

## **Influence of Truck Size and Weight on Highway Crashes**

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## **Influence of Truck Size and Weight on Highway Crashes**

### **Introduction**

Maximum sizes and weights of trucks allowed on public roads were for many years regulated by each state. Under state regulations, permitted truck maximums varied considerably. Maximum gross vehicle weights ranged from 73,280 pounds in Arkansas, Illinois, and Missouri to 129,000 pounds in Nevada. All but eight states restricted the width of trucks to 96 inches. Twin trailers (i.e., a tractor pulling two trailers) were permitted in most western states but not in most of the East.

Since passage of the "Surface Transportation Assistance Act of 1982" (P.L. 97-424), which increased the federal tax on fuel and earmarked the proceeds for highway purposes, the maximum allowable limits on truck sizes and weights are required to be *at least*:

- 80,000 pounds gross weight, with axle loads up to 20,000 pounds for single axles and 34,000 pounds for double axles
- 102 inches in width for all trucks
- 48 feet in length for semitrailers and trailers
- 28 feet in length for each twin trailer

No state is allowed to establish limits on overall truck length. In addition, legal gross vehicle weights must satisfy the limiting conditions in the bridge gross weight formula, which establishes maximum allowable weights for all groupings and spacings of axles. These provisions apply to all trucks operating on interstate and other "qualifying" federal-aid highways. States not complying with the new regulations by October 1983 will have their federal highway aid apportionments withheld.

The basic safety question raised by the new federal provisions for truck size and weight is whether they are likely to increase the already large numbers of deaths and injuries resulting from crashes involving large trucks. Increases could result from higher truck crash frequencies and/or greater crash severity.

### **Magnitude of the Truck Crash Problem**

In 1978, large trucks (10,000 pounds and greater) were involved in 432,000 crashes, about six percent of the national crash total (1). In the same year, large trucks contributed to 12 percent of the national total of fatal crashes.

Trucks have a lower crash rate per mile than cars, but their fatal crash rate is significantly higher. The overall crash rate for large trucks in 1978 was 474 per hundred million vehicle miles compared to 825 for cars (1). The fatal crash rate for large trucks, however, was 5.3 per hundred million vehicle miles compared to 2.8 for cars.

Combination trucks (i.e., tractor semitrailers or tractor semitrailers plus trailers) have almost twice the crash rate of straight trucks — 604 per hundred million vehicle miles traveled compared to 351. Combination trucks also have a very high fatal crash rate, 8.6 per hundred million vehicle miles traveled. Thus, although on a per mile basis large trucks are less involved in crashes than passenger cars, large truck crashes usually are much more severe.

A principal reason for the overinvolvement of large trucks in fatal crashes is the difference in weight between trucks and other involved vehicles. In 1977, about 74 percent of fatal crashes involving large trucks also involved other vehicles, and 65 percent of these other vehicles were passenger cars (1). More than 3,000 car occupant deaths resulted from such crashes.

The proportion of all fatal crashes involving trucks has remained at 11 or 12 percent since 1977. During this period, however, the relative risk of death to occupants of passenger cars has been increasing. Table 1 shows the ratio of occupant fatalities in passenger cars to fatalities in trucks for fatal crashes involving cars and trucks. As the table indicates, the relative risk of death to passenger car occupants increased steadily between 1977 and 1980; this is most likely attributable to the increased risk of death in small cars, and these cars increased greatly in number during 1977-1980.

<b>TRUCK TYPE</b>	<b>1977</b>	<b>1978</b>	<b>1979</b>	<b>1980</b>
<b>Single-Unit</b>	16.7	17.8	22.9	25.6
<b>Combination</b>	26.0	28.9	30.8	32.9
<b>ALL LARGE TRUCKS</b>	22.9	25.2	28.6	30.6

Source: Eicher, J.P., Robertson, H.D., and Toth, G.R., "Large Truck Accident Causation," National Highway Traffic Safety Administration Technical Report No. DOT HS-806-300, July 1982.

