Crash Involvement of Large Trucks by Configuration: A Case-Control Study

HOWARD S. STEIN, MS, AND IAN S. JONES, PHD

Abstract: For a two-year period, large truck crashes on the interstate system in Washington State were investigated using a case-control method. For each large truck involved in a crash, three trucks were randomly selected for inspection from the traffic stream at the same time and place as the crash but one week later. The effects of truck and driver characteristics on crashes were assessed by comparing their relative frequency among the crash-involved and comparison sample trucks. Double trailer trucks were consistently overinvolved in crashes by a factor of two to three in both single and multiple vehicle crashes. Single unit trucks pulling trailers also were overinvolved. Doubles also had a higher frequency of jackknifing compared to tractor-trailers. The substantial overinvolvement of doubles in crashes was found regardless of driver age, hours of driving, cargo weight, or type of fleet. Younger drivers, long hours of driving, and operating empty trucks were also associated with higher crash involvement. (*Am J Public Health* 1988; 78:491–498.)

Introduction

Large trucks (10,000 lbs gross vehicle weight or greater) are a major safety problem on the nation's highway.[1,2] They are involved in about 6 per cent of all police-reported crashes but account for 12 per cent of all fatal crashes.[3] Each year, about 4,800 people die in truck crashes, and almost 75 per cent of these fatalities are to people in a vehicle other than the truck.[4] Trucks are overrepresented in severe crashes, but on a per-mile basis trucks appear to have fewer crashes than cars because they travel predominantly on interstate highways, which are low-risk roads.[1] However, when car and truck crashes are compared on similar roads, trucks have higher crash rates.[5] In recent years, both the number of crashes and the percentage of fatal crashes involving large trucks have been increasing.[6,7]

Although the involvement of large trucks in crashes has been extensively studied, little is known about the *relative* involvement of different truck configurations or the role played by factors such as load, type of cargo, or driver characteristics.[1,3] The influence of truck size, configuration, and weight has become an important issue because the 1982 Surface Transportation Act authorized the use of heavier, wider, and longer trucks and permitted double-trailer truck combinations to operate, on certain roads, in every state. Prior to the Act, 14 states had prohibited double trailers.[8]

The relative safety of double trailers has been an issue for some time; however, most studies that attempted to compare the crash rates of different truck configurations have used mileage estimates as measures of exposure to risk and were unable to adjust these estimates for the variation in travel patterns among different truck configurations. Because of these differences, the crash rates computed in many studies for doubles and tractor-trailers were not readily comparable.[9] The most reliable studies with more comparable exposure measures concluded that doubles had higher crash involvement rates than tractor-trailers.[8,10,11]

The potential problems in operating doubles are well documented in studies reporting significant handling problems related to the inherent instability of a second trailer.[12,13] Relatively small tractor steering movements (e.g., in a lane change maneuver) are magnified by the second trailer and can reach unmanageable levels, producing exaggerated sway and subsequent rollover of the rearmost trailer. The same steering maneuvers do not produce rollover in tractor-trailers. The increased trailer sway and rollover potential of doubles is also evident in crash data that indicate significantly higher proportions of rollover in fatal crashes involving double or triple combination vehicles.[14] Poor handling and stability were also reported in several driving studies and surveys of drivers,[15,17] which all concluded that driving doubles requires greater alertness and concentration than driving singles.

Nonetheless, there has been no reliable estimate of the overinvolvement of doubles in crashes relative to other truck configurations that is based on comparable exposure measures. Because doubles carry more volume than tractor-trailers, fewer are needed to transport a given amount of freight, and it has been claimed that this greater carrying capacity more than compensates for their potential overinvolvement in crashes.[8] Moreover, doubles are used on longer trips, travel more at night, are more likely to have been fully loaded, and have been used predominately in western states.[8] Other factors such as driver characteristics also may vary among truck types.

A research approach that can adjust for differences in exposure is the case-control method. The present study was designed to compare the vehicle and driver factors of large trucks involved in crashes with those of a comparison group on the interstate highway system in Washington State.

Method

Washington State has allowed a diversity of truck configurations including western doubles, Rocky Mountain doubles, and truck-trailers as well as tractor-trailers, tractors (bobtails), and single unit trucks to operate on all its roads (see Figure 1) for more than 25 years. The state provides a wide variety of climate and terrain ranging from the temperate coastal region through the Cascade Mountains to the desert areas in the eastern part of the state. Our study was conducted primarily on Interstate 5, which carries north-south traffic, and on Interstate 90, which has east-west traffic. Data were collected over a two-year period from June 1984 through July 1986.

Truck data were collected by the Commercial Vehicle Enforcement Section (CVES) of the Washington State Patrol. Approximately 100 officers are responsible for the weight enforcement and inspection programs in the state, which includes weigh stations on interstates and other major

From the Insurance Institute for Highway Safety. Mr. Stein is now with Callow Associates, Inc. Address reprint requests to Ian S. Jones, PhD, Director, Engineering Research, Insurance Institute for Highway Safety, Watergate 600, Suite 300, Washington, DC 20037. This paper, submitted to the Journal April 14, 1987, was revised and accepted for publication November 17, 1987.

Editor's Note: See also related editorial p 486 this issue.

