

**INSURANCE INSTITUTE  
FOR HIGHWAY SAFETY**

September 15, 1999

The Honorable Julie Cirillo  
Program Manager  
Office of Motor Carrier and Highway Safety  
Federal Highway Administration  
U.S. Department of Transportation  
400 Seventh Street, S.W.  
Washington, D.C. 20590

**Request for Clearance of a New Information Collection:  
Graduated Commercial Driver's License Survey  
Docket No. FHWA-99-5942**

Dear Ms. Cirillo:

The Insurance Institute for Highway Safety has several recommendations for improving the planned survey concerning a graduated commercial driver's licensing system. Views of the motor carrier industry, drivers, driver training schools, insurance companies, and government agencies are to be collected, according to the Federal Highway Administration. However, nonprofit safety groups and knowledgeable university researchers also should be surveyed, and their expertise should be given substantial weight.

Existing research indicates substantially increased risk of crash involvement among younger truck drivers. Attached is a summary of three pertinent studies (copies are enclosed). Taken together, these and other studies suggest that permitting drivers younger than 21 to operate large trucks in interstate commerce will have detrimental effects on the safety of not only these young drivers but also people sharing the road with them.

Sincerely,

*Elisa R. Braver*

Elisa R. Braver, Ph.D.  
Senior Epidemiologist

cc: Docket Clerk, Docket No. FHWA-99-5942

Attachment

Enclosures (3)

**Attachment**

**Summary of Studies of Truck Driver Age and Crash Risk**

<b>Author, year</b>	<b>Outcome</b>	<b>Study population</b>	<b>Number of drivers</b>	<b>Study design</b>	<b>Ages of young drivers</b>	<b>Magnitude of risk</b>	<b>Comments</b>
Jones and Stein, 1987; Stein and Jones, 1988	Crashes	Tractor-trailer drivers on interstate highways in Washington state	300 drivers in crashes, 576 drivers not involved in crashes, 1984-86	Case-control study	30 or younger	1.5-fold increased risk if truck drivers were 30 or younger	Adjusted for other risk factors for truck crash involvement; matched by location, day of week, and time of day
Frith, 1994	Crashes	Drivers of large trucks in New Zealand	199 drivers in crashes, 1988-90  199 drivers not involved in crashes, 1992-93	Case-control study	Younger than 20; 20-24	>2-fold increased crash risk among truck drivers 24 or younger	Matched by location, day of week, and time of day
Campbell, 1991	Fatal crashes	Drivers of large trucks in United States	24,119 drivers of large trucks involved in fatal crashes, 1980-84  5,000 owners of large trucks (probability sample), 1985	Cohort study	Younger than 21; 21-26	4.3 to 6.2-fold increased fatal crash risk among truck drivers younger than 21  1.5 to 2.2-fold increased risk if drivers were ages 21-26	Controlled for large truck mileage; younger drivers overinvolved in daytime and nighttime crashes on all types of roads

## FATAL ACCIDENT INVOLVEMENT RATES BY DRIVER AGE FOR LARGE TRUCKS

KENNETH L. CAMPBELL

The University of Michigan, Transportation Research Institute,  
Ann Arbor, Michigan, U.S.A.

(Received 27 July 1989; in revised form 5 September 1990)

**Abstract**—Survey data on large trucks involved in fatal accidents and on the travel of large trucks provide estimates of fatal accident involvement rates by driver age. The analysis is focused on the implications of lowering the minimum age for drivers of commercial trucks operating interstate from 21 to 19 years. Fatal accident involvement rates for drivers of large trucks are found to increase with decreasing driver age. The younger drivers are over-involved until about age 27. Drivers under the age of 21 are over-involved by a factor of 6 in comparison to the overall rate for all drivers. Other factors known to have significant influences on the probability of involvement in a fatal accident were examined to determine their association with the over-involvement of younger drivers. The general pattern of over-involvement for younger drivers pervades virtually every combination of factors examined. Thus, it is concluded that the basic trend with driver age shown in the aggregate data is primarily associated with age and is not associated with the other factors examined. The results of this analysis substantiate an elevated risk of fatal accident involvement for younger drivers of large trucks.

### INTRODUCTION

The minimum age for drivers of commercial vehicles engaged in interstate commerce is currently 21 years. Previous studies have examined accident rates of passenger vehicles in relation to the age of the driver. Williams (1985) focused on the involvement rates of teenage drivers in fatal accidents using the data from the 1977 National Personal Transportation Study conducted by the Bureau of the Census and from the National Highway Traffic Safety Administration (NHTSA) Fatal Accident Reporting System (FARS) files for 1976–1978. Male drivers under 19 had fatal accident involvement rates (involvements per hundred million miles) about 4–6 times the overall rate. Rates for male drivers aged 19–20 were 2–3 times the overall rate. Younger male drivers continued to be over-involved until about age 25. Williams also examined driving at night. Nighttime rates for young males are about 4 times the daytime rates, and young males did somewhat more of their driving at night as compared to older males. Young females were also over-involved in fatal accidents, and the pattern of over-involvement was very similar to that for males. However, the fatal accident involvement rates for young females were about half those of young males. All of these rates were developed for drivers of passenger vehicles only (cars, light trucks, and vans).

The probability of fatality in an accident involving a large truck is about twice as high as in accidents not involving large trucks (Eicher, Robertson, and Toth 1982). This is a direct consequence of the weight of large trucks in general and the disparity in weight between large trucks and the passenger cars that are most commonly the other vehicle involved in the accident. If the risk of fatal accident involvement for young males when they are driving commercial trucks is as high as when they are driving passenger vehicles, then the Williams study cited above indicates that, if the minimum driving age were lowered to 19, these new drivers of commercial trucks would be expected to have fatal accident involvement rates 2–3 times the overall rate for commercial truck drivers.

Information is not available in the literature on the relationship of the age of commercial vehicle drivers to their accident experience. One might expect younger drivers to do better when they are employed to drive, particularly since their elevated rates in passenger vehicles are associated to some extent with nighttime driving and alcohol consumption. The basic question is the extent to which the risk of accident involvement for younger drivers of large trucks is improved in comparison to their risk as drivers of

passenger vehicles. The Center for National Truck Statistics (CNTS) at the University of Michigan Transportation Research Institute (UMTRI) has collected survey data on fatal accidents involving large trucks and on large truck travel that will support calculation of fatal accident involvement rates by driver age. This paper **describes** the data, methods, and results of an analysis carried out by the author for the Federal Highway Administration (Campbell et al. 1988b).

#### METHOD

Calculation of fatal accident involvement rates by driver age requires data on the **age of drivers** of large trucks involved in fatal accidents for the numerator and the mileage traveled by large trucks broken down by the age of the driver for the denominator. Over the past several years, UMTRI has conducted national surveys of fatal accidents involving large trucks and of the travel of large trucks. These survey files provide the necessary data for this analysis of fatal accident involvement rates by driver age. Each is described briefly in the following paragraphs.

In 1981, a survey of all large trucks involved in fatal accidents in the United States was initiated, with 1980 being the first year covered. This survey combines information from the NHTSA Fatal Accident Reporting System (FARS) with accident **data** from the MCS 50-T report submitted to the FHWA Office of Motor Carriers **by** interstate carriers, the original police accident reports, and comprehensive telephone surveys conducted by UMTRI staff to produce the data file called Trucks Involved in Fatal Accidents (TIFA). Essentially, the file has the data elements from both FARS and the MCS 50-T form with complete national coverage of both interstate and intrastate carriers. Pickup trucks are excluded from the survey, as are all passenger vehicles (vans, utility vehicles, buses, and ambulances) and fire trucks. Otherwise, all trucks with a gross vehicle weight **rating** greater than 10,000 pounds are included. Trucks involved in fatal accidents in Alaska and Hawaii are excluded. The **TIFA** files are currently complete for five years, 1980-1984. More than 25,000 large trucks were involved in fatal accidents over that period. A more complete description of the TIFA files is provided by **Carsten and Pettis (1987)**, along with one-way tabulations of every variable in the five-year file.

In 1985, the National Truck Trip Information Survey (**NTTIS**) was initiated. For this survey, the owners of nearly 5,000 large trucks were contacted four times over a **12-month** period to obtain detailed information on the use of the truck. The information collected includes the configuration, cargo, actual weight, and the route the truck followed. The **NTTIS** began with a probability-based sample of trucks registered in the United States as of July 1, 1983. The sample was drawn from registration records maintained **by** R. L. Polk and Company, Cincinnati division.

For each survey-day, the owner was asked to describe every trip made by the selected truck. Trips were split **by** time of day into day and night, and each trip was mapped on special atlases prepared by UMTRI. These maps show the boundaries of every urban area having a population over 5,000 based on FHWA definitions obtained from each state. Roads are classified as limited access, other major or primary highways (largely U.S. and state routes), and other roads (mostly county roads and city streets). By mapping out the travel, each mile is characterized by the actual loading and configuration of the vehicle including the driver age. Each mile is also categorized **by** road type, rural/urban area, and day/night. Travel estimates are computed from the trip-level files by summing across trips and across the categories defined by the levels of each of the **desired** factors (vehicle type, carrier type, road type, etc.). A complete description of the **NTTIS** data is provided **by** Blower and Pettis (1988). The combination of the accident data in **TIFA** with miles traveled from **NTTIS** provides estimates of fatal accident involvement **rates**.

The "relative risk" is used for this analysis to facilitate comparisons. Relative risk is calculated by dividing the raw rates (fatal accident involvements per hundred million vehicle miles) for every subset by the overall raw rate. The overall relative risk, then, is 1.0. Subsets with a relative risk less than 1.0 are under-involved in comparison to the

overall rate, and subsets with a relative risk greater than 1.0 are over-involved. The relative risk is also equal to the proportion of involvements for the subset divided by the proportion of travel for the subset. For example, if a subset has 10% of the involvements and 5% of the travel, the relative risk is  $10/5$ , or 2.0. The actual number of involvements, estimated travel, and raw rates for each category are shown in the tables in this report.

