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HEAVY TRUCK CAB SAFETY STUDY

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16. Abstract

Nearly 1000 occupants of large trucks die each year in traffic accidents. Examination of yearly trends shows about a 25% decline in tractor-driver fatalities from 674 in 1984 to 508 in 1987. Over that same period of time, restraint use by tractor drivers involved in fatal accidents increased from 9.6% to 37.3%. The primary factors associated with tractor driver fatalities remain the same as identified in earlier studies. About 80% are single vehicle accidents. Rollover is identified as the most harmful event in 41.4% and frontal impact is the most harmful event in 40.3%. Thirty-four percent of the fatally-injured tractor drivers were ejected and 21.5% required extrication. Fire on the truck was associated with 16.2% of the tractor driver fatalities.

The recent TIFA data on restrained truck drivers indicates that restraint use reduces the probability of fatality by 77%. However, this estimate must be tempered by the evidence of over-reporting of restraint use on police accident reports. Information obtained through a review of 186 National Transportation Safety Board (NTSB) reports on truck driver fatalities in eight states indicated that there was not sufficient occupant survival space in about 65% of the collisions examined. Forty-two percent were judged to be not survivable because of the severity of the impact. Restraint use alone appears sufficient to alter the outcome of only about 27%. Cab structural modifications sufficient to maintain adequate survival space, particularly in rollover, will be required in order to address an additional 23% that appeared survivable.

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HEAVY TRUCK CAB SAFETY STUDY

Introduction

Nearly 1000 occupants of medium and heavy trucks die each year in traffic accidents. Previous studies (1,2,3)[1] of the accident experience of heavy trucks have identified many of the significant characteristics of these collisions. The majority of large-truck occupant fatalities result from rollover, frontal collisions, or both. Approximately 80% are single-vehicle accidents. About one-third of the fatally injured truck drivers are ejected from the cab. Ejection occurs nearly as often in frontal impacts as in rollover. Extrication is required for 21.5% of the fatally injured drivers, and a post-crash fire on the truck is reported for 16.2% of the fatalities. However, there is a lack of information that describes the situations where crashworthiness countermeasures might be appropriate, or that defines the requirements of such countermeasures (4). For example, occupant restraints are an obvious countermeasure for ejection. Historically, most truck drivers have not used the available restraints (5). What are the potential benefits of increased restraint use? Before the 1972 door latch standard, FMVSS 206, most ejections were out the open door (3). What is the most common area of ejection now? Cab structure is critical to preventing ejection and maintaining sufficient survival space for restraints and interior surfaces to function correctly in a collision. What is the extent of cab damage for ejections, and was there sufficient survival space if the driver had stayed in the cab? Cab interior surfaces, particularly the steering assembly (1), are another possible means of reducing the potential for injury for occupants that are not ejected if there is sufficient survival space. Do conventional cabs protect the occupant better than cab-over-engine designs? A more thorough analysis of existing accident data can provide a better picture of the number and the nature of truck-occupant fatal accidents with regard to potential countermeasures.

This report begins with an examination of the trends in large-truck occupant fatalities since 1980. Tractor driver fatalities have declined since 1984, while increases in restraint use are shown. In the next section, accidents involving rollover and frontal impacts are shown to be the primary collision types resulting in driver fatality. The remainder of this section illustrates the relationship of ejection, extrication, and fire to these collision types. The substantial increase in reported belt use among tractor drivers involved in accidents allows estimates of restraint effectiveness in reducing the probability of injury to be calculated for the first time. Estimates are developed from 9 years of data in the UMTRI Trucks Involved in Fatal Accident files, 1980-1988, and from the NHTSA General Estimates System files for 1988-89. While the results show belts to be very effective in a variety of collision situations, there is reason to question the accuracy of police-reported restraint use.

