issued a notice of proposed rulemaking that would have required spray protectors on most heavy trucks; these devices consisted of fenders, modified side skirts, and mudflaps. However, subsequent tests indicated that use of this equipment caused a dangerous level of brake heat buildup, The National Highway Traffic Safety Administration withdrew the proposal in 1973. See 35 *Federal Register 14091* (Sept. 4, 1970) and 38 *Federal Register 28840* (Oct. 17, 1973).

[72] Section 223 of the Motor Carrier Safety Act of 1984, Public Law 98-554, 98 Stat. 2847. New trucks were to have been required to comply with splash and spray suppressant standards within 1 year after they are promulgated. Existing trucks were to be retrofitted within 4 years after the standards were issued.

[73] 50 *Federal Regisrer 14631* (Apr. 12, 1985). Spray suppressant flaps hang down behind tires and are designed to reduce the amount of spray. Side skirts are flat surfaces that hang down from the side of a vehicle

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suggested that flaps capable of varying levels of spray reduction would be required.[74] FHWA also published a proposed rule, consistent with NHTSA requirements, requiring the installation of flaps and side skirts on truck tractors and certain semitrailers manufactured on or after 1 year from the effective date of a final rule. Older vehicles would be retrofitted within 4 years.[75] The motor carrier industry reacted negatively to the proposed rulemakings, and in late spring 1988, NHTSA formally dropped all proposed requirements for spray reducing materials on heavy trucks.

While recent research generally shows that these devices decrease the density of the spray cloud, test results vary according to the type of vehicle used and other environmental conditions.[76] For example, drop-frame trailers, such as those used by United Parcel Service (UPS) and some household goods moving companies, do not have much distance between trailer and road surface, and the wheel well creates a compact area where the water is contained.[77] Nevertheless, UPS is using effective splash and spray retarding equipment on tractor-trailer combinations. The cost per unit is in excess of $200 ($30 for tractor hardware, $25 for the dolly, $120 for side skirt mounting, $5 per flap, and $40 to install the splash suppressant bristles on the side of the trailer). UPS believes that it provides a safer environment for motorists and improves the public's perception of the trucker.

However, maintenance problems are associated with some splash and spray guards. Rubber flaps tend to break off. Ice builds up on the flap face and eventually falls onto the roadway in chunks, creating a different safety hazard. On some vehicle configurations, such as tankers, dump trucks, and loggers, plastic bristles do not stay on the flaps of the truck for very long. Perhaps the most pressing application is for splash and spray controls on longer combination vehicles and triple-trailer combinations, where water is thrown out by additional axles and wheels. Oregon has a regulation that requires all triples to install splash and spray equipment. Tests of aerodynamically-shaped tractors and trailers show that properly designed side deflectors and dams on tractors and skirts on trailers can substantially reduce splash and spray.[78]

Open-graded asphalt used in road construction can also decrease splash and spray, give good traction in wet weather, and reduce road noise dramatically. The effective lifetime of this material is around 5 years, yet the cost of laying down the pavement is relatively modest.

Truck Visibility

Automobile drivers have a difficult time at night correctly perceiving the shape, road position, location, and speed of poorly illuminated trailers. This problem makes rear and/or side underride accidents even more likely. A NHTSA test using relatively inexpensive reflective markings for the rear ends of trailers showed that the markings significantly reduced rear and side collisions at night. It is estimated that $50 to $100 worth of reflective tape (purchase and installation per trailer) could produce a 15-percent accident reduction.[79]

(continued from previous page)
and prevent water coming off the top wheel wells, tires, and vehicles bottom from forming into spray clouds,

[74] The National Highway Traffic Safety Administration also stated that when flaps capable of achieving a 75-percent reduction in spray became available (anticipated within 4 years), new vehicles would be required to have the improved flaps.

[75] 50 *Federal Register 14630* (Apr. 12, 1985).

[76] Miller, op. cit. footnote 65; and Neil Thomas, Office of Motor Carriers, Standards Development Division, personal communication, Mar. 25, 1987.

[77] Thomas Hardeman, United Parcel Service, in Office of Technology Assessment, op. cit., foomote 67, p. 161.

[78] Farrel Krall, Navistar International Corp., personal communication, Aug. 5, 1988.