\*E.g., in 1977 a car occupant was 22.9 times more likely than a truck occupant to be killed in a fatal large truck-car crash; in 1980, 30.6 times more likely.

The crash involvement rate of trucks is higher in urban areas than rural areas (2), but the severity of the crashes is greater in rural areas because of higher travel speeds (3). Truck crash involvement rates on controlled access roads (freeways, etc.) are significantly lower than on other roads (4), although even on controlled roads truck involvement in fatal crashes is disproportionately high. Trucks account for 20 percent of vehicle mileage on freeways, but they are involved in 35 percent of the fatal crashes on such roads.

### **Influence of Truck Configuration on Crash Involvement Rates**

Most truck safety studies have focused on the influence of truck configurations on crash involvement. The twin trailer configurations permitted by the fuel tax bill are the so-called "Western Doubles" (already permitted in western states), which consist of two 28-foot semitrailers hauled by a tractor unit. These are not to be confused with "Eastern" or "Turnpike Doubles," which are tractors pulling two 40- to 45-foot semitrailers.

The most recent Federal Highway Administration study has shown that "Western Doubles" have significantly higher crash involvement rates than single tractor trailers, regardless of the type of road on which they are traveling. Their crash rates (shown in Table 2) are based on accident and mileage data collected from selected road sections in California and Nevada where singles and doubles are operated under about the same conditions.

**TABLE 2**

**Truck Crash Rates Per 100 Million Miles  
Singles and Doubles by Roadway Type**

TRUCK TYPE	RURAL		URBAN	
	Freeway	Nonfreeway	Freeway	Nonfreeway
Singles	110	99	214	93
Doubles	228	468	388	428

Source: Vallette, G.R., McGee, H.W., Sanders, J.H., and Enger, D.J., "The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, Volume 3: Accident Experience of Large Trucks." Federal Highway Administration Report No. FHWA/RD-80/137. Washington, D.C., July 1981, PB No. 82 139726.

Campbell and Carsten reached similar conclusions (5). Their rates — based on data from the Bureau of Motor Carrier Safety and the National Highway Traffic Safety Administration's Fatal Accident Reporting System, and exposure data over a two-year period from a random survey of truck fleets — show that doubles are overinvolved in crashes on a per mile basis (Table 3). They also show that crash involvement rates for bobtail tractors (those not pulling a semitrailer) are substantially higher than for tractors pulling either single or double trailers.

**TABLE 3\***

**Truck Crash Involvement Rates Per 100 Million Miles  
(Intercity Use Only)**

TRAILER TYPE	FATAL	INJURY
	(FARS 1976-78)	(BMCS 1976-78)
Singles	6.5	47.9
Doubles	9.5	126.3
Bobtails	90.0	913.5

Source: Campbell, K.L., and Carsten, O., "Fleet Evaluation of FMVSS 121," UM-HSRI-81-9, Highway Safety Research Institute, Final Report National Highway Traffic Safety Administration Contract No. DOT-HS-6-01286, August 1981.

The important feature of the studies by Vallette et al. and Campbell and Carsten, from which Tables 2 and 3 are drawn, is that they compute crash rates on the basis of mileage and crash data from comparable trips. Other studies have compared the crash rates of different truck configurations, but their results have been misleading because their exposure data were not comparable for the various types of trucks they studied (6,7,8,9).

**Influence of Vehicle Load on Truck Crash Involvement Rates**

The study by Vallette et al. (2) is one of the few available that has considered the effects of load. It reported that empty and near-empty combination trucks have substantially higher crash involvement

\*Since publication of this research the authors have stated that this comparison is in error because the exposure data underrepresented regions of the country with high concentrations of doubles. See addendum for further details.

rates — higher by at least a factor of two — than loaded trucks. Empty doubles reportedly show a relationship between weight and crash experience that is similar to that of singles, but for all weight classes doubles have a higher crash involvement rate than singles.