The rates are based on the five-year TIFA file (1980–1984) and the NTTIS file. Since the travel survey was mostly conducted in 1986, the time period for the exposure does not match the time period of the accidents, although the vehicle population in terms of distribution by model year is fairly comparable for the 1980–1984 TIFA and the NTTIS files. Obviously, it would have been more desirable to have travel data for the same period of time as the involvements, but the availability of funding and other problems preclude a better match at this time. It will be another year before the 1986 TIFA file is complete, and several years of accident data are needed to produce sufficient sample sizes. When considering possible conclusions based on the results of these analyses, the reader must remember the mismatch in time periods between the involvements and the travel. The author believes that the percent distributions across the factors presented are quite stable over time. Although the raw rates may vary, the relative risk should be more stable.

#### FINDINGS

The relative risk of fatal accident involvement for large trucks of all types is shown in Fig. 1 by driver age group. It should be noted here that nearly 98% of the drivers of large trucks involved in fatal accidents from 1980–1984 were male. Although the females were not actually excluded from the tabulations, the results essentially describe the experience of male drivers. Except for the first and last group, ages have been combined into two-year groups to provide sufficient sample sizes. The overall trend shown in this figure, and in particular the over-involvement of younger drivers, is very similar to the findings of Williams (1985) cited earlier. Drivers under the age of 19 are over-involved by a factor of 4, and drivers aged 19–20 are over-involved by a factor of 6. Drivers of large trucks continue to be over-involved through age 26. The only difference that one notices in comparing the trend in Fig. 1 with Williams's (1985) findings for drivers of passenger vehicles is that Fig. 1 shows the under-19 group to be somewhat lower than the 19–20 age group rather than continuing the upward trend expected. Even when combined into a three-year group, the sample sizes for drivers of large trucks under age 19 are very small. This group accounts for less than .2% of the travel and less than .8%

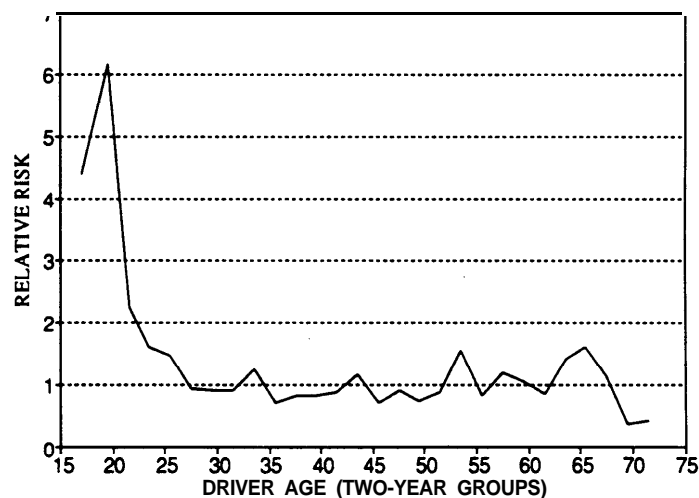


Fig. 1. Risk of fatal accident involvement by driver age.

Table 1. Fatal accident involvement rates by 28 truck driver age groups for all truck types—NTTIS and 1980–84 TIFA Files

Driver Age Group	10 <sup>6</sup> VMT	Column Percent	Involve ments	Column Percent	Raw Rate	Relative <sup>a</sup> Risk
Under 19	0.92	0.18%	187	0.78%	40.45	4.39
19-20	2.02	0.39	574	2.39	56.72	6.16
21-22	10.12	1.94	1049	4.37	20.72	2.25
23-24	19.11	3.66	1420	5.91	14.86	1.61
25-26	24.27	4.65	1632	6.79	13.45	1.46
27-28	40.14	7.69	1716	7.14	8.55	0.93
29-30	38.51	7.38	1585	6.60	8.23	0.89
31-32	25.44	7.15	1541	6.42	8.26	0.90
33-34	44.81	4.87	1466	6.10	11.53	1.25
35-36	-----	8.59	1438	5.99	6.42	0.70
37-38	34.05	6.52	1283	5.34	7.54	0.82
39-40	34.86	6.68	1280	5.33	7.34	0.80
41-42	28.93	5.54	1160	4.83	8.02	0.87
43-44	20.10	3.85	1059	4.41	10.54	1.14
45-46	30.11	5.77	992	4.13	6.59	0.72
47-48	21.30	4.08	888	3.70	8.34	0.91
49-50	25.02	4.79	844	3.51	6.75	0.73
51-52	20.16	3.86	810	3.37	8.04	0.87
53-54	11.27	2.16	805	3.35	14.28	1.55
55-56	17.39	3.33	649	2.70	7.46	0.81
57-58	9.13	1.75	496	2.07	10.86	1.18
59-60	8.57	1.64	415	1.73	9.68	1.05
61-62	7.12	1.37	278	1.16	7.80	0.85
63-64	2.78	0.53	179	0.75	12.89	1.40
65-66	1.22	0.23	90	0.37	14.78	1.61
67-68	1.42	0.27	74	0.31	10.39	1.13
69-70	2.77	0.53	48	0.20	3.47	0.38
Over 70	3.00	0.58	60	0.25	4.00	0.43
<b>Total</b>	<b>521.91</b>	<b>100.00%</b>	<b>24018</b>	<b>100.00%</b>	<b>9.20</b>	<b>1.00</b>

<sup>a</sup>Relative Risk = (% of Involvements)/(% of Travel)

of the fatal accidents, as shown in Table 1. Drivers aged 19–20 accounted for only .4% of the travel and 2.4% of the fatal accidents. With these small sample sizes, such differences are not likely to be statistically significant. These statistics underscore the pervasiveness of the current minimum driving age.

Having prepared Fig. 1 showing the overall relationship of driver age to fatal accident involvement rates for large trucks of all types, the next objective was to examine the extent to which other factors were associated with driver age in general and the younger drivers in particular. A previous analysis of large truck fatal accident rates (Campbell et al. 1988a) has shown substantial differences in the probability of involvement associated with factors such as time of day (day as 6:00 A.M. to 9:00 P.M. and night as 9:00 P.M. to 6:00 A.M.), truck type (single-unit versus combination), and road type (limited-access versus nonlimited). For example, on rural limited-access roads, the probability of fatal accident involvement is three times higher at night than in the day. For rural daytime travel, the probability of fatal accident involvement is five times higher on nonlimited-access roads as compared to limited-access. If factors such as these are associated with the driving experience of younger drivers, they might contribute to, or be partially responsible for, the apparent over-involvement of the younger drivers. These factors were examined separately and in combination by partitioning the data according to the levels of the factor, or combination of factors, and then calculating fatal accident involvement rates in each age group. Comparison among the age groups can be made within each level and combination of levels of the factors defining the subgroup. The overall rate for the subgroup is indicative of the risk associated with the subgroup itself.

The relative risk of nighttime versus daytime operation is shown by driver age group in Fig. 2. For this analysis, the age groups were expanded to five years to maintain sample size except for the first two groups, under 25, and the last group. Figure 2 and

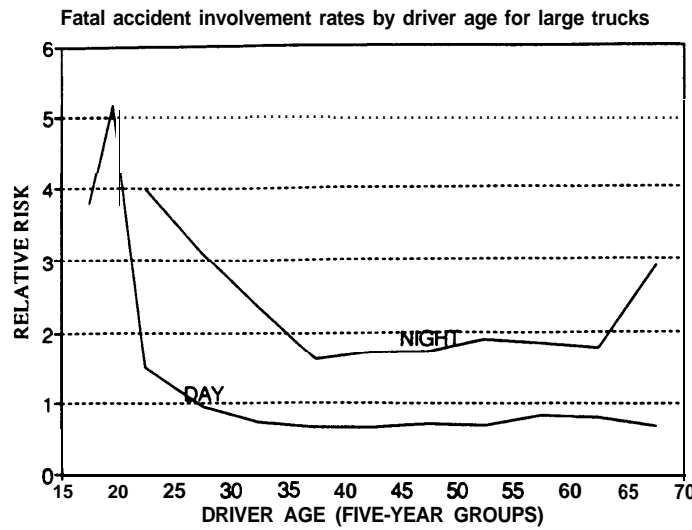


Fig. 2. Daytime vs. nighttime risk of fatal accident involvement by driver age.

Table 2 illustrate that overall, the fatal accident rate is more than double at night as compared with daytime. The over-involvement of the younger drivers is comparable in both the daytime and the nighttime. As an aside, it is interesting that the older drivers are not further over-involved at night. One might have expected the generally poorer nighttime visual acuity of older drivers to be reflected in these accident rates. Mortimer and Fell (1988) found males over 65 to be over-involved in fatal accidents at night as drivers of passenger vehicles, but under-involved as drivers of large trucks. Apparently,

Table 2. Fatal accident involvement rates by 12 driver age groups for day vs. night—NTTIS and 1980–84 TIFA Files

Driver Age Group	10 <sup>8</sup> VMT	Column Percent	Involvements	Column Percent	Raw Rate	Relative Risk
<b>DAY (6AM-9PM)</b>						
Under 19	0.86	0.18%	157	0.66%	36.39	3.78
19-20	1.87	0.38	465	1.96	49.71	5.16
21-24	25.07	5.10	1641	7.77	14.69	1.52
25-29	63.06	12.82	2920	12.32	9.26	0.96
30-34	74.19	15.08	2594	10.95	6.99	0.73
35-39	70.81	14.39	2235	9.43	6.31	0.66
40-44	58.64	11.92	1871	7.89	6.38	0.66
45-49	45.53	9.25	1561	6.59	6.86	0.71
50-54	40.37	8.21	1344	5.67	6.66	0.69
55-59	23.66	4.81	933	3.94	7.89	0.82
60-64	11.92	2.42	458	1.93	7.69	0.80
Over 64	6.66	1.35	221	0.93	6.64	0.69
<b>SUBTOTAL</b>	<b>422.64</b>	<b>85.91</b>	<b>16600</b>	<b>70.05</b>	<b>7.86</b>	<b>0.82</b>
<b>NIGHT (9PM-6AM)</b>						
Under 19	0.00	0.00%	29	0.12%	—	—
19-20	0.00	0.00	96	0.41	—	4.00
21-24	8.02	0.68	1593	8.06	38.55	3.09
25-29	21.24	1.78	4183	20.36	24.39	1.93
30-34	9.98	2.03	1135	4.79	22.74	2.36
35-39	13.74	2.79	1075	4.54	15.65	1.62
40-44	11.54	2.35	961	4.06	16.66	1.73
45-49	8.54	1.74	714	3.01	16.71	1.73
50-54	7.28	1.48	664	2.80	18.24	1.89
55-59	4.73	0.96	421	1.78	17.80	1.85
60-64	2.09	0.33	178	0.75	28.13	2.92
Over 64	2.09	0.33	178	0.75	17.01	1.77
<b>SUBTOTAL</b>	<b>69.30</b>	<b>14.09</b>	<b>7099</b>	<b>29.95</b>	<b>20.49</b>	<b>2.13</b>
<b>GRAND TOTAL</b>	<b>491.94</b>	<b>100.00%</b>	<b>23699</b>	<b>100.00%</b>	<b>9.63</b>	<b>1.00</b>

<sup>a</sup>Relative Risk = (% of Involvements)/(% of Travel)

among older truck drivers, other factors compensate for decreased nighttime visual acuity and other age-related factors.