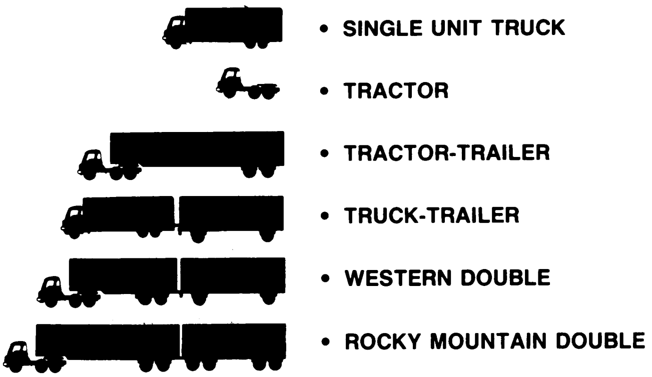


FIGURE 1—Truck Configurations. NOTE: Western doubles were defined as a tractor with two trailer units with the first trailer 35 feet or less in length; nearly all had two 28 foot trailers. Rocky Mountain doubles were tractors hauling two trailers with the first trailer greater than 35 feet in length; the majority had a first trailer of 40 feet with second trailers of various lengths.

routes as well as port-of-entry weigh scales. The officers conduct detailed inspections of truck equipment including brakes, steering, tires, and other major systems. They also provide assistance to the Washington State Patrol in the investigation of truck crashes. Truck inspections followed the procedures detailed by the Commercial Vehicle Safety Alliance (CVSA) and the National Uniform Driver-Vehicle Inspection Manual.[19]

Study Design

The study included all crashes involving trucks with gross vehicle weight rating (GVWR) greater than 10,000 pounds that occurred on the interstate highway system (see Methods) and involved property damage of at least $1,500 or personal injury. Each crash-involved truck was inspected by a CVES officer to check the condition of the major truck components including brakes, steering, and tires. Where possible, quantitative measures of performance were used; for example, brake adjustment was measured from pushrod travel and tire condition from the tread depth. Truck weight, size, and configuration; driver age and experience; and the type of trip were also recorded.

One week after each crash, the CVES officers conducted a random roadside truck inspection at the crash location. For every crash-involved truck, three trucks were selected for the comparison sample: one approximately 30 minutes before the time of the crash, one at the time of the crash, and one 30 minutes later. The only criterion for selection of comparison sample trucks was that they have a gross vehicle weight rating of 10,000 pounds of greater. Because of safety and convenience considerations, the inspection site was usually at the next interchange, weigh scale, or rest area. Each comparison truck selected was inspected following the same procedures used for the crash-involved trucks. If the inspection was at the roadside, truck weights were obtained using portable scales or estimated from shipping papers. The inspection was typically completed within 30 minutes, which allowed the officers to select the next truck at the appropriate time.

This sampling procedure could not always be followed; some crash locations did not have sufficient area at the roadside to conduct an inspection or a convenient alternate site before the next interchange. In these cases, the inspection site was moved to an appropriate location as near the crash site as possible, and the inspecting officers confirmed that the selected truck had passed the crash location. Because of very severe weather or because the officers were investigating other crashes, a small number of the comparison sample inspections were conducted two or three weeks after the original crash. In addition, some comparison inspections were omitted because the crash had occurred in congested areas (e.g., downtown Seattle), where it was not possible to apply the sampling procedure satisfactorily. Crashes that occurred on ramps were not analyzed in this paper because of the difficulty and hazards of selecting comparison trucks. The study analyzed 676 crashes involving 734 large trucks that occurred between June 1984 and July 1986. Almost 85 per cent of the crash-involved trucks were successfully matched with sample trucks, and only these cases were used in the subsequent analyses of relative involvement.

Data Analysis

Truck configurations were classified as shown in Figure 1. The variables used in these analyses included truck configuration, age of driver, weight of load, hours of driving, truck body type, and fleet size (number of trucks operated by a given company). Variables with continuous ranges, such as driver age or hours of driving, were classified into three groups of equal size (i.e., low, medium, and high) based on the comparison sample. If a variable of interest was unknown for a crash-involved truck, then both crash and comparison trucks were excluded from the particular analysis. In the small number of cases (typically 3 per cent or less) where the value of a variable for one of the comparison trucks was unknown, a representative value was randomly assigned based on the distribution of this variable by truck configuration in the rest of the comparison sample.

To determine whether particular factors were overinvolved in the crash vehicles, contingency tables were constructed using the crash and comparison samples.[20] The statistical analyses were performed using the CATMOD procedure of the SAS Institute.[21] To present the effect of particular factors on crash involvement, involvement ratios were computed by dividing the percentage of trucks with that particular characteristic in the crash group by the percentage of trucks with the same characteristics in the comparison group. An involvement ratio greater than 1.0 indicated that the particular factor was overinvolved in the crash sample, and an involvement ratio of less than 1.0 indicated it was underinvolved.

Analyses were also performed stratifying the data by the study design parameters, which included crash type (single vehicle or multiple vehicle), day/night, route, and roadway alignment. In these analyses, the comparison sample was adjusted to include only those inspections corresponding to the specific parameter under study. For example, in analyzing the involvement of trucks in single vehicle crashes, the comparison sample included only those trucks sampled at the sites of single vehicle crashes. However, extraneous factors, such as weather, are randomly distributed throughout the sample of trucks, and it would have been inappropriate to match the cases by these factors.