[79] William J. Burger et al., *Improved Commercial Vehicle Conspicuity and Signalling Systems: Task 3, Field Test Evaluation of Ve-*

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Photo credit: Freightliner Corp.

Aerodynamic side deflectors and dams are attached to this cab to increase fuel efficiency and reduce splash and spray.

industry has taken its own initiatives in this area as part of corporate marketing. For example, Frito-Lay places a reflective company logo on the rear door of each trailer. However, this can present a separate hazard if other drivers mistake a vehicle for a fixed facility on the side of a roadway. A performance standard that improves luminosity without restricting corporate graphics is likely to gain industry acceptance.

Poorly illuminated trailers can also increase risk of side underride collisions. For example, a trailer being maneuvered into position at a loading dock of an older urban plant or warehouse may briefly block the travel lanes of a busy city street. Without special measures to increase its visibility at night, the trailer may not be reflected soon enough for the car driver to react. Flatbed trailers pose special problems because their lack of exterior surfaces does not provide sufficient area for extensive safety-lighting fixtures.

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hicle Reflectionization Effectiveness (Washington, DC: National Highway Traffic Safety Administration, September 1985), p. 111-8 per errata sheet.

Color also plays a role in truck visibility at night. It can assist another vehicle driver in determining the speed of an approaching truck. The color green is used in Japan on trucks weighing over 17,600 pounds. A series of green vehicle marker lights signal the speed of a truck; one light indicates the truck engine is running; two lights mean the truck is going more than 25 mph; and three lights indicate the truck speed to be 38 mph or greater.[80] Colors also cause bias in depth perception, an important factor for drivers of vehicles moving at different speeds at night. For example, the color red is seen before the color blue on a distant object,[81] and the arrangement of lights can also provide cues about an object's proximity and its relative speed.[82] Moreover, one's reaction to lights and colors is somewhat dependent on knowing what one is looking at.[83]

[80] Jim Winsor, "Japanese Trucking: Tougher Equipment Safety Regs," *Heavy Duty Trucking,* December *1987,* p. *16.*
[81] Louis Siverstern, research section chief, Systems and Research Center, Honeywell, Inc., personal communication, Apr. 27, 1988.
[82] Rudolf Mortimer, professor, Department of Health and Safety Studies, University of Illinois, Urbana, personal communication, Apr. 27, 1988.
[83] Ibid.

MOTOR CARRIER DRIVER SAFETY

Although much of the attention to truck safety has focused on the impact of truck safety on other vehicle occupants, the safety of a truck driver is also of concern. Ejection is one of the leading causes of fatalities and injuries among tractor-trailer occupants, and all available data indicate drivers sustain proportionately more serious injuries if they are thrown from the vehicle.[84] The simplest way to prevent ejections is through use of safety belts, and a driver that remains seated has a chance to regain control of the vehicle after an accident. Nevertheless, reluctance to use a safety belt remains a major problem among truck drivers: Efforts have been under way since 1980 to encourage more drivers to wear **safety** belts, and industry groups have assisted motor carriers with programs to convince cab occupants to wear safety belts. Current designs, however, are based upon passenger car standards and are not necessarily appropriately designed for truck installation.[85]

Truck Cab Structure

Strengthening the structure of truck cabs could make them more crush resistant and better able to protect occupants. However, many serious injuries sustained by truck occupants who remain inside the vehicle during accidents result from contact with interior components, primarily the steering wheel. Research on cab interiors has focused on materials, fire resistance, noise absorption, and projectile reduction.

Since the majority of crash-involved truck drivers move in more than one direction during the crash sequence, contacts with the steering wheel, windshield, instrument panel, and surfaces of doors and

[84] National Highway Traffic Safety Administration, *Truck Occupant Protection,* prepared in response to the Motor Carrier Safety Act of 1984 (Washington, DC: U.S. Department of Transportation, December 1986).

[85] Robert E. Heglund, assistant vice president and manager, Transportation Services Loss Prevention Department, Liberty Mutual Insurance Group, personal communication, Mar. 22, 1988.

door headers are common sources of injury .86 At least one European truck manufacturer uses a steering wheel that is both smaller and more flexible than those typically installed in U.S. trucks. Limited case study evidence has shown that this design causes fewer and less severe driver injuries in crashes.[87] Research in this area has lagged in the United States.