The next factor examined individually was the type of truck. The relative risk of fatal accident involvement is shown by driver age group separately for single-unit trucks and combinations in Fig. 3. Single-unit trucks are those without trailers. Tractors without trailers (bobtails) are included in this group. Combination trucks are those with trailers, and this group includes both tractors and straight trucks pulling one or more trailers. Twelve driver age groups are used in this figure. Drivers under 21 are over-involved by about a factor of 6 when driving either single-unit or combination trucks. About 60% of the travel by drivers under 21 was in a single-unit truck, and only 40% was in combination trucks. Overall, combination trucks accounted for almost 70% of the large-truck travel.

The over-involvement of an age group relative to a subgroup can be obtained by dividing by the relative risk for the subgroup. From Table 3, it can be seen that single-unit truck drivers aged 19-20 have a relative risk of 4.82 (relative to the rate for all large trucks shown as 1.00 at the bottom of Table 3). Single-unit trucks as a group have a relative risk of 0.80, so that the risk for drivers aged 19-20 of single-unit trucks relative to that for all single-unit trucks is  $4.82/0.80$ , or 6.03. The risk for drivers aged 19-20 of combination trucks relative to the rate for all drivers of combination trucks is  $9.00/1.09$ , or 8.99. Thus, the over-involvement of younger drivers of both single-unit and combination trucks, 6.03 and 8.99, is quite similar when compared to the overall rate for the respective vehicle type.

Other factors were also examined. Eight travel categories were formed from all possible combinations of three two-level travel factors. They are road type (limited-access vs. non-limited-access), area type (rural versus urban), and time of day recoded into "day" (6:00 A.M.-9:00 P.M.) and "night" (9:00 P.M.-6:00 A.M.). An examination of the distribution of travel for younger drivers across the eight travel categories revealed that they traveled somewhat more on non-limited-access roads during the day, but somewhat less on limited-access roads at night. Adjusted rates were calculated to remove these differences from the comparison of younger drivers to all drivers. However, the adjusted rates are not appreciably different from the original rates. For drivers under 25, the adjusted rate was 2.17 as compared with the unadjusted rate of 2.15. This calculation indicates that differences in the type of travel of younger drivers is not responsible for their over-involvement in the aggregate data. Relative risks were also compared for each of the eight travel categories. The younger drivers were over-involved in each driving environment.

Another factor examined was the split between interstate carriers and intrastate carriers. For this tabulation, the eight travel categories have been reduced to four by

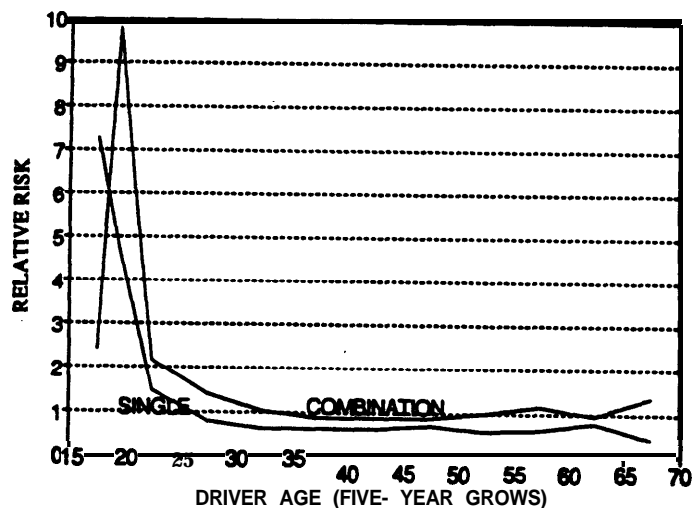


Fig. 3. Single-unit vs. combination truck risk of fatal accident involvement by driver age.

Table 3. Fatal accident involvement rates by 12 driver age groups for single-unit and combination trucks—NTTIS and 1980-M TIFA Files

Driver Age Group	10 <sup>8</sup> Column VMT Percent	Involve Column Percent	Raw Rate	Relative Risk <sup>a</sup>
<b>SINGLE-UNIT</b>				
Under 19	0.36	0.07%	120	0.51%
19-20	1.3s	0.27	306	1.29
21-24	13.99	2.69	944	3.9s
25-2s	28.63	5.51	1066	4.51
30-34	29.85	5.74	856	3.62
35-3s	22.72	4.37	683	2.89
40-44	18.26	3.51	524	2.21
45-49	13.99	2.69	473	2.00
50-54	14.89	2.86	408	1.72
55-5s	9.55	1.84	293	1.24
60-64	4.79	0.92	174	0.74
Over 64	6.30	1.21	133	0.56
<b>SUBTOTAL</b>	<b>164.72</b>	<b>31.68</b>	<b>5980</b>	<b>25.28</b>
<b>COMBINATIONS</b>				
Under 19	0.56	0.11%	62	0.26%
19-20	0.57	0.11	255	1.08
21-24	14.85	2.86	1482	6.26
25-29	47.24	9.09	3023	12.78
30-34	59.55	11.45	2871	12.13
35-39	65.11	12.52	2633	11.13
40-44	56.41	10.85	2293	9.69
45-49	43.34	8.34	1800	7.61
50-54	34.75	6.68	1606	6.79
55-5s	20.39	3.92	1061	4.48
60-64	10.28	1.98	460	1.94
Over 64	2.11	0.41	133	0.56
<b>SUBTOTAL</b>	<b>355.16</b>	<b>68.32</b>	<b>17679</b>	<b>74.72</b>
<b>GRAND TOTAL</b>	<b>519.87</b>	<b>100.00%</b>	<b>23659</b>	<b>100.00%</b>

<sup>a</sup>Relative Risk = (% of Involvements)/(% of Travel)

omitting the rural/urban split. In order to maintain sample sizes, ages were combined into five groups: under 25, 25-34, 35-44, 45-54, and over 54. These, in turn, are shown for four subsets: single-unit trucks in interstate operation, single-units in intrastate operation, combination trucks in interstate operation, and combinations in intrastate operation. The inter- vs. intrastate distinction is made at the level of the carrier, or owner. If any of the carrier's trucks operate interstate, then all of the travel of the trucks operated by that carrier is designated as interstate. Conversely, all of the trucks operated by an intrastate carrier operate within a single state.

Combination trucks in interstate operation are the largest of the four major divisions and account for almost 60% of all large truck travel. Combinations in intrastate operation account for about 12% of the large truck travel, a group comparable in travel to each of the single-unit groups. The results for the under-25 age group can be summarized for the four major divisions by aggregating the rates for this age group across the four travel categories in each truck type/operation and calculating the relative risk with respect to the overall rate for the truck type/operation, as described previously. When summarized in this way, the over-involvement of the under-25 group by truck type/operation is as follows:

- Single-unit/interstate 2.06
- Single-unit/intrastate 2.45
- Combination/interstate 2.33
- Combination/intrastate 1.75

Overall, these results do not vary appreciably from the 2.15 rate for the aggregate. The overall trend of over-involvement pervades every type of vehicle and operation examined.

Information on the driver is **carried** over from the NHTSA FARS files to the TIFA file. Tabulations of these variables were prepared comparing the drivers under 21 with truck drivers of all ages. For the years 1980-1984, there were a total of 24,119 drivers of large trucks involved in fatal accidents that were included in the tabulations. Of these, 747 (3.1%) were under 21. Twice as many of the drivers under 21 had an invalid license as compared with all drivers. That is, 12.4% of the **drivers** under 21 did not have a valid license at the time of the accident as compared to 5.3% of all truck drivers involved in fatal accidents. About 25% of the drivers under 21 were charged with a violation in connection with the accident as compared with only 15% for truck **drivers** of all ages in fatal accidents. The types of violations the younger **drivers** were more frequently charged with included speeding, other moving violations, and violations of unknown type. However, only 2.4% of the drivers under 21 were identified as "had been drinking" as compared to 3.3% of all **truck drivers**. Perhaps the most suggestive variable available is the one identifying driver-related factors. Overall, no driver related factor is **coded** for 60% of the truck drivers, whereas no factor is **coded** for 45% of the drivers under 21. Most of the factors coded are grouped as "miscellaneous causes." These include following improperly, failure to keep in lane (and ran off road), reckless operation, driving too fast, and many others. One of these miscellaneous causes was coded for 45% of the drivers under 21 as compared with 31% for all drivers. The available accident **data** do not identify the underlying causes of the over-involvement of younger drivers. However, the factors that are associated with the younger drivers **suggest** a lack of maturity and judgment.

#### DISCUSSION

The most significant finding is the pervasive nature of the over-involvement of young drivers. Williams (1985) described the effectiveness of curfews in limiting nighttime driving among teens in passenger vehicles. Nighttime is associated with a higher risk of fatal accident involvement for drivers of all ages and for all types of vehicles. Limiting nighttime driving may be an appropriate countermeasure for teenage drivers of passenger vehicles, since driving after dark may be less essential and it carries the greatest risk. Although curfews are effective in that they reduce the exposure in the high risk periods, they **do** not in any way modify the general over-involvement of this group when they **do** drive. If one is considering lowering the minimum driving age for commercial vehicles, then the significant finding of this analysis is that the younger drivers are over-involved in virtually all of the conditions examined in this study. They are over-involved in the day just as much as at night, on all types of roads, and in both rural and urban areas. Furthermore, younger drivers are over-involved as drivers of commercial vehicles to about the same degree as when they are drivers of passenger vehicles. The fact that they are employed to drive commercial vehicles apparently **does** not alter the essential pattern of over-involvement that is shown when they drive passenger vehicles.