It should be noted that Vallette's findings about the effects of truck weight on crash involvement depend on the correct identification of both empty truck exposure and the involvement of empty trucks in crashes. A data review indicates that these were incorrectly estimated to different extents. Using Vallette's data and making appropriate adjustments to reflect more accurately the exposure and crash involvement of empty trucks, the Insurance Institute for Highway Safety has concluded that Vallette's findings were not justified from these data.

However, studies other than Vallette's have reported low crash involvement rates where it was known that trucks were traveling substantial portions of their journeys fully loaded. High crash involvement rates were reported where partial or empty loads were more characteristic (9,10). In addition, engineering considerations indicate that empty trucks are dynamically less stable and cannot generate braking forces as large as loaded trucks. This also suggests higher crash rates for such trucks.

### **Effect of Increased Gross Vehicle Weights on Truck Braking Performance**

The new federal gas tax law allows gross vehicle weights of 80,000 pounds, a higher weight limit than has been allowed in some states. For fully loaded trucks, increasing the weight generally increases stopping distances, because maximum braking capability is exceeded.

Unloaded trucks usually have longer braking distances than loaded trucks. A number of studies (2,10) have suggested that empty combination or single unit trucks and "bobtails" have higher crash rates, because truck brake characteristics are biased toward loaded conditions. When trucks are unloaded, premature wheel lockup and consequent stability problems may occur.

Federal motor carrier safety regulations require large trucks (air brake-equipped) traveling at 20 mph to stop in 35-40 feet, and cars to stop in 20-25 feet. In 1974, the Federal Highway Administration tested this stopping capability for 1,200 trucks and 366 cars selected randomly from highway traffic (11). Eighty-seven percent of the cars tested met the 25-foot requirement, but high percentages of the trucks did not meet their stopping requirements; only 29 percent of the single unit trucks, 65 percent of the tractor trailers, and 44 percent of the tractors with twin trailers could stop within their required distances.

A large number of trucks in service thus are not meeting existing stopping distance requirements, even though such requirements are well within truck design capabilities. If future brake systems are designed to accommodate higher gross vehicle weights, without improved brake technology such as load proportioning or anti-lock systems, the already large difference in braking distance between cars and trucks is likely to increase. Additionally, the disparity between loaded and unloaded truck braking distances will increase, as will the inherent stability problems caused by this disparity.

### **Cargo Type and Truck Crash Involvement**

The consensus of studies of trailer configuration and cargo type is that tanker trucks and flatbed trailers operated as doubles have much higher crash rates than those operated as singles — higher by a factor of four in the case of tankers, and by a factor of more than two for flatbeds (2,9). The crash rates for dump trucks also have been found to be consistently high, regardless of the trailer configuration (2,6). Again, these results indicate that trucks which operate exclusively either heavily loaded or empty have high crash involvement rates.

There is some discrepancy concerning rates for van trailer doubles. Their crash involvement rates have been found to be higher than singles in one study (2), but about the same in another study (9). However, van doubles included in the latter study had a high proportion of their crashes at night and on

divided highways. This suggests a use pattern which would tend to reduce exposure to multiple vehicle crashes.

### **Influence of Truck Length and Width on Crash Involvement**

For single trailer configurations, there is some evidence of decreasing crash rates with increasing trailer lengths (2). However, there are insufficient data to analyze crash involvement rates by individual cargo area configurations, and this may confound the results. In a comparison of 40- and 45-foot semi-trailers in six states, no significant differences in crash rates were found (2).

Because trucks and trailers have almost universally been restricted to a maximum width of 96 inches, there are insufficient data to determine whether increasing overall truck widths by six inches — as provided for in the new federal gas tax bill — would affect crash rates.

### **Influence of Truck Dimensions on Crash Severity**

Because the mass ratio between a large truck and a car weighing 3,000 pounds already is in excess of 20 to 1, there is little evidence that increasing the maximum weight of a truck to 80,000 pounds would significantly affect the already unacceptably high risk of serious or fatal injury in crashes between cars and trucks. Primary factors influencing injury in a crash include the velocity change that the car experiences, together with the protection afforded to vehicle occupants; these would not be affected appreciably by truck weight increases.