To examine the simultaneous effects of the various study factors, a matched logistic regression model was used to estimate the adjusted odds ratio for each of the factors included in the model.[22] The odds ratio is the odds of crash involvement given a particular factor divided by the odds of crash involvement in the absence of that factor. To fit the model, the logistic regression procedure MCSTRAT from the

TABLE 1—Distribution of Crash-Involved Trucks and Control Sample Trucks by Configuration and Crash Type

	Per Cent Distribution of Truck Configurations						
Crash Type	Single Unit	Tractor Only	Tractor-Trailer	Truck-Trailer	Western Double	Rocky Mountain Double	Total* Number of Trucks
All Crashes							
Crash Involved	8	4	59	9	18	3	604
Comparison Sample	23	5	59	5	6	1	1,812
Single Vehicle							
Crash Involved	9	3	52	9	25	3	222
Comparison Sample	21	5	62	4	8	1	666
All Multiple Vehicle							
Crash Involved	8	4	62	9	14	2	382
Comparison Sample	25	5	57	6	5	1	1,146
Rear End**							
Crash Involved	9	8	64	7	13	1	104
Comparison Sample	24	8	51	8	7	1	312
Sideswipe**							
Crash Involved	7	4	67	8	14	1	108
Comparison Sample	27	4	59	6	3	1	324

*Some totals do not equal 100 per cent due to rounding
**Truck struck other vehicle

SAS Users Group International (SUGI) Supplemental Library was used.[23]

Note that the involvement ratio bears a direct relationship to the odds ratio. If the crude odds are computed with respect to tractor-trailers, for example, the involvement ratios could be transformed to odds ratios by dividing each involvement ratio by the ratio for tractor-trailers.

With a case-control study of this type, it is only possible to compute *relative* involvements, which cannot be converted into crash rates. Consequently, these results cannot be directly compared to other studies that compute crash involvement rates on a per-miles-traveled basis. Also, because the crash-involved trucks were compared with randomly sampled trucks, if one value of a variable (e.g., a particular truck configuration) is overrepresented in the crash sample, some other values of the same variable must be underrepresented. By definition, every overinvolvement in the crash sample must be balanced by underinvolvement. Thus overinvolvements or underinvolvements are *relative* to the overall involvement of large trucks in crashes on the interstate highway system. Consequently, the results from this study cannot be compared directly with the crash involvement rates of other vehicles.

Results

Truck Configuration

Table 1 provides an overview of the data sets that were analyzed, and it shows the distributions of the crash-involved trucks and comparison sample trucks by configuration. Tractor-trailers were involved in 59 per cent of all crashes, doubles (including Western and Rocky Mountain doubles) in 21 per cent, truck-trailers in 9 per cent, and single unit trucks in 8 per cent. Corresponding figures for the comparison sample are 59 per cent tractor-trailers, 7 per cent doubles, 5 per cent truck-trailers, and 23 per cent single unit trucks. Thus, among large trucks, the crash experience of tractor-trailers parallels their exposure on the road, whereas doubles and truck-trailers are substantially overrepresented in the crash sample and single unit trucks are underrepresented.

Involvement ratios by truck configuration are given in Figures 2 and 3 for all single vehicle and multiple vehicle crashes, respectively. Compared to tractor-trailers, doubles were overinvolved in both types of crashes, although their overinvolvement was greatest in single vehicle crashes.

Although truck configuration plays a major role, crash involvement is affected by other factors. The factors of interest were separated into three major categories:

- truck operating characteristics (load, fleet size),
- driver characteristics (age, hours of service), and
- environmental/road conditions (day/night, curve/grade).

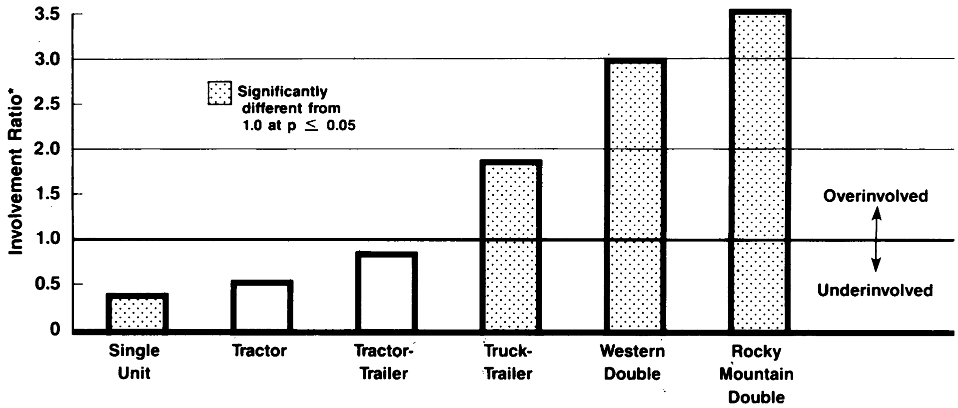
These various factors were analyzed in conjunction with truck configuration and the results are presented in Figures 4–7. Although many other factors affected crash involvement, truck configuration was the dominant effect and the other factors, in general, had less effect. Note that although all truck configurations were analyzed, only the results for the three configurations with the largest samples—single unit trucks, tractor-trailers, and doubles (Western and Rocky Mountain)—are presented.

Truck Operating Characteristics: Body Type, Load, and Fleet Size

Figure 4 gives crash involvement both by truck configuration (expressed as a percentage of the truck's GVWR), and by load. Compared to fully loaded trucks, empty trucks were overinvolved in crashes and partially loaded trucks were underinvolved. Load did not appear to have as large an effect for single unit trucks or tractor-trailers as for doubles. Doubles were overinvolved in all crashes, but empty doubles were move involved than partially or fully loaded doubles. An analysis of crash involvement by truck body type (i.e., van trailers, flatbeds, tankers, etc.) showed that no one particular body type was consistently overinvolved or underinvolved. Fleet size was not related to the crash involvement of tractor-trailers (Figure 5), but there was a trend of increasing involvement with decreasing fleet size for doubles and single unit trucks. However, irrespective of fleet size, doubles were always overinvolved in crashes.