Adjustment of the rates by age category for road type, day/night, and rural/urban area did not appreciably alter the pattern of over-involvement. Since this trend was not found to be a consequence of travel factors known to have rather large effects individually, and since the trend was exhibited in every subset examined, the author concludes that it is appropriate to regard the rates by age group in the aggregate **data** as primarily associated with age and not the other factors examined here. **The advantage** of aggregating the **data** for all large **trucks** is that sample sizes are increased for the younger age groups of interest here.

The fatal accident involvement rates calculated from the UMTRI survey data for large truck drivers aged 19-20 are about double the rates presented by Williams for male drivers of the same age. This result is consistent with the statistics reported by **Eicher** et al. (1982) indicating that the probability of fatality in accidents involving a large truck is **about double** that of accidents not involving a large truck. The results of this analysis, then, indicate a risk of fatal accident involvement for young **drivers** of large trucks that is consistent with their pattern of over-involvement as drivers of passenger vehicles.

In closing, it should be pointed out that although these findings substantiate a high risk for young drivers of large trucks, they do not identify the fundamental causes of this risk. It would seem that the driving situation for young drivers of trucks would be much different than for young drivers of passenger vehicles. The nighttime driving with peers and associated alcohol consumption that characterizes teenage passenger car use is much less likely to be a part of their truck driving. However, truck driving is a more demanding task. Training and experience may be more important. Unfortunately, years of experience is not coded in the accident files used for this analysis. Although this analysis does not shed any light on the fundamental causes of the over-involvement of younger drivers, it does illuminate the likely consequences if the minimum age for commercial drivers is lowered without addressing this fundamental problem.

#### REFERENCES

- Blower, D. F.; Pettis, L. C. National truck trip information survey (nttis). Report No. UMTRI-88-11. Ann Arbor, MI: The University of Michigan Transportation Research Institute; 1988.
- Campbell, K. L.; Blower, D. F.; Gattis, R. G.; Wolfe, A. C. Analysis of accident rates of heavy-duty vehicles. Report No. UMTRI-88-17. Ann Arbor, MI: The University of Michigan Transportation Research Institute; 1988a.
- Campbell, K. L.; Wolfe, A. C. Fatal accident involvement rates by driver age for large trucks. Report No. UMTRI-88-43. Ann Arbor, MI: Transportation Research Institute, The University of Michigan; 1988b.
- Carsten, O. M. C.; Pettis, L. C. Trucks involved in fatal accidents, 1980-84, by power unit type. Report No. UMTRI-87-38. Ann Arbor, MI: The University of Michigan Transportation Research Institute; 1987.
- Eicher, J. P.; Robertson, H. D.; Toth, G. R. A report to Congress on large-truck accident causation. DOT/HS-806-300. Springfield, VA: National Technical Information Service; 1982.
- Mortimer, G. R.; Fell, J. C. Older drivers: Their night fatal crash involvement. 32nd annual proceedings of the Association for the Advancement of Automotive Medicine. Des Plaines, IL: AAAM. 1988: 327-342.
- Williams, A. F. Nighttime driving and fatal crash involvement of teenagers. *Accid. Anal. Prev.* 17:1-5; 1985.

## 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 tragic 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.<sup>1,2</sup> They are involved in about 6 per cent of all police-reported crashes but account for 12 per cent of all fatal crashes.<sup>3</sup> 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.<sup>4</sup> 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.<sup>5</sup> However, when car and truck crashes are compared on similar roads, trucks have higher crash rates.<sup>5</sup> In recent years, both the number of crashes and the percentage of fatal crashes involving large trucks have been increasing.<sup>6,7</sup>

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.<sup>1,3</sup> 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.\*

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.<sup>9</sup> The most reliable studies with more comparable exposure measures concluded that doubles had higher crash involvement rates than tractor-trailers.<sup>8,10,11</sup>

The potential problems in operating doubles are well documented in studies reporting significant handling problems related to the inherent instability of a second trailer.<sup>12,13</sup>

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.<sup>14</sup> Poor handling and stability were also reported in several driving studies and surveys of drivers,<sup>15,17</sup> 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.<sup>8</sup> 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.<sup>8</sup> 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.

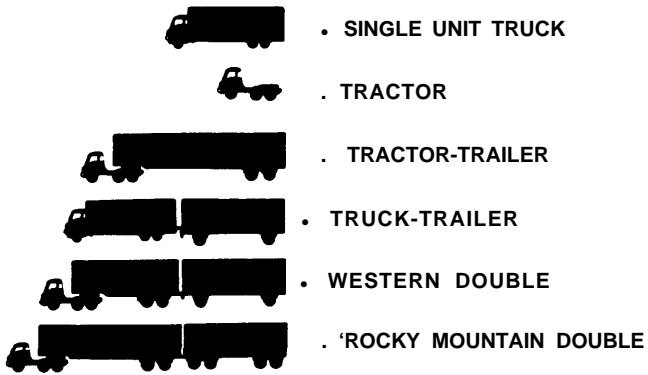


FIGURE 1—Truck Configurations. NOTE: Western doubles were defined as a tractor with two trailer units with the first trailer 35 feet or less in length; nearly all had two 28 foot trailers. Rocky Mountain doubles were tractors hauling two trailers with the first trailer greater than 35 feet in length; 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.<sup>19</sup>

#### 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 or 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. Be-

cause 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.<sup>20</sup> The statistical analyses were performed using the CATMOD procedure of the SAS Institute.<sup>21</sup> 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.<sup>22</sup> 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

Crash Type	Per Cent Distribution of Truck Configurations						Total Number of Trucks
	Single Unit	Tractor Only	Tractor-Trailer	Truck-Trailer	Western Double	Rocky Mountain Double	
All crashes							
Crash Involved	8	4	59	9	18	3	604
Comparison Sample	23	5	59	5	6	1	1,612
Single Vehicle							
Crash Involved	9	3	52	9	25	3	222
comparison sample	21	5	62	4	6	1	666
All Multiple Vehicle							
Crash Involved	6	4	62	9	14	2	362
Comparison Sample	25	5	57	6	5	1	1,146
Rear End**							
Crash Involved	9	6	64	7	13	1	104
Comparison sample	24	6	51	6	7	1	312
Sideswipe**							
Crash Involved	7	4	67	6	14	1	106
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.<sup>23</sup>

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

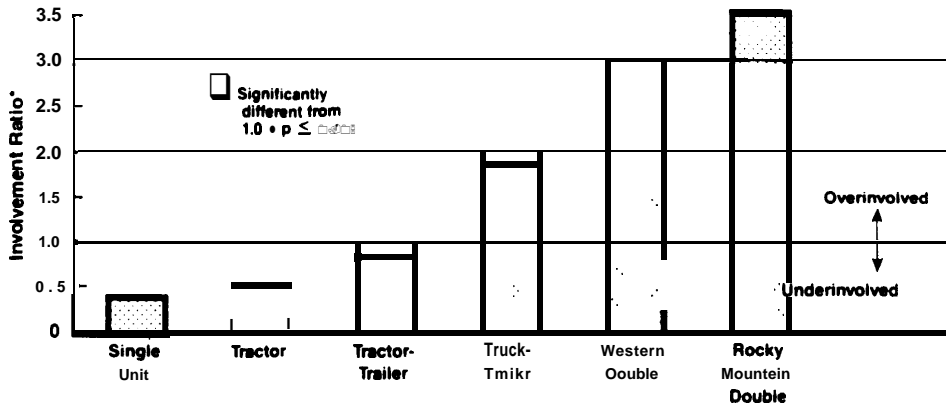
These various factors were analyzed in conjunction with truck configuration and the results are presented in Figures 4-7. Although many other factors **affected** crash involvement, truck configuration was the dominant effect and the other factors, in general, had less effect. Note that although all 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 more 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

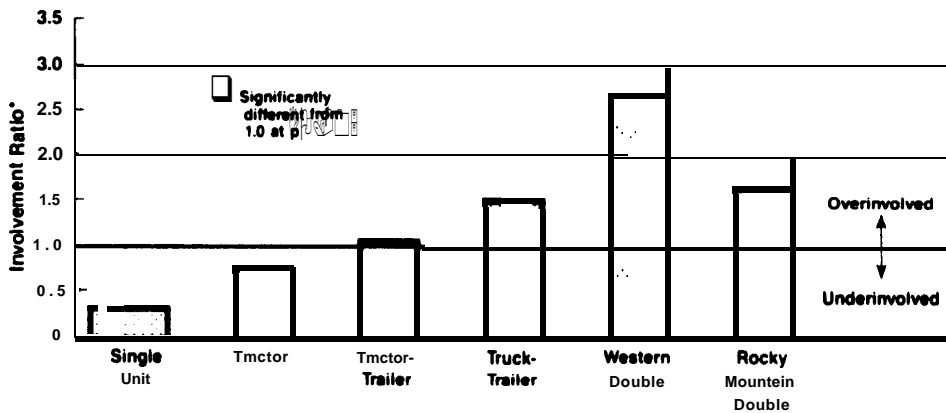
**TABLE 1—Truck Configuration Crash Involvement Ratios by Time of Day, Highway, and Roadway Alignment**

Factor	Single Vehicle Crashes			Multiple Vehicle Crashes		
	Single Units	Tractor-Trailer	Doubles	Single Units	Tractor-Trailer	Doubles
<b>Time of Day</b>						
Day	0.6	0.6	4.9	0.4	1.1	2.9
Night	0.2	0.9	2.5	0.2	1.0	2.0
<b>Roadway Alignment</b>						
Straight/level	0.3	1.0	2.6	0.3	1.2	2.4
Curve/Grade	0.6	0.8	3.3	0.4	1.0	2.9
<b>Interstate Route</b>						
5	0.5	0.9	2.5	0.4	1.1	2.6
90	0.2	0.7	3.6	0.4	0.9	2.5

doubles were overinvolved in crashes relative to tractor-trailers, regardless of route.