Post-Crash Fires

In most cases, it is extremely difficult to pinpoint the exact source of truck fires, especially when more than one vehicle is involved in the crash. Fuel from the truck is apparently a primary factor. Improvements to address this issue focus on the concept of "cab fireworthiness. " Suggestions have been made to incorporate on-board automatic fire suppression equipment; "kill switches" for electrical systems to eliminate ignition sources; use of flame-resistant, nontoxic materials in the cab; and methods and devices to protect cab occupants during a cab-engulfing fire for a limited time period. At least one truck manufacturer currently locates the batteries under the cab, to try to reduce the likelihood of fire after a collision.

Cab Environment

The immediate working environment for the truck driver is the truck cab. Equipment manufacturers and the trucking industry have examined seats, safety belts, controls, access, and noise to determine the best design for actual driver's use.[88] A properly designed truck cab can ". . . increase the productivity of drivers of heavy trucks by reducing driver fatigue, improving driver satisfaction and morale, and reducing the number of accidents."[89]

The ambient environment within the truck cab also has an effect on the driver. Tests have shown that contamination from diesel vehicle carbon monoxide is not a problem, but that nitrous oxide levels can be higher than recommended by the National Institute for Occupational Safety and Health.[90]

Photo credit: Michael Hines, OTA staff

Heat, noise, and vibration in the truck cab contribute to a stressful working environment for drivers.

Ride quality in heavy trucks is sometimes very poor. This complex issue is a product of variations in the truck design including wheel base, axle location, frame stiffness, and suspension type as well as vehicle load and road surface condition. The large engine in close proximity to the cab adds vibration, noise, and heat. Heat and humidity have an adverse effect on driver physiology and performance, noise levels are often high enough to have adverse effects, and vibrations are at a level that creates fatigue.[91] These pose formidable challenges for researchers and manufacturers.

On-Board Recording Devices

On-board devices that record engine revolutions per minute, vehicle speed, oil temperature and pressure, cooling system temperature, and so forth are currently available for approximately $1,500 to $2,500. Although the information collected permits the examination of distance traveled, driving time, breaks, daily rest periods, and speed limit compliance, carriers usually purchase these systems to manage fuel efficiency. Safety advocates have proposed

[86] National Highway Traffic Safety Administration, op. cit., footnote 84, p. 76.
[87] Ibid., p. 78.
[88] Mark Sanders, "U.S. Truck Driver Anthropometric and Truck Work Space Data Survey," prepared for the Society of Automotive Engineers, January 1983.
[89] Thage Berggren, "Equipment Productivity: At What Price?" unpublished remarks to the American Trucking Associations Foundation Meeting, Ocean Reef, FL, Apr. 29, 1988.
[90] Federal Highway Administration, *Toxic Gases in Heavy Duty Diesel Truck Cabs*, Report No. FHWA-RD-77-139 (Washington, DC: U.S. Department of Transportation, October 1977).
[91] National Highway Traffic Safety Administration, *A Study of Hear, Noise, and Vibration in Relation to Driver Performance and Physiological Status*, Report No. HS-801313 (Washington, DC: U.S. Department of Transportation, December 1974).

using on-board recording devices to improve compliance with hours-of-service rules and speed limits.

One firm reports that an on-board device pays for itself in 6 months through cost savings in fuel, maintenance, and driver time (reduced paperwork requirements).[92] It also helps streamline the preparation of reports that must be kept on file by the company for oversight agencies,[93] providing an economic incentive for installing the device. The system also includes an alarm that is activated if a driver operates at speeds greater than 55 mph for more than 1 minute, a capability that made the company decide installation of speed governors was unnecessary. Management made major efforts to gain acceptance from drivers before installing the devices, giving seminars to help drivers understand how and why the organization was going to use the recorders. After initial resistance, drivers understood that the recorders could be advantageous, proving, for example, that a late delivery stemmed from following the rules.[94]

Another large transport company reported that since it installed on-board recording devices, fuel mileage has improved by 12 percent, tire mileage has increased to 270,000 miles, brake lining life has increased, and insurance rates have dropped. To gain acceptance among drivers, the company initiated an incentive plan based on the driver's performance evaluation. From information gathered by the recording device, each driver receives a grade based on a cumulative average of all major functions on the trip, such as maximum speed, engine revolutions, and idle time. The incentive plan pays drivers an extra 2 cents a mile if they receive a performance grade of 10, and 1 cent per mile for a grade of 9. Some drivers now prefer trucks equipped with the devices so that they can earn extra compensation.[95]