Driver Characteristics: Age and Hours of Driving

Figure 6 gives the effect of driver age as a function of truck configuration. Compared to older drivers, young driv-



*Ratio of truck crash involvement percentage to comparison sample percentage.

FIGURE 2—Involvement of Trucks in Single Vehicle Crashes by Truck Configuration

ers are significantly overinvolved in crashes independent of truck configuration. Just as important, the Figure also shows that doubles are overinvolved in crashes irrespective of the ages of their drivers.

Figure 7 shows the effect of hours of driving on crash involvement. Drivers with six or more hours driving prior to their crash were more involved in crashes than those with fewer hours. Single unit trucks and tractor-trailers were less affected by driving hours than were doubles. Doubles showed an overinvolvement that increased steadily as the number of driving hours increased. There was a particularly high crash involvement if the doubles' driver had been driving six or more hours.

Environmental and Road Conditions

The involvement ratios for daytime (daylight conditions including dusk and dawn) and nighttime (dark) crashes as a function of truck configuration are shown in Table 2. Doubles were overinvolved in crashes compared to tractor-trailers, but for all configurations nighttime involvement ratios were generally lower than daytime ratios.

Table 2 also shows that the involvement ratios for single unit trucks and doubles were greater on curves or grades than straight level roads but that the involvement ratios for tractor-trailers were lower on curves or grades.

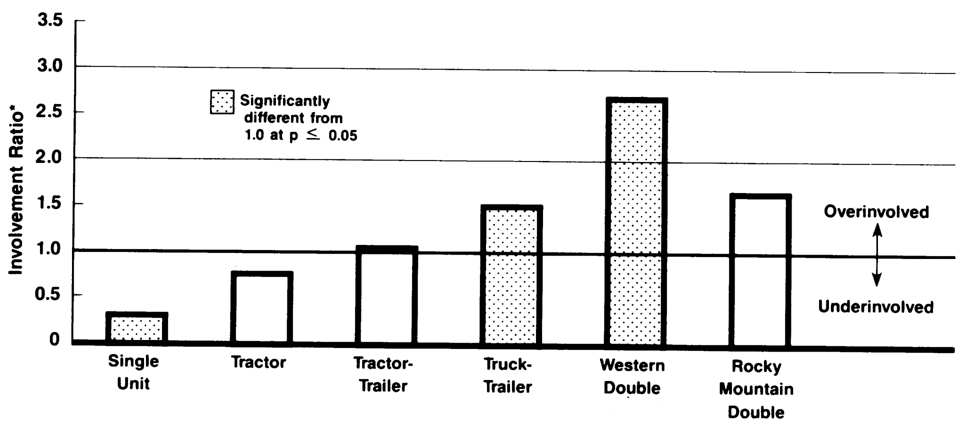
The crash involvement ratios were comparable on Interstate 5 and Interstate 90. These ratios further confirm the basic finding that single unit trucks were underinvolved, and doubles were overinvolved in crashes relative to tractor-trailers, regardless of route.

TABLE 2—Truck Configuration Crash Involvement Ratios by Time of Day, Highway, and Roadway Alignment

	Single Vehicle Crashes			Multiple Vehicle Crashes		
Factor	Single Units	Tractor-Trailer	Doubles	Single Units	Tractor-Trailer	Doubles
Time of Day						
Day	0.6	0.8	4.9	0.4	1.1	2.9
Night	0.2	0.9	2.5	0.2	1.0	2.0
Roadway Alignment						
Straight/level	0.3	1.0	2.8	0.3	1.2	2.4
Curve/Grade	0.6	0.8	3.3	0.4	1.0	2.9
Interstate Route						
5	0.5	0.9	2.5	0.4	1.1	2.6
90	0.2	0.7	3.8	0.4	0.9	2.5

Relative Risk of Crash Involvement by Various Factors

The various two-way analyses that have been presented suggest the possibility of interaction effects although with the current sample size the effects could not be reliably assessed. To examine the simultaneous effects of these study factors (body type, load, fleet size, driver age, driving hours), a matched logistic regression model was used without interac-



*Ratio of truck crash involvement percentage to comparison sample percentage.

FIGURE 3—Involvement of Trucks in Multiple Vehicle Crashes by Truck Configuration