**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**

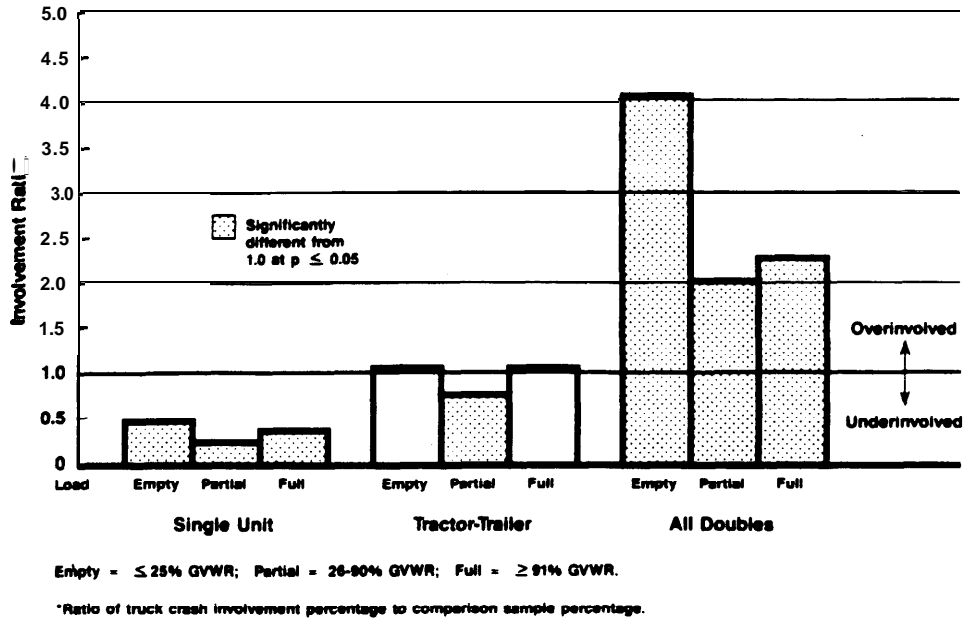


FIGURE 4—Involvement of Trucks in Crashes by Truck Configuration and Load

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

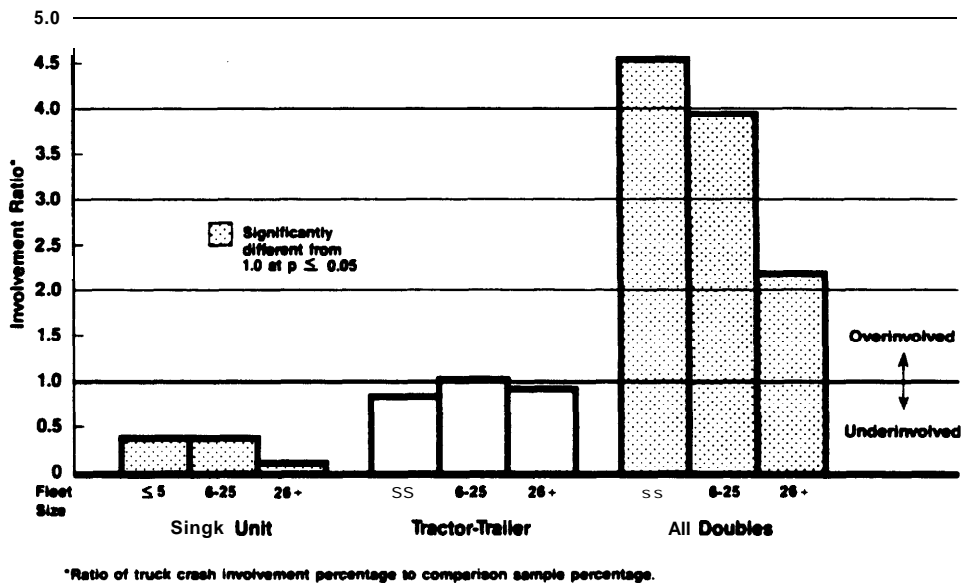
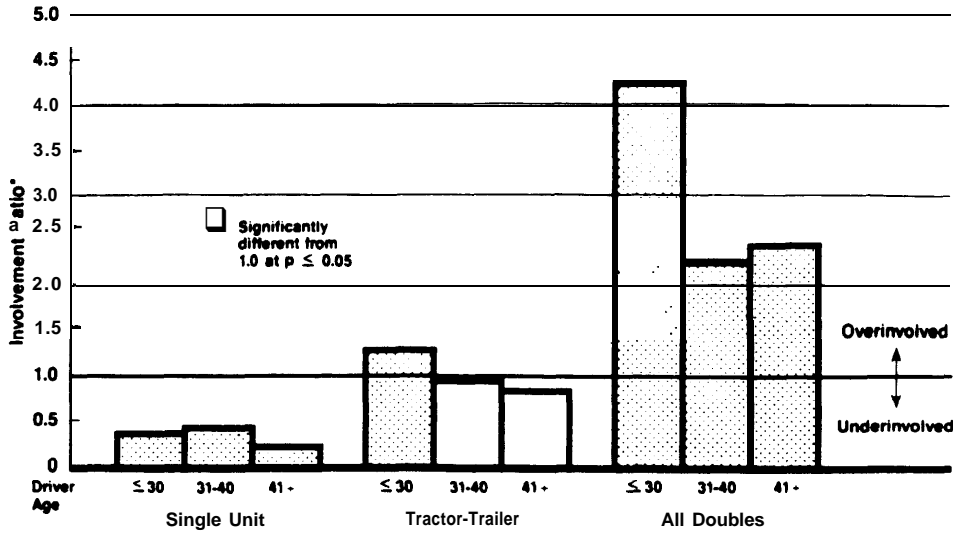


FIGURE 5—Involvement of Trucks in Crashes by Truck Configuration and Fleet Size



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

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

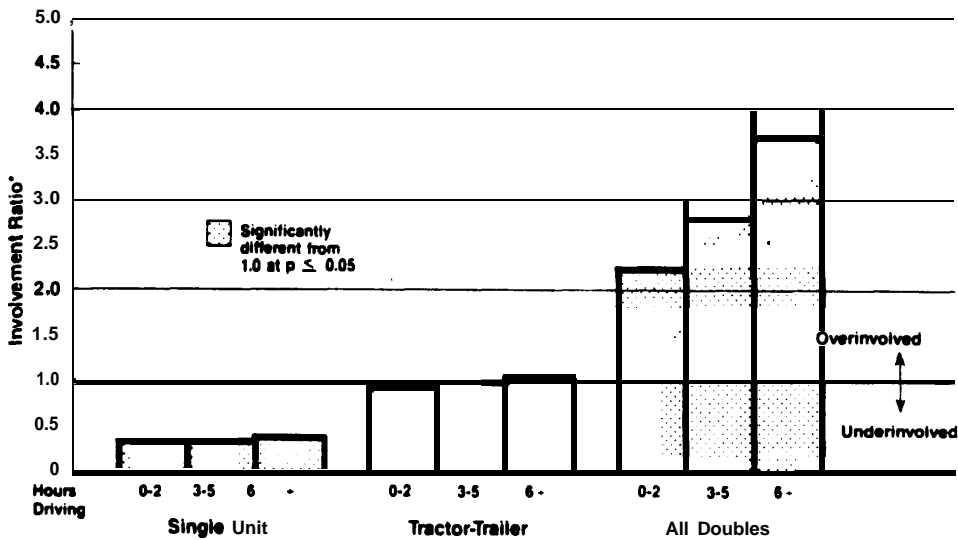
the tractor-trailer combination with one trailer. The proportion of rollover in single vehicle crashes was the same for doubles and tractor-trailers (about 45 per cent), but it was higher for truck-trailers and single unit trucks. The risk of injury was higher when rollover occurred: 49 per cent of single 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.<sup>12,13,15</sup> 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 (Tractor-Trailers)**	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 (Full)	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, 1.63)	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, 2.64)	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 (Common)	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\*\* had a lower involvement than truck-trailers but were more involved in crashes than

\*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, 7.63)	2.45	(1.64, 3.67)
Others (Tractor-Trailers)**	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 (Full)	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, 1.66)	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.

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.<sup>8,16,24</sup> Doubles were particularly overinvolved on curves.

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.<sup>25</sup>

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.<sup>8</sup> 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.<sup>26</sup> 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**

Truck Configuration	Percentage of Single Vehicle crashes Involving			Number of Trucks**	Percentage of Multiple Vehicle Crashes Involving			Number of Trucks**
	Roll-over	Jack-knife	Separation of units		Roll-over	Jack-knife	Separation of units	
Single Und	73			22	12	18		41
Tractor-trailer	43	51	0	129	5	37	2	308
All Doubles	48	75	39	89	11		12	73
Truck-Trailer	81	87	29	21	15	24	11	48

\*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**

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).  
 Insurance Institute for Highway Safety, A. Fleming (ed): *Big Trucks*. Washington, DC: IIHS, 1986.  
 Eichler JP, Robertson HD, and Toth GR: Large Truck Accident Causation. Washington, DC: National Highway Traffic Safety Administration (DOT HS-806300), July 1982.  
 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.  
 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.  
 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, 19%.  
 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. *Ingenieur Archiv* XXX1 1 1-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. Mikulcic EC: Hitch and Stability Problems in Vehicle Trucks. Alberta, Canada: Department of Mechanical Engineering, University of Calgary, May 1973.  
 17. Wilson LJ, Homer 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, Stamer 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, 19%.  
 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 19%; 17:1-12.

# A CASE CONTROL STUDY OF HEAVY VEHICLE DRIVERS' WORKING TIME AND SAFETY

**WJ. Frith**

Land Transport Safety Authority. New Zealand

This material may be protected by  
copyright law (Title 17 U.S. Code).