An insurance case was recently settled on the basis that the tape from an on-board recording device showed that a truck driver had geared down in anticipation of an automobile driver's cutting in front of him to enter a ramp. The device showed that the truck driver did, in fact, gear down, but could not do so fast enough to prevent the accident. The automobile driver lost the case.[96]

While several European countries currently require on-board recording devices in their heavy trucks, installation of these devices on trucks in the United States remains voluntary, although their use is increasing.[97] Companies using on-board recorders as standard fleet equipment are doing so for multiple management-related reasons, not primarily to improve the fleet safety record.[98] Although some devices may not be tamper proof, FHWA has determined that tampering with on-board computers is not a serious problem.[99]

[92] Phillip Brown, The Travelers Companies, in Office of Technology Assessment, op. cit., footnote 67, p. 183.

[93] The Department of Transportation has accepted recording device output in lieu of logbooks for some carriers.

[94] Phillip Brown, The Travelers Companies, in Office of Technology Assessment, op. cit., footnote 67, p. 186.

[95] *Private Line*, "A Driver Incentive Plan, With an On-Board Computer, Rewards Proper Vehicle Operation," October 1986, p. 15.

[96] Phillip Brown, The Travelers Companies, in Office of Technology Assessment, op. cit., footnote 67, pp. 236-237.

[97] Freightliner estimates that about 5 percent of their new trucks are equipped with electronic recorders at the customer's request (Otto Carroll, Freightliner, personal communication, Aug. 3, 1988). Rockwell estimates that on-board electronic recording systems are currently being used on about I percent of the heavy trucks in operation. G.J. Flannery, Rockwell International, personal communication, Feb. 25, 1987.

[98] Victor Jennings, Ryder Truck Rental, in Office of Technology Assessment, op. cit., footnote 67, pp. 185-186.

[99] Notice of Proposed Rulemaking, Federal Highway Administration, Mar. 13, 1988.

CONCLUSIONS AND POLICY OPTIONS

Highway system design issues and heavy vehicle safety technologies interact as parts of a system. Yet, too frequently, components of the system are treated **as isolated and separate by government agencies and the respective industries. While some technical improvements for heavy vehicles are under development, major safety issues remain unaddressed. Changes to government policies allowing larger** truck sizes and heavier weights have occurred far faster than changes to highway design standards. **OTA finds that Congress may wish to require DOT to develop a systematic Federal approach to motor carrier safety. A first step is better coordi" nation on heavy vehicle and highway safety issues among DOT agencies, including NHTSA and FHWA'S Office of Motor Carriers (OMC), high.**

way planning, safety, and design offices. Key components include accumulation of objective data to identify highway design problems and aggressive testing programs to determine the point at which equipment technologies and accident countermeasures are reliable and cost-effective. Also important are consistent Federal regulations, long-overdue at DOT–NHTSA and OMC brake standards still differ in some respects.

Furthermore, OTA finds that resolving conflicts, such as industry's push for still longer vehicles and the limitations of the Nation's road network, will require far better communication and cooperation by Federal and State governments and industry. State decisions on permissible vehicle sizes and weights are often not consistent with the ability of the highway system to accommodate the vehicles. Working groups that can focus on setting research agendas and model standards, developing interim countermeasures, voluntary field testing by industry, and the sharing of experimental data can contribute. No governmental mechanism exists currently that adequately deals with such difficult issues, and active participation by Federal and State officials is essential to a systems approach.

While the stability and braking characteristics of heavy trucks have been well studied by NHTSA, cab occupant protection and reducing the effects of car/truck collisions are two areas that need additional research. Congress may wish to encourage NHTSA to step up work on these important safety technology issues with the goal of determining and implementing appropriate standards.

The Federal Government has a role to play in determining whether safety technologies should be specified as *performance criteria* (which state minimum acceptable capabilities) or as mandated design *standards* (which specify in detail the equipment that must be used).[100]

Vehicle equipment compatibility issues are extremely difficult for industry to resolve without active Federal participation. OTA concludes that Federal agencies such as OMC, NHTSA, and industry must jointly seek solutions to compatibility issues.[101] While truck manufacturers and users agree that upgraded Federal brake standards are needed, they also stress that industry should work with NHTSA and FHWA to test new technologies and to develop appropriate regulations.