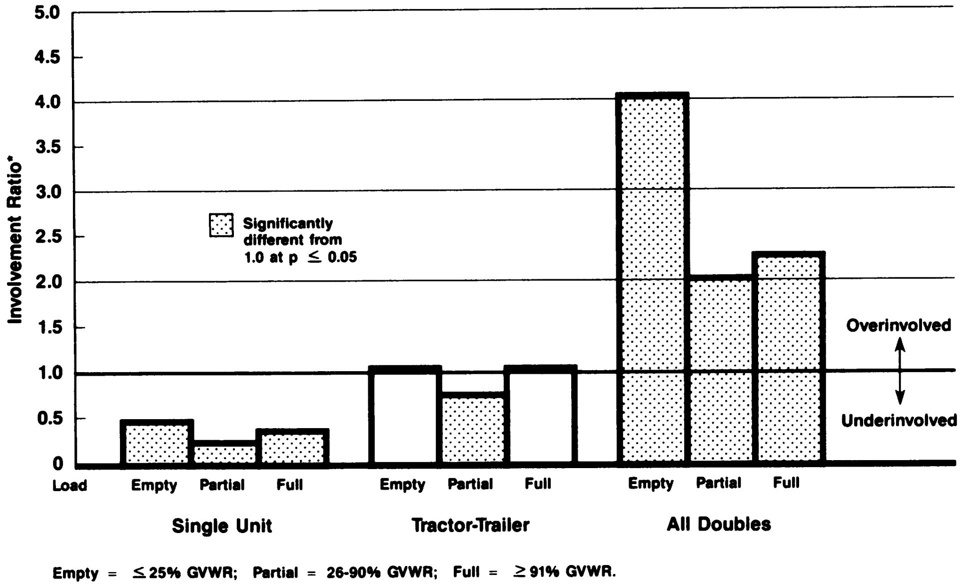


FIGURE 4—Involvement of Trucks in Crashes by Truck Configuration and Load

tion terms. Table 3 gives the crude and adjusted odds of crash involvement by the various study factors. Truck configuration is the dominant effect; after adjusting for the other study factors, the relative crash risk for doubles was more than three times that for tractor-trailers. Type of carrier operation (interstate versus intrastate), driver age (<30), driving hours (>6), and load (empty versus full) all showed higher adjusted odds.

Table 4 gives the adjusted odds computed separately for single vehicle crashes and multiple vehicle crashes. For single vehicle crashes, the relative risk of crash involvement for doubles increased to 4.8 from 3.2 for all crashes. The odds for the driver age and carrier operation variables were similar, and those for load and driving hours were reduced. In multiple vehicle crashes, the adjusted odds for truck configuration, load, driver age, and carrier operation were about the same as for all crashes; however, the odds for driving hours (>6) were higher, suggesting a stronger relationship between hours of driving and overinvolvement in multiple vehicle crashes.

Trailer Stability: Rollover, Jackknifing, and Trailer Separation

Table 5 gives the frequency of rollover and jackknifing in single vehicle and multiple vehicle crashes as a function of truck configuration. Doubles were involved in a higher proportion of single vehicle crashes (49 per cent) compared with tractor-trailers (30 per cent). An obvious question is whether this occurred because the doubles configuration with the two trailers is more prone to rollover or jackknifing than

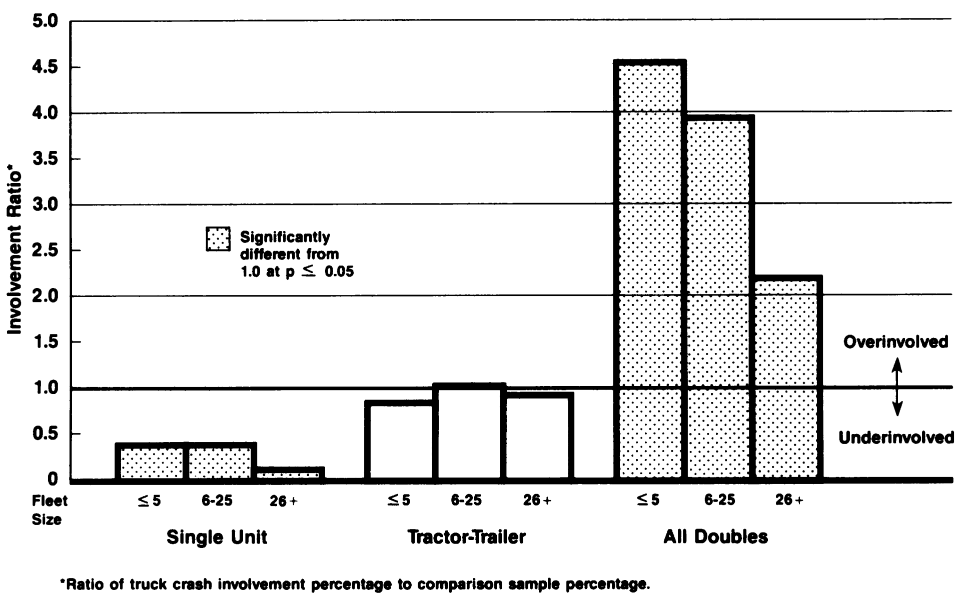
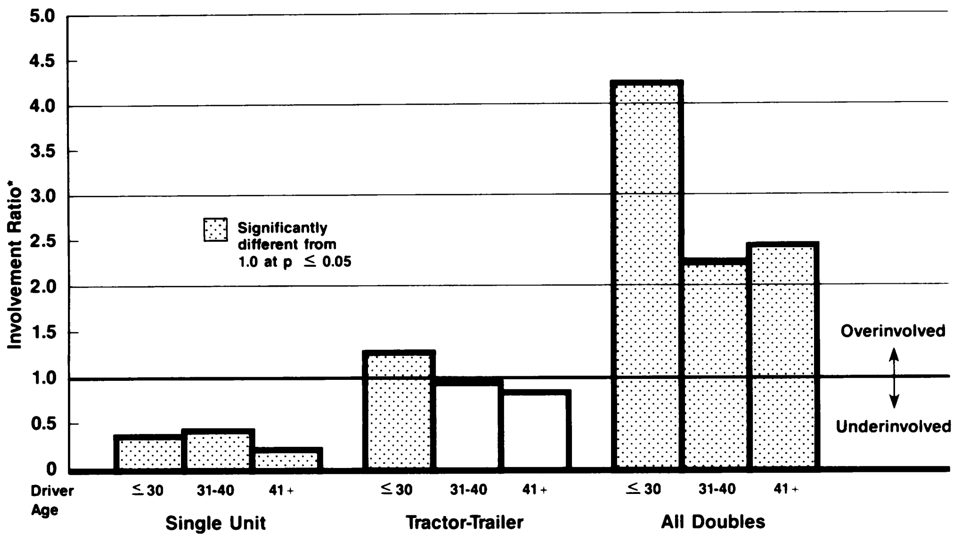