Although Herzog (12) has reported that the risk of fatality for non-truck occupants increases steadily with truck weight, the effects of road type and location were not considered. It seems probable that the apparent weight effect may have been a surrogate for increased impact speed. This view is endorsed by Hedlund (3), who has concluded that among large trucks weight is not an issue in determining fatality risk, in part because risk can be predicted from crash location (rural or urban) and road type (number of lanes), both of which are surrogates for vehicle speed.

### **Summary and Conclusions**

Large trucks account for six percent of the nation's highway crashes and 12 percent of all fatal crashes. On a per mile basis, trucks are less frequently involved in crashes than cars, but trucks are involved in twice as many fatal crashes. The proportion of fatal crashes involving trucks has remained constant since 1977, while the relative risk of death for car occupants in crashes with large trucks has steadily increased from 23:1 to 31:1.

Combination trucks — tractor semitrailers or tractor semitrailers plus trailers — have almost twice the crash rate of straight trucks, and a fatal crash involvement rate three times that of cars. Twin trailer configurations — tractor semitrailers plus trailers — have higher crash involvement rates than tractor semitrailers. However, the exposure of different truck types varies in terms of miles traveled, kinds of highways used, and times of day operated, and the influence of these variations on crash rates has not been adequately quantified. Until detailed exposure data are collected, comparisons of truck crash experience by configuration will be limited.

In the near future, trucks of increased size and weight, as well as double configuration trucks, will be permitted by federal law on the interstate system and other "qualifying" federal-aid highways in all states. While researchers have had difficulty in precisely quantifying the influence of truck size and weight on crash involvement, there is evidence that the new legislation will almost certainly increase the magnitude of the truck crash problem.

## Notes

1. Eicher, J.P., Robertson, H.D., and Toth, G.R., "Large Truck Accident Causation," National Highway Traffic Safety Administration Technical Report No. DOT HS-806-300, July 1982.
2. Vallette, G.R., McGee, H.W., Sanders, J.H., and Enger, D.J., "The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, Volume 3: Accident Experience of Large Trucks." Federal Highway Administration Report No. FHWA-RD-80-137. Washington, D.C., July 1981, PB No. 82 139726.
3. Hedlund, J., "The Severity of Large Truck Accidents," National Highway Traffic Safety Administration Report No. DOT-HS-802-332, April 1977.
4. Meyers, W.S., "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. Transportation Research Board, Washington, D.C., 1981.
5. Campbell, K.L., and Carsten, O., "Fleet Evaluation of FMVSS 121," UM-HSRI-81-9, Highway Safety Research Institute, Final Report National Highway Traffic Safety Administration Contract No. DOT-HS-6-01286, August 1981.
6. Scott, R.E. and O'Day, J., "Statistical Analysis of Truck Accident Involvements," National Highway Traffic Safety Administration Report No. DOT-HS-800-627, December 1971.
7. Bureau of Motor Carrier Safety "Safety Comparison of Doubles versus Single Semitrailer Operation," Federal Highway Administration, Washington D.C. November 1977.
8. Yoo, S.C., Reiss, M., and McGee, W.H. "Comparison of California Accident Rates for Single and Double Tractor-Trailer Combination Trucks," Federal Highway Administration Report No. FHWA-RD-78-94, March 1978.
9. Chirachavala, T. and O'Day, J., "A Comparison of Accident Characteristics and Rates for Combination Vehicles with One or Two Trailers," Highway Safety Research Institute, PB-82-209412, Federal Highway Administration, Washington, D.C., May 1982.
10. Heath, W.M., "California Tank Truck Accident Survey," California Highway Patrol, Enforcement Services Division. December 1981.
11. Winter, P.A., "1974 Brake Performance Levels for Trucks and Passenger Cars," Bureau of Motor Carrier Safety, Federal Highway Administration, Washington, D.C., 1975.
12. Herzog, T.N., "Injury Rate as a Function of Truck Weight in Car-Truck Accidents," National Highway Traffic Safety Administration Report No. DOT-HS-801-472, NHTSA Technical Note N43-31-7, June 1976.