The case materials from the National Transportation Safety Board investigations of all large-truck driver fatalities occurring in eight states from October 1987 through September 1988

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[1]Numbers in parentheses designate references listed at the end of the report.

were reviewed for information on cab structural integrity (7). Information was retrieved from the case materials on the direction of roll and number of quarter turns, the area of ejection, and the reduction of cab interior space. Based on this information, estimates are developed of the potential for survival offered by prevention of ejection, restraint use, and prevention of fire. Overall, sufficient survival space was maintained in only 35% of the cases. About 40% were judged to be too severe for survival. A subset of the TIFA files was created that included all driver fatalities in the United States over the same time period as the NTSB study. This file shows that the NTSB cases are generally representative of the national experience except for some over-representation of doubles and older cabover tractors. A final section summarizes conclusions.

Trends

The number of fatalities in large trucks in the United States is shown by year in Figure 1.[2] The data presented are from the Trucks Involved in Fatal Accidents (TIFA) files compiled by the Center for National Truck Statistics at the University of Michigan Transportation Research Institute. The number of fatalities declined by about 20% from 1984 to 1987. Occupants of straight trucks are shown separately from tractors, illustrating that the decline is confined to tractor occupants. As would be expected, nearly 90% of the occupant fatalities are drivers, and about 75% are in tractors. Since the majority of large truck occupant fatalities are tractor drivers, the remaining sections of this report will focus on this group.

The overall involvement of large trucks in fatal accidents has not shown a comparable decline over the same time period. When a large truck is involved in a fatal accident, most of the time the fatalities are not truck occupants. This is illustrated in Figure 2 showing truck driver fatalities as a percentage of all large trucks involved in fatal accidents. The fact that driver fatalities have declined relative to the overall fatal-accident involvement of large trucks is illustrated by a decline in this percentage for tractors from about 18.1% in 1984 to 13.9% in 1987. The decline in driver fatalities as a percentage of fatal accident involvements is similar for straight trucks and tractors.

A possible explanation for this trend is provided by Figure 3, which shows restraint use among tractor drivers involved in fatal accidents to be increasing substantially over this same time period. Data from the NHTSA Fatal Accident Reporting System (FARS) and the General Estimates System (GES) have been added in order to extend this trend to 1989 and compare reported belt use. Since the TIFA file incorporates the FARS data, restraint use figures are the same for these two files, about 40% in 1988. However, reported belt use among tractor drivers is over 70% in the 1988 GES file. This figure is simply too high to be credible. These belt use rates are based on accident data: fatal accidents for the FARS and TIFA files, and police-reported accidents for the GES file. Looking at the tractor drivers that were fatally injured in the accident, only 11% were restrained in 1988.

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[2]Figures are in Appendix A at the end of the report. Numerical data for each figure are provided in tabular form on the same page.

Since many states have passed laws requiring restraint use among front-seat passenger car occupants, reported belt use on police accident reports has been observed to be biased toward elevated belt use rates, particularly for uninjured occupants. For example, in Michigan, observational surveys indicated that belt use among passenger car drivers was 20-25% in early 1985 (8) before the law took effect and increased to about 50% after the law took effect in July 1985 (9). Belt use recorded on accident reports was 35-40% before the law and 90% after the law (10). However, reported belt use for injured occupants was more in line with observed use rates. Since the bias is in the direction of overstating the number of uninjured occupants that are restrained, the probability of injury will be under-estimated for restrained occupants and exaggerated for unrestrained occupants. The net effect of such bias is to overstate the effectiveness of restraints in reducing the probability of injury. Belt use in the FARS, TIFA, and GES files is taken from the police accident report. Particularly for the recent GES files, it would appear that belt use is over-stated for tractor drivers as well. Although the reported belt use rates are substantially lower in the fatal accidents, the accuracy of this information cannot be confirmed.

An observational survey of belt use by heavy truck drivers sponsored by NHTSA in 1982 found only about 6% restrained (5). A similar observational survey was recently completed. Robert Clarke, NHTSA, provided a preliminary usage rate from this survey of 55% (6). This figure is not inconsistent with an extension of the trend in belt use as reported in the FARS file that is shown in Figure 3. Even though the overall belt use rate is approximately consistent with observed rates, errors of the type described above in the recording of belt use among accident-involved drivers could still bias restraint effectiveness estimates. With this cautionary note, estimates of belt effectiveness will be calculated from both the TIFA and GES files in a later section.