FIGURE 5—Involvement of Trucks in Crashes by Truck Configuration and Fleet Size



*Ratio of truck crash involvement percentage to comparison sample percentage.

FIGURE 6—Involvement of Trucks in Crashes by Truck Configuration and Driver Age

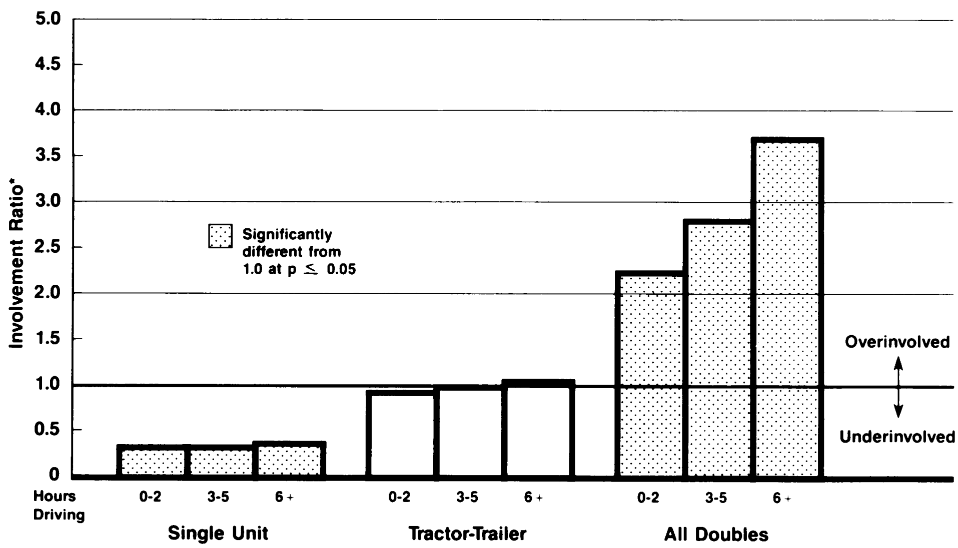
the tractor-trailer combination with one trailer. The proportion of rollover in single vehicle crashes was the same for doubles and tractor-trailers (about 45 per cent), but it was higher for truck-trailers and single unit trucks. The risk of injury was higher when rollover occurred; 49 per cent of single vehicle crashes with rollover involved injury, compared to 33 per cent without rollover. In multiple vehicle crashes truck-trailers, single unit trucks, and doubles all had a higher frequent of rollover than tractor-trailers.

Jackknifing of doubles occurred frequently in both single vehicle crashes (75 per cent) and multiple vehicle crashes (37 per cent). Truck-trailers jackknifed less frequently than doubles but more than tractor-trailers. In single vehicle crashes, jackknifing was almost twice as frequent on wet roads as on dry roads.

Table 5 also gives the frequency of trailer separation following a crash. Separation of units occurred in nearly 40 per cent of single vehicle crashes involving doubles and in 12 per cent of their multiple vehicle crashes; it was almost as frequent for truck-trailer crashes. Trailer separation generally occurred as a result of the crash although there are some cases reported where the separation of the second trailer precipitated the crash. Trailer separation was rare for tractor-trailers.

Discussion

Previous studies have documented the inherent stability problems of double trailer configurations.[12,13,15] The findings of this study suggest that trailer instability is one of the causes of the overinvolvement of doubles in crashes. Truck-trailers,



*Ratio of truck crash involvement percentage to comparison sample percentage.

FIGURE 7—Involvement of Trucks in Crashes by Truck Configuration and Hours Driving

TABLE 3—Crude and Adjusted Odds of Crash Involvement—All Truck Crashes

Study Variable	Crude Odds Ratio	95% Confidence Interval	Adjusted Odds Ratio	95% Confidence Interval
Configuration (N = 604)				
Single Unit	0.35	(0.25, 0.48)	0.48	(0.32, 0.71)
Doubles	2.92	(2.20, 3.87)	3.17	(2.33, 4.31)
Others	1.18	(0.87, 1.60)	1.40	(0.99, 1.97)
(Tractor-Trailers)**	(1.0)		(1.0)	
Load				
Empty	1.37	(1.10, 1.70)	1.05	(0.79, 1.38)
Partial	0.63	(0.51, 0.78)	0.83	(0.64, 1.08)
(Full)	(1.0)		(1.0)	
Driver Age (N = 604)				
≤30	1.21	(0.98, 1.49)	1.51	(1.20, 1.92)
(>30)	(1.0)		(1.0)	
Hours Driving (N = 555)				
(1–2)	(1.0)		(1.0)	
3–5	1.43	(1.12, 1.83)	1.25	(0.96, 1.62)
≥6	1.49	(1.13, 1.97)	1.32	(0.99, 1.76)
Carrier Operation (N = 603)				
Interstate	2.02	(1.61, 2.54)	1.54	(1.17, 2.02)
(Intrastate)	(1.0)		(1.0)	
Carrier Type (N = 603)				
Private	0.48	(0.38, 0.60)	0.86	(0.66, 1.14)
Contract	1.78	(0.91, 1.52)	1.34	(1.01, 1.77)
(Common)	(1.0)		(1.0)	