## Addendum

Since the "Influence of Truck Size and Weight on Highway Crashes" was published in 1983, Campbell and Carsten (5) consider their comparison of doubles' and singles' crash involvement rates to have been in error. The authors became aware, after the study was completed, that their exposure estimates were underepresented in areas of the country with high concentrations of doubles, particularly California. Underestimating exposure according to the authors will have the effect of falsely elevating the involvement rates for doubles.

However, even if the exposure data in their study are considered to be unreliable, other current data support the trends reported by Vallette et al. (2) and substantiate the conclusion that double trailer configurations (tractor semitrailers plus trailers) in general have higher crash rates than tractor semitrailers. The study by Chirachavala and O'Day (9), for example, compares crash involvement rates for combination vehicles with one and two trailers using the BMCS accident data and exposure data from the Truck Inventory and Use Survey. The overall crash involvement rate given for doubles is 122.8 per  $10^8$  miles of travel compared to 123.4 per  $10^8$  miles of travel for singles. However, 92 percent of the doubles in the overall population considered were van trailers (compared to 65 percent for singles), and intercity trips accounted for 85 percent of the total mileage (for both singles and doubles), so that intercity van trailer rates dominate the overall population.

A more detailed analysis presented in the study of involvement rate by individual trailer types (see Table A-1) shows that van doubles and van singles on intercity trips have comparable involvement rates. This exposure difference explains why the overall rates quoted for doubles and singles are similar. However, when other types of trailers are considered (as shown in Table A-1), doubles with tanker trailers have 1.5 times the crash involvement rate of singles, and flatbed trailers operated as doubles have 2.5 times the crash rate of singles. The lower rate for van doubles on local trips, 68.4 accidents per  $10^8$  vehicle miles versus 168.0 accidents per  $10^8$  vehicle miles for singles, appears encouraging until the corresponding accident severities are examined (see Table A-2). The authors suggest that the percentage of fatalities plus injuries in accidents for doubles is lower than for singles, but they omit to point out that the percentage of fatalities is invariably higher. Moreover, this comparison underestimates fatal and injury involvements for doubles because the number of property damage only accidents meeting the \$2,000 BMCS reporting criterion will be higher for doubles by virtue of the involvement of the second trailer.

In a later study also using BMCS data, Chirachavala et al. (A1) confirmed this severity problem for doubles. They found that, although the ratio of injury to involvement was higher for singles than for doubles, the ratio of fatality to involvement was higher for doubles. This was particularly true for car-truck collisions on rural divided highways. It should also be emphasized that BMCS data are self-reported by truck companies, and it is likely that the reporting criteria for injury and severity varies considerably between companies. However, the recording of fatalities is likely to be more consistent.

### Lateral and Roll Stability of Double Combinations

In addition to the evidence provided by accident studies on the relative safety of doubles versus singles, the potential problems in operating doubles can be assessed by reviewing the theoretical and experimental studies that have looked at their inherent stability. An excellent review is provided by Chirachavala and O'Day (9) who point out that Jindra (A2) and others (A3, A4, A5, A6) have all emphasized the response of the last trailer as the key dynamic feature distinguishing the safety qualities of doubles versus singles. The amplified response of the rearmost trailer causes it to cover a wider swath during rapid lane change maneuvers. It can also cause a premature rollover of the last trailer at a level of maneuvering severity that would be insufficient to produce rollover in a comparably loaded tractor semitrailer. The latter effect was established particularly by Ervin (A7) in an analysis of rollover mechanisms for semitrailer and double configurations. He showed that the rollover threshold for the second trailer of a double combination is generally lower than the first and that the reduction can amount to as

much as 11 percent depending on the load. This translates to an 11 percent increase in the frequency of rollover. It is pertinent that Ervin (A8) also reports that doubles experience the majority of their rollover incidents as rear-trailer-only rollovers.