OTA finds that issuing standards for antilock brakes will be warranted within the next 3 to 5 years. The NHTSA test program for antilock brakes on tractors now underway is an essential step. Antilock systems for tractors and trailers is the ultimate goal. If manufacturers of both tractors and trailers are involved in the rulemaking process, the development and acceptance of compatible and well-balanced braking systems will be accelerated.[102] The Tractor Trailer Brake Research Group, an industry group (see figure 5-11), has been working very slowly toward resolving longstanding brake and compatibility issues. Active participation by NHTSA and OMC could speed the process. OTA concludes that the Federal Government could play an active role in brake lining performance tests and identification methodology, with the goal of issuing performance criteria and compatibility standards for both original and replacement linings, Other longer-range brake research activities also warrant Federal support. Examples of basic research include "braking by wire" and improving tire/braking force capability.

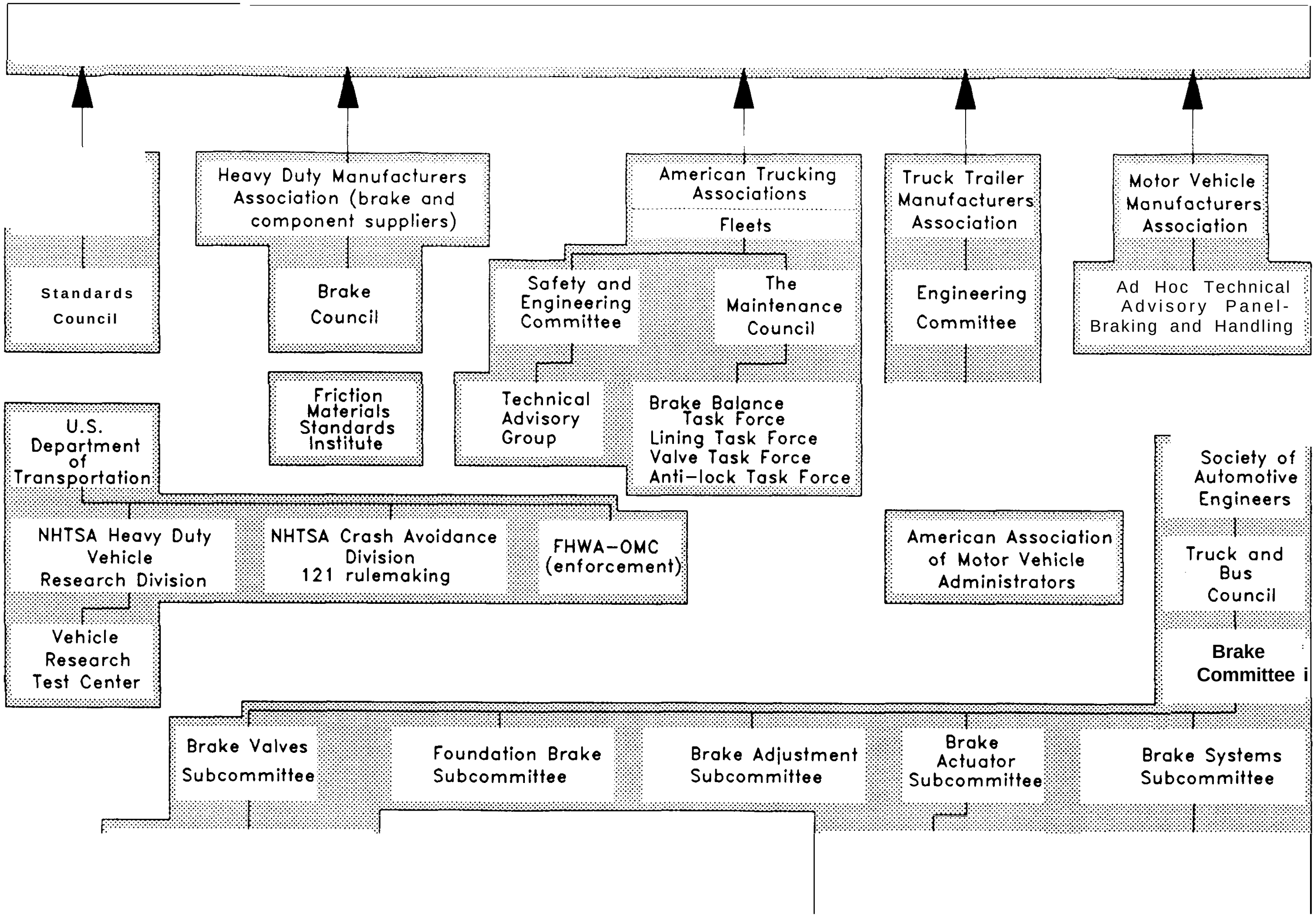
Critical needs exist for maintaining existing technologies even while new innovations are under consideration—initiatives for improving brake maintenance, for example. Widespread misunderstanding of truck brake systems and brake maintenance and adjustment suggests a need for a comprehensive education program for owners and operators of all fleets and mechanics. A training requirement for mechanics could be an important step.