## SUMMARY

Throughout the world there is concern regarding the effect on crash risk of the long periods behind the wheel, often combined with potentially disruptive rest patterns, which are common in the lives of drivers of long distance heavy vehicles. In New Zealand heavy vehicle drivers carry log-books in which details of their driving hours must be recorded. It was decided to use this information to carry out a study on the risk of crash with respect to driving hours and other time intervals related to the drivers' working lives. In the study a 'case' group of heavy vehicles involved in crashes (for which details of drivers' hours were known from their log-books) was compared with a 'control\*' group of vehicles. The control group was selected by Police going to the scenes of crashes on an anniversary of the crash, at the same time of day as the crash and stopping a heavy vehicle. Where possible a vehicle was selected which was travelling in the same direction as the crash vehicle and which was of a similar configuration. This was to provide a group as close as possible to the crash group in terms of immediate exposure to risk and vehicle configuration. The driving hours details of the vehicle's driver were then taken along with some other vehicle and driver details. The crash group and control group were then compared. Evidence was found of an increased risk of crash in those cases where driving hours since the driver's last compulsory 10 hour **off-duty** period (as recorded in the log book) exceeded about eight. There were no other significant differences between the two groups with respect to other time intervals related to driving habits. This is in line with literature findings that driving time since the last long rest period is the most important variable. There was a significant difference between the age distribution of the crash and control drivers with the crash drivers generally younger. The major policy implication is that even with the relatively short distances driven in New Zealand, length of time behind the wheel is having an effect on the crash rate of trucks **and** enforcement of driving hours restrictions has merit as a road safety measure.

Gold Coast, Queensland, 15-19 August 1994; Australian Road Research Board Ltd (ARRB),  
500 Burwood Highway, Vermont South, Victoria, 3133, Australia



Bill Frith graduated **M.Sc.(Hons)** in Mathematics at Auckland University in 1969. After periods as a teacher and a statistician he joined the Ministry of Transport as an Assistant Traffic Engineer in 1973. In 1975 he graduated **M.Sc.** in Transport Engineering at Newcastle Upon Tyne. After experience in regional offices as a Traffic Engineer, Bill became Senior Traffic Engineer (Research) in the Ministry's Head Office in 1979 and gained a B.A. in Mathematical Statistics from Victoria University in 1980. In 1981 he became leader of the Engineering and Environmental group in the Ministry's Traffic Research Branch and in 1987 took over the leadership of that branch. He is now Manager, Traffic Research and Statistics in the New Zealand Land Transport Safety Authority and has written widely in the area of road safety.

## INTRODUCTION

1. The threatening presence of heavy vehicles on the road is a cause for concern world-wide. In New Zealand the long distance freight industry was deregulated in 1983. This resulted in an increase in the amount of **freight** carried by **road against a background** of increased competition. Concern has been expressed in the industry and community that safety standards should not be compromised by long distance drivers **becoming** excessively fatigued through inadequate rest periods or excessively irregular **working** hours. Equally there is concern that driving hours should not be *excessively* **regulated** so that industry productivity or the life-styles of drivers are adversely affected without commensurate safety benefits. Industry representatives generally desire flexibility within a framework of limits based on safety criteria. These concerns have provoked this study which investigates whether and to what extent drivers' hours behind the wheel are linked to crashes in the New Zealand situation.

### THE INTERNATIONAL LITERATURE

2. There is only a very imperfect relationship between number of hours driven and the risk of crash involvement. Road safety depends on three major elements: the driver, the road and adjacent environment, and the vehicle.

3. Major factors affecting the safety of the professional driver are:

- experience (of both the driving task and of "fatigue" situations),
- mental attitude,
- physical aptitude and strength,
- driving schedule vis-a-vis circadian rhythms.

Many studies have indicated increased crash risk or evidence of fatigue symptoms after a certain time driving heavy motor vehicles.

4. Harris and Mackie (1972) studied the driving and crash records of an American interstate freight company. They found an increase in risk beginning after about 5 hours driving and asymptoting very steeply by the 10 hour mark. The study also concluded that single vehicle heavy truck crashes were almost 2.5 times more frequent between the hours of midnight and **8am** than would have been expected on the basis of driver exposure.

5. Fuller (1984) studied professional drivers of heavy trucks in Ireland, over four consecutive days, each day including one eleven hour driving shift. The measure of driving performance used was time headway between vehicles. The results showed that the only measured variable affecting time headway and its variability was the number of hours driven. Overall though, there was no measurable evidence of driver impairment as a function of prolonged driving hours. Risk taking did increase as the driving shift continued, although only a small proportion of time **headways** could be described as '**risky**' by the observers.

6. Linklater (1980), after conducting interview surveys of New South Wales heavy truck drivers, concluded that truck drivers were more likely to be involved in a crash if they spent more than 55 hours per week driving. An American study (Mackie and Miller 1978) reported that fatigue effects become evident after 8 hours on regular **shifts**, and earlier if shifts are irregular.

7. The American National Transportation Safety Board (1990) published a report **analysing** human factors involved in heavy truck crashes, using on-site crash **investigation** techniques. Of 186 fatal-to-the-driver heavy truck crashes, fatigue was

cited as a probable cause in 5 / (51%).

8. Jones and Stein (1987), using a method broadly similar to this study, studied the crash involvement of tractor-trailers on the interstate system in Washington State by configuration and some other variables. They found that drivers who drove more than 8 hours on end were at increased crash risk.

9. Lin, Jovanis and Yang (1993) **modelled** the effect of American heavy freight driver service hours on crash risk using time dependent logistic regression. They found that driving time had the strongest effect on crash risk. While the first four hours were indistinguishable, there was then a 50% increase up to 7 hours. The 8th and 9th hours then showed further increases to 80% and 130% respectively, above the 4 hour level. They also found a generally elevated collision risk at night.

10. Many researchers state that the role of fatigue is often under-estimated. Drivers tend to down-play the role of fatigue in any crash for fear of incrimination. To partially circumvent the driver response problem, one of the more recent fatigue involvement studies (Haworth, Heffeman and Home, 1989), used Coroners' records. This yielded estimates of the involvement of fatigue in Victorian heavy motor vehicle crashes of between 9.1% (based on the Coroners' judgements) and 19.9% (based on the authors' judgements of the evidence available in the reports).

## THIS STUDY

### INTRODUCTION

11. Heavy motor vehicle crashes in New Zealand are recorded in the Land Transport Safety Authority's Traffic Accident Report (TAR) database. This covers all reported motor vehicle crashes involving injury and can be manipulated to obtain very detailed crash information such as cause factors, weather, road and vehicle conditions. There is also a data-base of crashes held in the Authority from which the crash data for this study were taken. This contains TAR and logbook information on a set of heavy motor vehicle crashes considered serious enough by Police to be reported to members of the Police Commercial Vehicle Investigation Unit (CVIU). The CVIU is a 40 strong **nation-wide** unit which **specialises** in the enforcement of laws relating to commercial vehicle operation. Approximately 650 heavy motor vehicle crashes dating back to 1987 are present in this database. This paper describes an attempt to mount a case control study of the risk of driving heavy motor vehicles with respect to various work related variables. The project was carried out jointly by the then Land Transport Division of the Ministry of Transport (now the Land Transport Safety Authority) and the CVIU.

### THE CASE CONTROL METHOD

12. This method, used very widely by epidemiologists, compares a "case" group (in this instance the sample of crash involved vehicles and drivers) with a "control" group operating under similar conditions. It has been used in the road safety area before, notably the landmark Grand Rapids study of the risk involved in driving with alcohol in the blood stream. (Borkenstein, Crowther, **Schmate**, Ziel and **Zylman**, 1964). The method was also used by Stein and Jones (1988) to study the crash involvement of large trucks on the interstate system in Washington State, by configuration and some other **variables including drivers' hours**.

## RELEVANT FACTS REGARDING HEAVY MOTOR VEHICLE OPERATION IN NEW ZEALAND

13. In New Zealand a heavy motor vehicle is defined as one of over 3500 kg **gross** laden mass. In New Zealand 10 hours continuous rest is required in each 24 hour period. A maximum of 11 hours daily driving is allowed, with a maximum working day of 14 hours. A break of 30 minutes is required after 5.5 hours continuous driving. The maximum working week is 70 hours, with maximum weekly driving of 66 hours.

### THE SURVEY METHOD

14. The objective of this survey method was to achieve as closely as possible a case sample of crash-involved heavy motor vehicles and a control sample matched for location, time of year, time of day, day of week and configuration of the vehicle. It was impractical to match for other variables such as weather, speed and **behaviour** of other motorists. To carry out the study, **officers** of the **CVIU** visited sites of crashes as close as possible to an exact anniversary of the crash (adjusted so that the day of the week was the same). The sites visited were, as it happened, evenly split between urban and rural areas. They then examined log-book details of the first heavy vehicle of a similar configuration to the crash involved vehicle which came along in the same direction. If, **after** an hour of waiting, no suitable vehicle came they were instructed to take a vehicle of a different configuration. Matching by configuration was possible in 143 out of 199 **useable** pairs. Similarly, they could take a vehicle going in the opposite direction if none were available in the right direction. In 150 cases out of the 182 cases where the survey vehicle's direction was reported by the Police, the survey vehicle was **travelling** in the same direction as the accident vehicle. This selection process was to ensure that the vehicle sampled was as close as possible in exposure to risk of crash to the crash involved vehicle. The crash dates ranged from 1988 through to 1990 so the anniversaries used ranged from the fourth down to the second. Details of driving and working hours from the log-book and discussions with the driver were then recorded, along with some information about the driver and the vehicle. In no case did the discussion result **in** driving hours different **from** those in the logbook being recorded. Thus henceforth these observations can be considered log-book observations.

### STUDY PERIOD

15. The study was carried out over the period June 1992 to July 1993.

### REFUSAL RATES

16. There were no **refusals**. The Police have the power to require the furnishing of such information. Any stopping instances in which data was not available were due the exemptions **from** the **carrying of** log-books. Any bias due to this would also have been present in the crash sample.

### THE TIME LAG BETWEEN CRASH AND CONTROL SURVEY

17. This varied between two years and four years tending towards the shorter time lags. It is not considered that the time lag involved is such that any significant change in driving habits or the driving environment would have happened which could invalidate the results of the study. Given present economic pressures, any move to shorter times behind the wheel in the interim period is unlikely. Thus, any possible biases in the driving hours of the control group vis-a-vis the crash group are likely to **affect** the results in a conservative direction.