*Matched logistic regression: 554 matched cases in adjusted model.
**Reference group is given in parentheses; the odds ratios are computed within each group.

which have one coupling point less than doubles, were nevertheless overinvolved in crashes although less so than doubles. Similarly, tractor-trailers*[1] had a lower involvement than truck-trailers but were more involved in crashes than single unit trucks. The high crash involvement of empty doubles may reflect the fact that when doubles are lightly loaded sway problems are worse and their braking performance is also reduced.[8,16,24] Doubles were particularly overinvolved on curves.

*Tractor-trailers and truck-trailers both have one coupling point, but the fifth wheel connection of a tractor-trailer has more roll and yaw stability than the pintle hook arrangement used on truck-trailers.

TABLE 4—Adjusted Odds of Crash Involvement for Single Vehicle and Multiple Vehicle Crashes

Study Variable	Single Vehicle Odds Ratio (N = 177)	95% Confidence Interval	Multiple Vehicle Odds Ratio* (N = 350)	95% Confidence Interval
Configuration				
Single Unit	0.56	(0.27, 1.16)	0.41	(0.26, 0.67)
Doubles	4.76	(2.91, 7.83)	2.45	(1.64, 3.67)
Others	2.12	(1.16, 3.90)	1.15	(0.76, 1.75)
(Tractor-Trailers)**	(1.0)		(1.0)	
Load				
Empty	1.02	(0.62, 1.66)	1.06	(0.75, 1.49)
Partial	0.96	(0.61, 1.51)	0.75	(0.54, 1.04)
(Full)	(1.0)		(1.0)	
Driver Age (years)				
≤30	1.58	(1.04, 2.40)	1.52	(1.13, 2.03)
(>30)	(1.0)		(1.0)	
Hours Driving				
(1–2)	(1.0)		(1.0)	
3–5	1.06	(0.67, 1.68)	1.39	(1.01, 1.97)
≥6	0.82	(0.50, 1.35)	1.68	(1.17, 2.41)
Carrier Operation				
(Intrastate)	(1.0)		(1.0)	
Interstate	1.64	(0.98, 2.75)	1.48	(1.07, 2.06)
Carrier Type				
(Common)	(1.0)		(1.0)	
Private	0.77	(0.47, 1.25)	0.92	(0.66, 1.29)
Contract	1.86	(1.11, 3.11)	1.14	(0.81, 1.61)

*Matched logistic regression.
**Reference group is given in parentheses; the odds ratios are computed within each group.

Although the proportion of rollover in single vehicle crashes was similar for doubles and tractor-trailers, the frequency of doubles in single vehicle crashes and thus their rollover frequency was much higher than for tractor-trailers. It was not possible to determine whether the high single vehicle crash involvement was the result of a tendency of the second trailer to rollover or whether rollover was the result of a loss of control crash. In nearly 40 per cent of single vehicle crashes involving doubles, trailer separation occurred. This high proportion of trailer separation has been noted by other researchers.[25]

The present study has shown that doubles have a much higher crash frequency than other truck configurations. However, a net benefit might be realized if this increase in crash frequency could be offset by substantial decreases in truck traffic because doubles' greater cargo carrying capacity reduces total truck mileage. The National Research Council study of double trailers estimated that their increased use would reduce combination truck mileage by about 10 per cent.[8] This reduction in mileage clearly does not compensate for the up to threefold increase in crash involvement of doubles over tractor-trailers.

The strength of the current results stems from the study design, which compared different truck configurations operating under similar conditions; this comparison is extremely difficult using conventional mileage-based methods. For example, a recent study used Fatal Accident Reporting System, Bureau of Motor Carrier Safety, and Truck Inventory Use Survey data to compute accident rates per 100 million miles of travel.[26] Unfortunately, that study suffers from the same data and method limitations as previous studies—rates for doubles and singles were not compared

TABLE 5—Frequency of Rollover, Jackknifing and Trailer Separation in Single Vehicle and Multiple Vehicle Crashes by Truck Configuration

	Percentage of Single Vehicle Crashes* Involving				Percentage of Multiple Vehicle Crashes* Involving			
Truck Configuration	Roll-over	Jack-knife	Separa-tion of units	Number of Trucks**	Roll-over	Jack-knife	Separa-tion of units	Number of Trucks**
Single Unit	73	—	—	22	12	—	—	41
Tractor-trailer	43	51	0	129	5	18	2	308
All Doubles	46	75	39	69	11	37	12	73
Truck-Trailer	81	67	29	21	15	24	11	46

*More than one crash event may have occurred for a specific crash involved truck.
**Includes *all* crash-involved trucks.

under similar conditions. The study concluded that overall crash involvement rates of the two configurations were similar but that 70 per cent of doubles crashes were on divided roads compared to 52 per cent of tractor-trailer crashes. However, the authors noted that per-mile crash rates are substantially lower on divided highways, thus "the accident picture is not quite as favorable to the current doubles as appears at first glance, since the doubles chiefly travel on relatively safe divided highways."