Primary Factors Associated with Driver Fatality

The objective of this section is to illustrate the primary factors associated with collisions resulting in fatal injuries to the tractor driver. It is worth pointing out that nearly 80% of these accidents are single vehicle. When a heavy truck strikes another vehicle, usually the other vehicle is a passenger car or light truck, much smaller than the heavy truck, so that the probability of injury to the heavy-truck driver is quite low. For the most part, only frontal collisions with other heavy trucks, massive fixed objects, or collisions resulting in rollover produce sufficient deceleration levels and/or cab deformation to pose a significant threat of fatality to the heavy-truck driver.

PRIMARY IMPACT POINT - Figure 4 shows the relationship of rollover to the primary impact point on the truck. Rollover is coded as the "most harmful event" for the truck in 41% of the driver fatalities. These are shown in the first column, separated into rollovers that occurred as the first event in the accident versus those that occurred subsequent to some other impact in the accident sequence. Looking at the rollovers that were coded as the most harmful event, about half occurred as the first event, and about half as a subsequent event. Nearly all of the remaining tractor driver fatalities were the result of a primary impact to the front of the tractor. Together, rollover and frontal impacts account for more than 80% of all tractor driver fatalities. It is also worth noting that about 23% of the frontal impacts also involved a rollover, usually as a subsequent event. In these cases, the frontal impact was coded as the most harmful event, rather than the rollover. Rollover, either as a first or subsequent event also makes up about half of the "unknown" primary impact cases, or about 5% overall. It might be argued that these should be moved to the "rollover as a primary event" group, in the absence of information indicating some other primary impact area. In all, nearly 60% of all tractor driver fatalities involve a rollover, making this the most frequent collision event associated with driver fatality, followed by frontal impact in 40%.

The information in Figure 4 has identified rollover and frontal impact as the primary collision events associated with tractor driver fatality. The remaining factors that will be described, ejection, extrication, and fire, pertain more to the mechanism of injury, than to the type of collision.

EJECTION - The next most frequent factor associated with driver fatality is ejection. About one-third of all fatally injured tractor drivers are ejected at some point during the impact. Figure 5 looks at the relationship between ejection and the primary impact point. Among passenger car occupants, most ejections occur as a consequence of rollover (4). Figure 5 shows that the ejection of tractor drivers occurs at only a slightly higher probability in rollovers as compared with the other primary impact points. However, most occur as a result of rollover or frontal impact, since these are the most frequent collision types associated with driver fatality. Ejections are coded as to whether the occupant was partially or totally ejected from the vehicle. The overwhelming majority of the tractor drivers were coded as total ejections. Earlier studies (3,4) have presented data showing that the probability of injury and death is dramatically higher if a truck occupant is ejected. However, the merits of staying in the vehicle may be questioned if one assumes that ejections only occur in the most severe impacts. Information from the NTSB investigations that will be presented in a subsequent section will address whether these collisions appear to be survivable if the driver had not been ejected.

The association of cabstyle with ejection is shown in Table 1. The percentage of fatally injured tractor drivers that were ejected is calculated for conventional cab tractors and cab-over-engine (cabover) tractors. The percentage of ejected drivers is nearly one-third higher for the cabover tractors. When the comparison is limited to rollover accidents the percent ejected is more comparable, 31% for the conventional and 37% for the cabover. However, in frontal impacts, the percent of fatally injured tractor drivers ejected is nearly 50% higher for the cabover, 26% and 38% respectively. Overall, 69% of the ejected drivers came from cabover tractors.