## ACCURACY OF LOG-BOOK ENTRIES

18. As in other countries where such systems operate, the drivers' log-book system in New Zealand is open to falsification. There are no scientific data available on the extent of such falsification in New Zealand. Such falsification would naturally result in changes **from** illegal working period durations to legal working period durations. In this study there were very few observations in which hours restrictions were violated. This suggests that falsification may have occurred. The probable effect of this in the data would be to shift, in both groups, some data which should rightly appear in illegal cells, into marginally legal cells. This effect may be greater in the crash sample than the control sample. Its effect on the major result is discussed in paragraph 30 .

## STATISTICAL TESTING

19. The symbol **Z** is used to denote the standard normal variate and a value of  $p < 0.05$  denotes a statistically significant difference.

## RESULTS

### CONFIGURATION OF VEHICLES

20. The Police were requested as far as possible to match the crash vehicles and the control vehicles by configuration. However this was not always possible. The configurations of the two samples are shown in figure 1.

### AGE DISTRIBUTIONS OF DRIVERS

21. Age distributions of drivers are shown in figure 2. Using the sign test, (Siegel, 1956) there was a significant difference ( $Z = 2.43$ ,  $p < 0.015$ ) between the two groups, with the crash group obviously the younger. This is in line with the general tendency for younger people to be at greater risk on the road than the middle aged.

### WORKING HABITS OF DRIVERS (OVERALL ANALYSIS)

22. Five quantities related to working habits were abstracted from the log-books with accuracy to the nearest 15 minutes. These were :

- The total elapsed time since the driver's last 24 hour off duty period (Note : total time includes driving, on duty, off duty and rest period time).
- On-duty hours worked since the driver's last 24 hour off duty time.
- Driving hours worked since the driver's last 24 hour off duty time.
- On-duty hours worked "today" since the driver's last 10 hour off duty time.
- Driving hours worked "today" since the driver's last 10 hour off duty time.

"Driving hours" include the statutory 30 minute break where required.

23. The responses **from** the two groups were compared, in the first instance, using the normal approximation to the simple paired sample t test' details of which are available in any simple statistics text (e.g. Roscoe, 1975). The normal approximation was used as the **final** number of pairs available (199) was **sufficient** for use of this approximation under the central limit theorem. The test used was a one-tailed test' with null hypothesis that

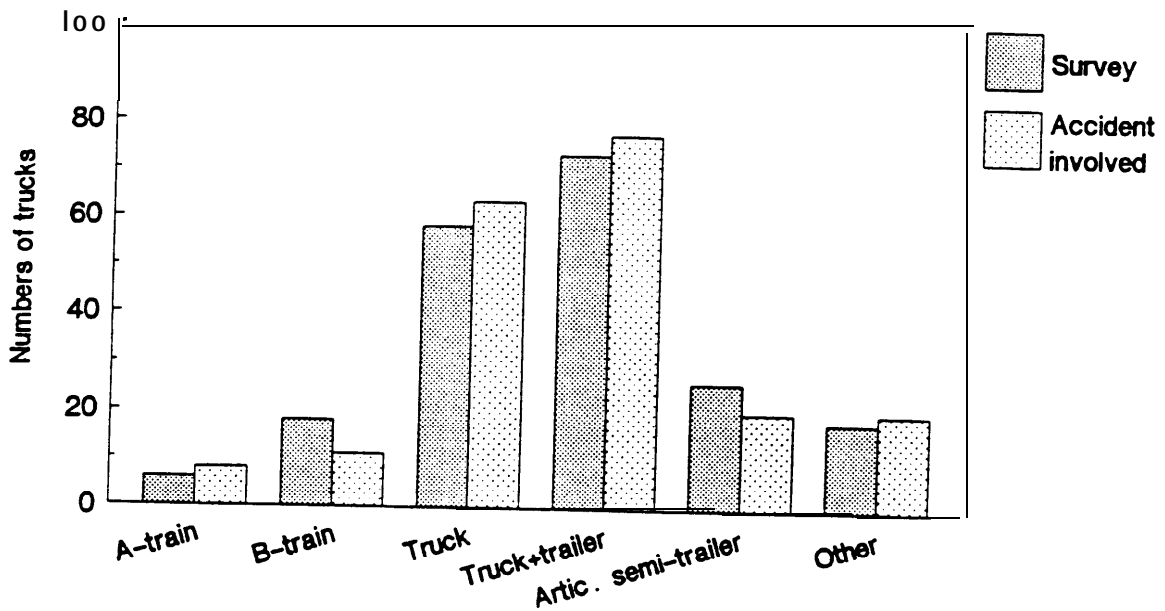


Fig. 1 - Vehicle Configurations

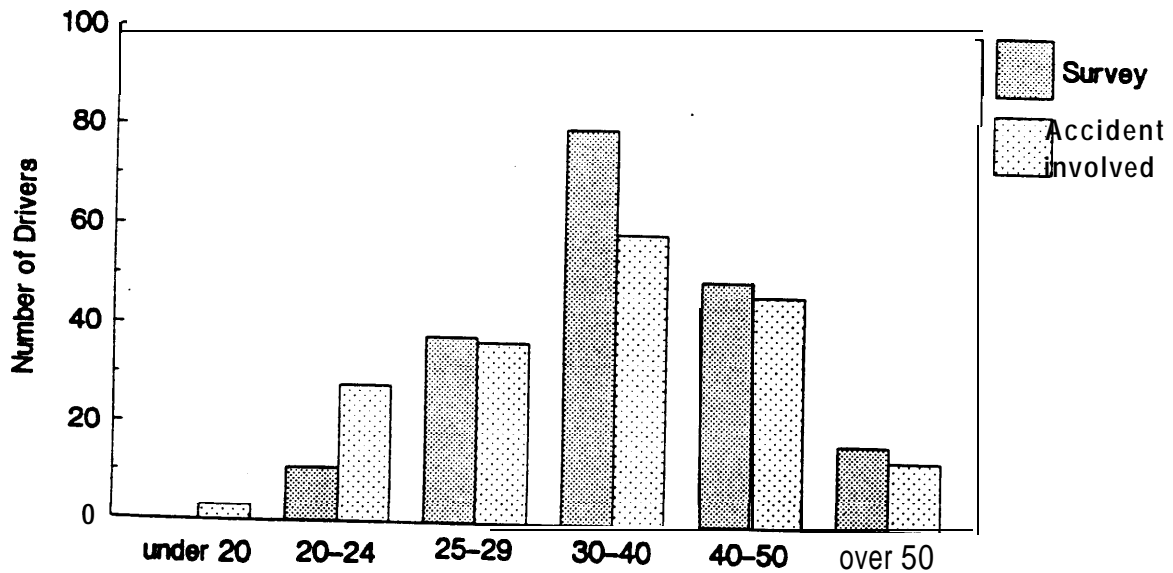


Fig. 2 - Age Distribution of Drivers

the mean difference between the observations for matched pairs (i.e. the log-book time for the crash driver and his/her matched control driver) was not greater than zero. The alternative hypothesis was that the mean difference between the observations for the pairs was greater than zero.

24. The following results were found:

**Total elapsed time since the driver's last 24 hour off duty period.**

*Means:*

Crash group: 41.78 hours  
Control group: 50.35 hours

*Mean difference between crash group hours and control group hours (one-tailed test):*

-8.59 hours                      **Z=-1.87 p<0.0376**

**On-duty hours worked since the driver's last 24 hour off duty time.**

*Means:*

Crash group: 20.38 hours  
Control group: 19.88 hours

*Mean difference between crash group hours and control group hours (one-tailed test):*

0.60 hours                      **Z=0.48 P<0.6297**

**Driving hours worked since the driver's last 24 hour off duty time.**

*Means:*

Crash group: 15.09 hours  
Control group: 14.05 hours

*Mean difference between crash group hours and control group hours (one-tailed test):*

1.12 hours                      **Z=1.10 P<0.2734**

**On-duty hours worked "today" since the driver's last 10 hour off duty time.**

*Means:*

Crash group: 5.51 hours  
Control group: 5.27 hours

*Mean difference between crash group hours and control group hours (one-tailed test):*

0.34 hours                      **Z=0.75 P<0.4545**

**Driving hours worked "today" since the driver's last 10 hour off duty time.**

Means :

Crash group: 4.38 hours  
Control group: 3.64 hours

Mean *difference* between crash group hours and control group hours (one-tailed test):

0.80 hours                       $Z=3.2$   $P<0.0015$

25. These results conform with overseas findings that driving time since the last **significant** rest period is the strongest effect. Given this and the strong level of significance of this effect, it was decided to further analyse driving hours since the last 10 hour rest period.

**FURTHER ANALYSIS OF DRIVING HOURS SINCE THE LAST 10 HOUR REST PERIOD.**

**Proportion of crash group and control group > 8 hours since last rest:**

26. The following proportions were calculated

Crash group: 13.1%  
Control group: 5.1%  
Difference: 8.0%

This difference is significant, using a one-tailed normal test for proportions. The null hypothesis is that the difference between the crash proportion and the control proportion is not greater than zero, and alternative hypotheses that it is greater than zero ( $Z=2.79$   $P<0.0029$ ).

**Variation Of Risk By Driving Hours**

27. This was investigated using methods developed by **Allsop** (1966) to analyse data from the Grand Rapids study (Borkenstein et al, 1964).

Let:

$a_i$  = the number of crash involved drivers in driving hours class  $i$ .

$c_i$  = the number of control drivers in driving hours class  $i$ .

$t$  = driving hours (since last 10 hour break).

$i$  refers to the interval  $i-1 < t < i$  where  $i$  is an integer greater than or equal to 1.

28. **Allsop** (1966) defines a variable  $r_i = \frac{a_i c_0}{a_0 c_i}$  which he refers to as the relative crash rate for the interval  $i-1 < t < i$ .

This expression may be rewritten thus:  $r_i = \frac{a_i / c_i}{a_0 / c_0}$

29. From the above it may be readily seen that its function is to compare the ratio of crash involved drivers in the interval  $i-1 < i$  to control drivers in the same interval with the similar ratio for the interval  $0 < i < 1$ . This produces an index of relative risk of the crash group vis-a-vis the control group in various intervals to that in the interval  $0 < i < 1$ .