Eshleman (A9) in an analytical and experimental study comparing a 27-foot van semitrailer, 45-foot van semitrailer, and a double with two 27-foot semitrailers confirmed the trailer swing problem and concluded that handling double trailer configurations on wet surfaces was tedious. This conclusion is reflected in studies that have reported driver experience with combination vehicles. Mikulcik (A10) concluded that driving doubles and triples required greater alertness and concentration than singles. Inexperienced or untrained drivers often encountered swaying problems. Swaying was more likely on downgrades and braking increased its magnitude although it could be eliminated by accelerating. Wilson and Horner (A11) in a survey of Teamsters Union drivers concluded that doubles were less comfortable to drive than singles.

The increased trailer swing and rollover potential of doubles are confirmed by the data presented in Table A-3, which are reproduced from an analysis of the FARS data by Wolfe, Filkens, and O'Day (A12). Table A-3 shows significantly higher proportions of rollover in fatal accidents involving three or four unit combination vehicles (23.6 percent) compared to two unit combinations (17.1 percent) despite the fact that fatal collisions involving doubles were more likely to occur on limited access roadways (interstates) that have inherently low rollover rates. Chirachavala (A1) also points out that "non-collision accidents are much more common with doubles than with singles; overall they account for 40 percent of the doubles' involvements and only 27 percent of single involvements."

**TABLE A-1**  
**Involvement Rates (per 10<sup>8</sup> Vehicle Miles)**  
**(ICC-Authorized Carriers Only)**

Trailer Type	Single				Double			
	Local		Intercity		Local		Intercity	
	Rate	CI	Rate	CI	Rate	CI	Rate	CI
Van	168.0	±12.2	74.9	±2.0	68.4	±16.2	73.0	±7.0
Flatbed	69.9	±13.1	106.8	±4.8	—	—	264.1	*
Tank	142.2	±34.6	78.1	±4.2	—	—	111.8	±8.8
Auto	241.6	±55.3	73.6	±3.7	—	—	—	—
Dump	46.1	±8.1	33.1	±3.6	—	—	—	—
Other	277.4	±122.0	250.7	±38.1	—	—	—	—
<b>Total</b>	<b>151.0</b>	<b>±10.5</b>	<b>81.2</b>	<b>±1.7</b>	<b>98.1</b>	<b>±20.5</b>	<b>83.3</b>	<b>±7.8</b>

\*Sample size is insufficient to estimate the sampling error, so that the confidence interval should be presumed to be large.

Source: Chirachavala, T. and O'Day, J., "A Comparison of Accident Characteristics and Rates for Combination Vehicles with One or Two Trailers." University of Michigan, Highway Safety Research Institute, 81-41, PB-82-20-9412, 1981.

**TABLE A-2**  
**Severity of Combination Vehicle Accidents**  
**(ICC-Authorized Carriers Only)**

Trip Length	Trailer Type	Percent of Each Severity Level					
		Single			Double		
		Fatal	Injury	Property Damage	Fatal	Injury	Property Damage
Local	Van	3.13	73.51	23.35	11.11	48.15	40.74
	Flatbed	5.62*	67.42	26.97	—	66.67	33.33*
	Tank	5.26*	64.47	30.26	10.0*	30.0*	30.0*
	Other	13.11*	54.10	32.79	—	50.0*	50.0*
Intercity	Van	7.52	60.35	32.13	8.60	51.55	39.86
	Flatbed	8.50	58.68	32.82	10.94*	56.25	32.81
	Tank	8.72	58.36	32.92	10.53*	39.47	50.0
	Other	7.41	61.78	30.81	3.23*	47.31	49.46
<b>Total</b>		<b>7.32</b>	<b>61.46</b>	<b>31.23</b>	<b>8.27</b>	<b>50.61</b>	<b>40.75</b>

\*Cell with frequency less than 10.

Source: Chirachavala, T. and O'Day, J., "A Comparison of Accident Characteristics and Rates for Combination Vehicles with One or Two Trailers." University of Michigan, Highway Safety Research Institute, 81-41, PB-82-20-9412, 1981.