Manufacturers indicate that enough is known about vehicle visibility and splash and spray for preliminary equipment standards and performance criteria to be developed. NHTSA may have overlooked some possible splash and spray control options. Congress may wish to request NHTSA to address these issues with renewed vigor and issue regulations in the near future.

[100] Joe R. Morris, "Safety Implications of Changes in Truck Size and Weight Limits," *Proceedings of Organisation for Economic Cooperation and Development Symposium on the Role of Heavy Freight Vehicles in Traffic* (Ottawa, Canada: Organisation for Economic Cooperation and Development, Apr. 27-30, 1987), vol. 3, pp. 4-14.

[101] Office of Technology Assessment, op. cit., footnote 67.

[102] Ibid., pp. 32-43.



KEY: NHTSA = National Highway Transportotion Safety Administration;
FHWA = Federal Highway Administration; OMC = Office of Motor Carriers

SOURCE: Office of Technology Assessment, based on information from American Trucking Associations, 1987.

The adoption of safety-related technologies by trucking firms and owner-operators is not an automatic process. The technologies must mitigate a perceived or apparent problem and provide a reasonably short-term return on investment. Because they do not have economies of scale available to large firms, owner-operators have difficulty realizing economic payback for safety-related equipment. Improved safety equipment that has clear economic benefit will eventually be accepted by industry,[103] as evidenced by purchases of technologies such as automatic slack adjusters. 104 **OTA finds that when economic advantages of equipment that has proven safety value are not apparent, setting minimum Federal standards for equipment that apply equally to all motor carriers, regardless of classification, is appropriate.**

Since many equipment safety issues do not translate directly into improved productivity, industry acceptance of new technologies is slow under any circumstances. The fragmentation of the industry hampers dissemination of safety information on new technologies. OTA finds that a thorough education and information program for new technology requirements could benefit purchasers and users. Congress may wish to allocate resources for such tasks. Video instructional displays at truck stops around the country could inform drivers of the risks they take by operating trucks with deficient brakes, tires, or lights. These displays could also present information on ways to avoid and correct other safety problems. States could coordinate these activities with their enforcement programs.

1[0]Ibid.

[104]William Leasure, National Highway Traffic Safety Administration, in Office of Technology Assessment, op. cit., footnote 67, p. 170.

Retrofitting trucks with newly mandated safety equipment can have significant costs. Difficulty in designing retrofit equipment adaptable to all older vehicles and the evolutionary nature of technology focus manufacturers' R&D efforts toward new vehicles.[105] Congress may wish to consider requiring DOT to develop implementation programs for new and retrofit technologies, and to set deadlines for programs.

Finally, the cost of educating drivers to use new safety equipment is one that will have to be accounted for in the marketplace. Although carriers may need to pay drivers and mechanics more for having additional technical skills, the higher costs to shippers and ultimately the public can be more than offset by reduced accident costs.

On-board recording devices are cost-effective management tools and can motivate drivers to be more efficient. Their use for driver oversight has also been successful if management followup is appropriate. However, management experience to date shows that careful dialog with drivers to minimize potential adverse reactions is important when introducing the devices. OTA finds that an immediate mandatory requirement for on-board recording devices may be premature. Education for management, labor, and enforcement officers is essential to promote acceptance of these tools as safety devices and prevent abuse. Congress may wish to consider requiring DOT to plan and implement a program to accomplish these goals.

[105]P.A. Gustafson, Cummins Engine Co., Inc., personal communication, Apr. 28, 1987.