TABLE 1

Ejection by Cabstyle
Fatally Injured Tractor Drivers
1980-86 TIFA

Cabstyle	Total	Ejections	Percent
Conventional	1,529	445	29.1%
Cab-over-engine	2,591	984	38.0%
All	4,120	1,429	34.7%

EXTRICATION - Extrication is coded for 21.5% of the fatally injured tractor drivers. Extrication refers to the use of mechanical equipment or other force to remove the occupant from the vehicle. This variable is often used as a surrogate for intrusion, the reduction of the passenger compartment space, since the cab deformation frequently prevents the proper operation of the doors and makes occupant removal difficult. However, the coding of extrication alone, does not provide any measure of the extent to which the occupant survival space has been reduced. The coding of vehicle damage extent in the FARS (and TIFA) files does not shed any light on this because nearly 95% of the driver fatalities are coded as "severe" damage, the highest category provided. Figure 6 shows the incidence of extrication by primary impact point. Extrication is coded somewhat more frequently in rollover accidents, about 26%, as compared to frontal impacts, 18%. Looking only at fatally injured drivers that are not ejected, 30.7% are coded in FARS as requiring extrication. This percentage is essentially the same for cabover and conventional cab tractors. The association between extrication, occupant survival space, and cabstyle will also be examined in the NTSB cases.

FIRE - The final factor associated with tractor driver fatalities is fire. Fire on the truck is identified in 16.2% of the driver fatalities, and is identified as the most harmful event in 8.1%. Figure 7 shows the relationship of fire to the primary impact point. The majority of the fires occur in frontal impacts. The probability of fire is greatest for "unknown" primary impact point at 27%, followed by frontal impacts at 24%, and right and left side impacts at 23%. Only about 5% of the cases with rollover indicated as the most harmful event also involved a fire on the truck. Like extrication, fire is another collision consequence that may be closely related to the severity of the damage. In assessing the potential benefits of preventing post-impact fires, one would like to know the available occupant survival space.

INTERACTIONS - The previous material has identified ejection, extrication, and fire as primary injury mechanisms associated with tractor driver fatalities. Taken together, more than 60% of the tractor driver fatalities involved one or more of these three factors. In thinking about the potential benefits associated with the prevention of fire or ejection, one would like to know the extent to which these factors overlap. How often does fire occur in combination with extrication? How many of the cases resulting in ejection also had a fire on the truck? Of course, ejection and extrication are mutually exclusive unless the ejection is only partial. The various combinations of ejection, extrication, and fire are shown in Figure 8. Generally the overlap is not great. Only about 12% of the ejections also involved a fire on the truck. These cases make up 24% of the fire cases. About 21% of the fires also involved extrication. Overall, 55% of the fires did not involve ejection or extrication. The critical information lacking is the occupant survival space. One cannot estimate the potential benefits of preventing either fire or ejection without information on the integrity of the occupant compartment. Making these assessments was a primary objective of the NTSB case review.

The primary factors associated with tractor driver fatality are summarized in Table 2. Nearly 80% are single-vehicle accidents, and rollover is the most prevalent collision event. Second to rollovers, are frontal impacts, usually with massive fixed objects, other large trucks, trains, or in combination with rollover. The remaining factors identified are related to the mechanism of injury. Ejection from the tractor cab is the most common injury mechanism for fatally injured drivers. One-third of all fatally injured tractor drivers are ejected. Extrication is required for 21.5% of all tractor driver fatalities. Excluding the ejected drivers, the percentage requiring extrication increases to 31%. Finally, 16% of the tractor driver fatalities are associated with fire on the vehicle. Except for the identification of fire, Ranney (1) compiled essentially the same description from the 1979 FARS data.

TABLE 2

Primary Factors Associated with Tractor Driver Fatality 1980-86 TIFA

Type of Collision	
Single Vehicle	78.2%
Rollover	41.4%
Frontal	40.3%
Injury Mechanism	
Ejection	34.0%
Extrication	21.5%
Fire	16.2%

These tabulations were all based on the 1980-86 TIFA files. For this time period, restraint use among fatally injured drivers ranged from about 2% in 1980 to 10% in 1986, resulting in an overall restraint usage rate of 3.4%. Thus it may be said that these results essentially describe the accident experience of unrestrained tractor drivers. Figure 3 from the previous section showed substantial increases in tractor driver restraint use after 1984. The next section presents estimates of restraint effectiveness developed from the more recent accident data.