**TABLE A-3**  
**Combination Vehicle Rollover by Combination**  
**Vehicle Type and Accident Type, Fatal Accident**  
**Involvements, 1978-1980\***

Combination Vehicle Type		Accident Type					
		Single Vehicle With Ped./Bic.	Single Vehicle With Train	Other Single Vehicle	Two Vehicles	Three or More Vehicles	Total
Two-unit	N	14	12	1133	703	151	2013
	%	1.7	12.0	67.0	9.1	10.6	17.1
Three or Four unit	N	1	2	56	43	14	116
	%	2.2	66.7	73.7	14.5	19.7	23.6
Bobtail**	N	0	0	42	27	6	75
	%	—	—	59.2	11.5	11.5	18.4
Total	N	15	14	1231	773	171	2204
	%	1.6	13.2	67.0	9.4	11.1	17.4

\* This variable was not included in the FARS data prior to 1978. The percentages shown are the percentages of all vehicle involvements in a given category which involved a rollover either as a first or subsequent event.

\*\* As explained in the Preface, the bobtail category in FARS appears to include *all* large single-unit trucks involved in fatal accidents in Pennsylvania for 1978-1981.

Source: Wolfe, A.C., Filkins, L.D., and O'Day, J. "Factbook on Combination Vehicles in Fatal Accidents 1975-1981". University of Michigan, Highway Safety Research Institute, 83-15.

## References

- A1. Chirachavala, T., D.E. Cleveland, and L.P. Kostynink, "Severity of Large-Truck and Combination-Vehicle Accidents in Over-the-Road Service: A Discrete Multivariate Analysis." Presented at the 63rd Annual Transportation Research Board Conference, Washington, D.C., 1980.
- A2. Jindra, F. "Lateral Oscillation of Trailer Trains," *Ingenieur Archiv*XXXIII-Band, 1964.
- A3. Nordstrom, O. and L. Strandberg, "The Dynamic Stability of Heavy Vehicle Combinations." Presented at the Third International Conference on Vehicle Systems Dynamics, Virginia, August 12-15, 1974.
- A4. Hales, F.D., "The Rigid Body Dynamics of Road Vehicle Trains." In *The Dynamics of Vehicles on Roads and Tracks*. Proceedings of IUTAM Symposium, Delft, August 1975.
- A5. Hazemoto, T., "Analysis of Lateral Stability for Doubles." Presented at meeting of the Society of Automobile Engineers, June 18-22, 1973. SAE Paper No. 730688.
- A6. Ervin, R.D., et al., *Ad Hoc Study of Certain Safety-Related Aspects of Double-Bottom Tankers*, Final Report. Highway Safety Research Institute, The University of Michigan, May 1978.
- A7. Ervin, R.D., "The Influence of Size and Weight Variables on the Roll Stability of Heavy Duty Trucks." Presented at SAE, West Coast International Meeting, August 1983, SAE Paper No. 831163.
- A8. Ervin, R.D. et al. "Influence of Size and Weight Variables on the Stability and Control Properties of Heavy Trucks." Final Report, Contract No. FH-11-9577, University of Michigan Transportation Research Institute Report No. UMTRI-83-10, March 1983.
- A9. Eshleman, R.L., S.D. Desai, and A.F. D'Souza, *Stability and Handling Criteria of Articulated Vehicles, Summary*. IIT Research Institute, June 1973.
- A10. Mikulcik, E.C., *Hitch and Stability Problems in Vehicle Trucks*. Department of Mechanical Engineering, University of Calgary, Alberta, Canada, May 1973.
- A11. Wilson, L.J. and T.W. Horner, *Data Analysis of Tractor-Trailer Drivers to Assess Driver's Perception of Heavy Duty Truck Ride Quality*, Final Report, No.: DOT-HS-805-139; PB-80-118144, September 1979.
- A12. Wolfe, A.C., Filkins, L.D., and O'Day, J., "Factbook on Combination Vehicles in Fatal Accidents 1975-1981." University of Michigan Transportation Research Institute 1-83-15, MVMA Project No. 1165, April 1983.