Although doubles have been operated in Washington State for more than 25 years, their crash involvement is much higher than that of other truck configurations. When the crash involvement of doubles was compared to that of tractor-trailers operating under similar conditions, doubles were involved in crashes two to three times more often. If the use of doubles becomes more widespread throughout the interstate highway system and connecting roads, an inevitable result will be increased numbers of truck crashes.

DEDICATION

This paper is dedicated to the memory of the late William Haddon, Jr, MD. Dr. Haddon was a pioneer in the field of injury control and used the case-control approach to study the contribution of alcohol to motor vehicle crash losses. Dr. Haddon was involved in the early stages of this project, and we feel he would be particularly pleased with our application of this technique to study the factors involved in truck crashes. We regret that he was unable to see this study through to its completion.

ACKNOWLEDGMENTS

This work was supported by the Insurance Institute for Highway Safety.

REFERENCES

1. Jones IS, Stein HS, Zador P: Influence of Truck Size and Weight on Highway Crashes. *Research Note 105*. Washington, DC: Insurance Institute for Highway Safety, 1983 (revised May 1984).
2. Insurance Institute for Highway Safety, A. Fleming (ed): Big Trucks. Washington, DC: IIHS, 1986.
3. Eicher JP, Robertson HD, and Toth GR: Large Truck Accident Causation. Washington, DC: National Highway Traffic Safety Administration (DOT HS-806300), July 1982.
4. National Highway Traffic Safety Administration. Fatal Accident Reporting System, A Review of Information on Fatal Traffic Accidents in the US. Washington, DC: US Department of Transportation, 1975–85.
5. Meyers, WS: Comparison of Truck and Passenger-Car Accident Rates on Limited-Access Facilities. Transportation Research Record 808. Highway Safety: Roadway Improvements Accident Rates, and Bicycle Programs. Washington, DC: Transportation Research Board, 1981.
6. Bureau of Motor Carrier Safety: Accidents of Motor Carriers of Property 1984. Washington, DC: Federal Highway Administration, May 1986.
7. Cerreli EC: Current Trends in Heavy Truck Accident Fatalities (1980–84). Washington, DC: National Highway Traffic Safety Administration (DOT HS-866896), November 1985.
8. National Research Council, Transportation Research Board: *Twin Trailer Trucks: Effects on Highways and Highway Safety*. Special Report 211. Washington, DC: National Research Council, 1986.
9. Freitas, M. Safety of twin-trailer operations. *Public Roads* 48:117–20. Federal Highway Administration, 1985.
10. Chirachavala T, O'Day J: A Comparison of Accident Characteristics and Rates for Combination Vehicles with One or Two Trailers. Ann Arbor: University of Michigan, Highway Safety Research Institute, 1982.
11. Vallette GR, McGee HW, Sanders JH, Enger DJ: The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, Vol. 3: Accident Experience of Large Trucks. Washington, DC: Federal Highway Administration (FHWA-RD-80-137), 1981.
12. Jindra F: Lateral Oscillation of Trailer Trains. *Ingeniur Archiv* XXX111-Band, 1964.
13. Ervin RD: The influence of size and weight variables on the roll stability of heavy duty trucks. Warrendale, PA: Society of Automotive Engineers (Technical Paper 831163), August 1983.
14. Wolfe AC, O'Day J: Factbook on Combination Vehicles in Fatal Accidents 1975–81. Project No. 1165. Washington, DC: Motor Vehicle Manufacturers Association, 1983.
15. Eshleman RL, Desal SD, D'Souza AF: Stability and Handling Criteria of Articulated Vehicles, Summary. Chicago: IIT Research Institute, June 1973.
16. Mikulcik EC: Hitch and Stability Problems in Vehicle Trucks. Alberta, Canada: Department of Mechanical Engineering, University of Calgary, May 1973.
17. Wilson LJ, Horner TW: Data Analysis of Tractor-Trailer Drivers to Assess Driver's Perception of Heavy Duty Truck Ride Quality. Washington, DC: National Highway Traffic Safety Administration (DOT-HS-805-139), September 1979.
18. Haddon W Jr, Valien P, McCarroll JR, Umberger CJ: A controlled investigation of the characteristics of adult pedestrians fatally injured by motor vehicles in Manhattan. J Chronic Dis 1961; 14:655–678.
19. Bureau of Motor Carrier Safety: National Uniform Driver-Vehicle Inspection Manual. Washington, DC: Federal Highway Administration, 1983.
20. Grizzle JE, Starner CF, Koch GG: Analysis of categorical data by linear models. Biometrics 1969; 25:489–504.
21. SAS Institute: SAS User's Guide: Statistics, Version 5. Cary, NC: SAS Institute, 1985.
22. Schlesselman JJ: Case Control Studies: Design, Conduct Analysis. New York: Oxford University Press, 1982.
23. SAS Institute: SUGI Supplemental Library, User's Guide, Version 5. Cary, NC: SAS Institute, 1986.
24. Jones IS: Truck Air Brakes—Current Standard and Performance. Proceedings of the 28th Annual Conference of American Association for Automotive Medicine, in Denver, Colorado. Morton Grove, IL: AAAM, 1984.
25. Waller PF, Council FM, Hall WL: Potential safety aspects of the use of large trucks on North Carolina highways. Proceedings of the 29th Conference of the American Association for Automotive Medicine. Morton Grove, IL: AAAM, *1985;* 213–227.
26. Carsten O, Campbell KL: The UMTRI large-truck survey program. UMTRI Res Rev 1986; 17:1–12.