30. Figure 3 is a bar chart of relative risk against time interval. It is apparent that the relative risk increases markedly after about 8 hours behind the wheel. However, there are few observations in the area of the curve relating to longer times behind the wheel, so the shape of the risk curve in these regions is not well established. Also, any falsification of log-book entries would be likely to involve the movement of actual driving times from the illegal (>11 hours) into the legal region, and involve the crash sample to a greater extent than the control sample. This is unlikely to affect the shape of figure 3 as the highest category in the figure (9 hours driving and over) includes both illegal driving hours and the upper reaches of legal driving.

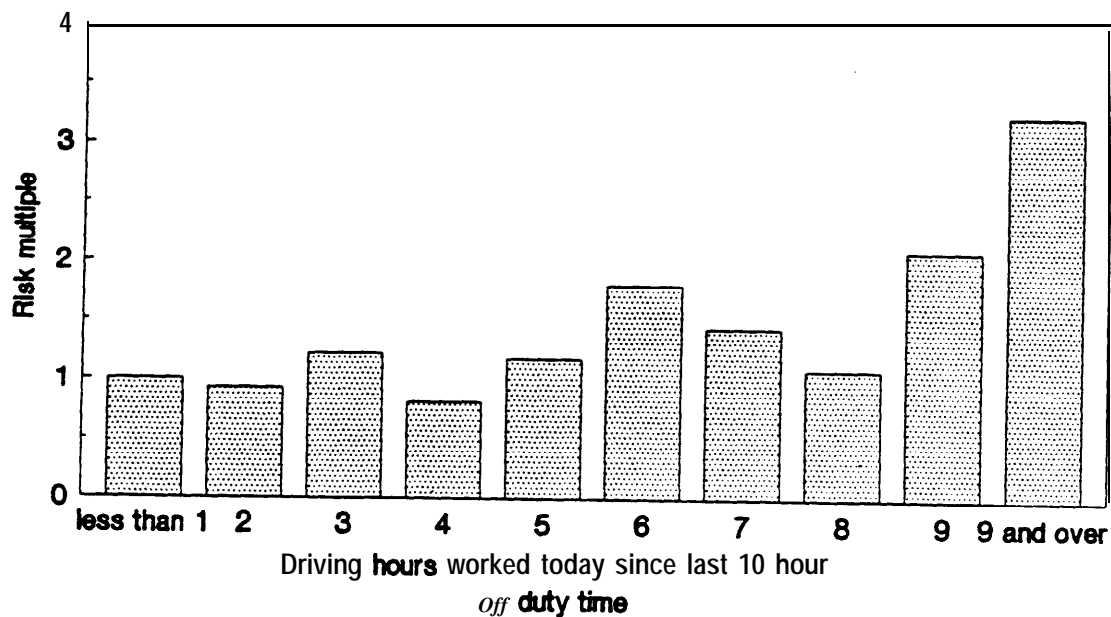


Fig. 3 - Risk compared with driving up to 1 hour

**Analysis Of Pairs Where The Crash And Control Vehicles Were Of The Same Configuration.**

31. For two vehicle configurations, single unit trucks and truck and trailer units there were enough pairs matched by configuration (respectively 63 and 77) for statistical analysis to be worthwhile. The results of these analyses are presented as follows:

**(a) Single unit trucks**

Driving hours worked "today" since the driver's last 10 hour off duty time.

*Means:*

Crash group: 4.45 hours  
Control group: 3.05 hours

*Mean difference between crash group hours and control group hours (one-tailed test):*

1.40 hours                      **Z=3.08 P<0.003 5**

*Proportion of crash group and control group > 8 hours since last rest.*

Crash group: 17.39%  
Control group: 4.34%  
Difference: 13.04%

This difference is marginally significant using a one-tailed normal test for proportions. (@= 1.95 P<0.057)

**(b) Truck and trailer units**

Driving hours worked "today" since the driver's last 10 hour off duty time.

*Means:*

Crash group: 4.77 hours  
Control group: 3.98 hours

*Mean difference between crash group hours and control group hours (one-tailed test):*

0.87 hours                      **Z= 1.97 P<0.053**

*Proportion of crash group and control group > 8 hours since last rest:*

Crash group: 12.1%  
Control group: 5.3%  
Difference: 7.0%

This difference is not significant using a one-tailed normal test for proportions (Z= 1.27 P<.21).

32. It is interesting that the matched groups exhibit greater increases in risk with time spent since the last rest period than the overall analysis reveals. This indicates that larger differences may have been obtained overall had better matching been attained. It is also interesting that the differences appear larger for the smaller rigs. This may be connected

with greater use of smaller rigs under more congested **conditons** such as urban operation. In such conditions the tired driver would have greater exposure to crash risk than one working in less congested conditions thus **amplifying** the differences. Further research would be necessary to confirm the above speculations.

### COMPARISON OF THE RESULTS WITH THOSE OF OTHER INVESTIGATORS

33. In strictly scientific terms, case control studies such as this are specific to the areas in which they are carried out. This is particularly relevant in the area of driving hours where there are many geographically linked confounding variables such as the cultural habits of drivers, the terrain and the length of haul. It is thus highly interesting that:

- These results, notwithstanding the differences in vehicle size in the samples, are close to those of Stein and Jones.
- Although derived differently, they also correspond well with those of Lin et al.

It may thus be that the relationship between the safety of driving heavy vehicles and driving hours is relatively robust to other influences.

### CONCLUSIONS

34. The study indicates that:

- Younger truck drivers tend to be involved in crashes more than older truck drivers.
- Crash involvement increases significantly after about 8 driving hours worked from the last 10 hour rest period.
- Crash involvement tends to increase more steeply for smaller rigs than larger rigs. This may possibly reflect greater use of smaller rigs by tired drivers in congested environments.

35. The above factors suggest the possibility of an interaction between youthful **risk-taking** behaviour and longer driving hours increasing the risk of crash occurrence.

36. The lengths of the following time periods related to drivers' work were not found to be statistically significantly related to crash risk.

- The total elapsed time since the driver's last 24 hour off duty period
- On-duty hours worked since the driver's last 24 hour off duty time.
- Driving hours worked since the driver's last 24 hour off duty time.
- On-duty hours worked "today" since the driver's last 10 hour off duty time.

However, there were indications of a rough progression towards statistical significance as the work-related periods measured became more immediately related to the final driving period. Significant changes in some of the above measurements may have been detected had a larger scale study been possible.

37. The similarity of this study's results to those of studies carried out using overseas data **suggests** that the relationship between the **safety** of driving heavy **vehicles** and driving hours may be relatively robust to other influences such as the cultural ethos of the drivers and the environments in which **they** drive.

38. The policy implications are that :

- Even with the relatively short distances driven in New Zealand, driving hours worked is **having** an effect on the crash rate of **trucks** and enforcement of driving hours restrictions has merit.
- With the young being over-represented in the crash group, targeting of the young with education, publicity and enforcement could well be **useful**.

#### ACKNOWLEDGEMENT AND DISCLAIMER

The assistance of **staff** of the Land Transport Safety Authority, particularly Michael Keall is acknowledged. This paper represents the views of the author and does not necessarily represent those of the Land Transport Safety Authority.

#### REFERENCES

ALLSOP, R. E.(1966). *Alcohol and road crashes. A discussion of the Grand Rapids study*. RRL Report No.6.(Ministry of Transport, Road Research Laboratory, United Kingdom)

BORKENSTEIN, R. F., CROWTHER, R. F., SHUMATE, R. P., ZIEL, W. B., and ZYLMAN, R.( 1964) *The role of the drinking driver in traffic crashes*. Department of Police Administration, Indiana University (Indiana University, Bloomington, Indiana)

FULLER, RAYMOND G. C. (1984). Prolonged driving in convoy: The truck **driver's** experience. *Accid. Annal. & Prev.* Vol. 16, No. 5/6, pp. 371-382.

HARMS W., and MACKIE R. R.( 1972). *A study of the relationships among fatigue, hours of service and safety of operations of truck and bus drivers*, Final Report, BMCS RD 7 1-2 Bureau of Motor Carrier Safety. (Federal Highway Administration, Washington D.C.)

HAWORTH N. L., HEFFERNAN C. J., HORNE E. J. (1989), *Fatigue In Truck Crashes*, Report no 3, Crash Research Centre. ( Monash University, Victoria).

JONES, IAN S. and STEIN, HOWARD S.(1987 ), *Effect of Driver Hours of Service On Tractor- Trailer Crash Involvement*. Insurance Institute for Highway Safety.(Insurance Institute for Highway Safety, Arlington, Virginia)

Lin, TZUOO-DING, JOVANIS PAUL P. And CHUN-ZIN YANG (1993), *Modeling the Effect Of Driver Service Hours on Motor Carrier Crash Risk Using Time Dependent Logistic Regression*, Reprint Paper No. 93093 1, 72nd Annual Meeting, Transportation Research Board,(Transportation Research Board. Washington, DC)

LINKLATER D. R. (1980), Fatigue and long distance truck drivers, *Proc.10th ARRB Conference*, 10(4), pp 193-201.

MACKIE R.R. and MILLER J.C. (1978), *Effects of hours of service, regularity of schedules and cargo loading on truck and bus driver fatigue*, Tech. Report 1765-F, (Human Factors Research Inc., Santa Barbara, California)

NATIONAL TRANSPORTATION SAFETY BOARD (1990), *Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes*, Report NTSB/SS-90/02. (Transportation Safety Board, Washington D.C.)

ROSCOE, JOHN T., (1975) *Fundamental Research Statistics for the Behavioral Sciences*, 2nd ed, pp. 224-23 1, (Holt, Rinehart and Winston, Inc, New York)

SIEGEL, SIDNEY (1956) *Nonparametric statistics for the behavioural sciences*, pp 68-73 (Mc Graw-Hill, New York)

STEIN, HOWARD S. and JONES, IAN S. (1988). *Crash Involvement of Large Trucks by Configuration: A Case-Control Study*. Insurance Institute for Highway Safety. (Insurance Institute for Highway Safety, Arlington, Virginia)