Restraint Effectiveness

Never before have appreciable numbers of large-truck drivers used restraints. The recent accident data on restrained truck drivers provides the first estimates of the effectiveness of restraints for heavy truck drivers. The previous analysis looked only at fatally injured truck drivers. However, the TIFA file also covers accidents involving large trucks that resulted in fatal injuries to someone other than the truck occupants. As shown in Figure 2, only 15-20% of the tractor drivers involved in fatal accidents received fatal injuries. The remainder received non-fatal injuries, or were not injured at all. Thus, the TIFA files can be used to calculate the probability of injury for the involved truck drivers. However, it should be kept in mind that fatal accidents represent a very severe subset of all accidents. Overall, the probability of injury to an unrestrained tractor driver involved in a fatal accident will be shown in Figure 9 to be about 0.46. Later in this section, similar estimates will be calculated from the NHTSA General Estimates System (GES) files that contain a probability-based sample of police-reported accidents in the United States. Based on this data, the overall probability of injury to an unrestrained tractor driver involved in a police-reported accident is only 0.12. The results from the TIFA files will be presented first.

TIFA DATA - Belt use is shown to virtually eliminate ejection in Table 3 below. Only 0.5% of the restrained tractor drivers were coded as ejected, and half of these are partial ejections. A few of the NTSB cases were so severe that the cab disintegrated and the driver was ejected along with his seat. This is a possible explanation for the very small percentage of ejected drivers that are coded as being restrained.

TABLE 3

Ejection by Restraint Use
Tractors Drivers Involved in Fatal Accidents
1980-88 TIFA

	Unrestrained		Restrained	
Ejection	N	%	N	%
None	24,417	91.7	6,078	99.5
Partial	388	1.5	14	0.2
Complete	1,804	6.8	15	0.3
TOTAL	26,609	100.0	6,107	100.0

Figure 9 shows the distribution of injury severity for restrained and unrestrained tractor drivers involved in fatal accidents. The probability of fatality is 77% lower and the probability of any injury (including fatality) is 24% lower for the restrained drivers. Looking at the distributions, the reduction for the restrained drivers is in the probability of fatal and serious (A) injuries, at the expense of somewhat greater proportions of non-incapacitating (B and C) injuries.

Similar results are obtained from the TIFA file for frontal impacts, as shown in Figure 10. The reduction in the probability of any injury is somewhat less than the overall figure, at 15.6%. The increased risk of injury to the driver in rollovers is illustrated in Figure 11. Restraint use shows only a modest 10.5% reduction in the probability of any injury, but the percentage of fatal injuries is reduced dramatically, with increases in the non-fatal injuries. The dramatic reduction in fatality may be due to the effectiveness of restraints in reducing ejection, as described earlier.

The elevated risk of injury from collisions resulting in fire is shown in Figure 12. Again, the overall reduction in injury for restrained drivers is modest, but the reduction in the probability of fatality is substantial. This result speaks directly to those concerned about restraint use interfering with the ability of the driver to escape from the cab when there is a fire. Clearly the restrained drivers are much better off. Apparently the restrained drivers are more likely to survive the impact in sufficent condition to exit the vehicle whereas the unrestrained drivers are less likely to be able to make an exit.

The probability of injury is shown by restraint use and cabstyle in Figure 13. Although restraint use reduces the probability of fatality and injury for drivers of both conventional and cabover tractors, the probability of injury and fatality is significantly higher in the cabover tractor for both restrained and unrestrained drivers. The probability of any injury is about 20% higher in the cabover and the probability of fatality is about 40% higher in the cabover. The higher ejection rate could account for the difference for unrestrained drivers, but as was shown earlier, virtually none of the restrained drivers were ejected. Based on the higher ejection rates shown in Table 1 and the higher probability of injury and fatality shown in Figure 13, it is clear that the cabover tractor does not protect the driver as well as the conventional tractor.

This finding is consistent with an earlier study by the author (12), the Truck Driver Injury Survey (TDIS). The TDIS was restricted to frontal impacts with no ejection, no roll, and no fire. Estimated collision severity was compared by tractor cabstyle for fatal impacts with fixed objects or other large trucks. This comparison showed that the drivers of cabover tractors received fatal injuries in less severe collisions than the conventional cab drivers. A comparison of intrusion showed appreciably more reduction in occupant compartment space for the cabover tractor in impacts with fixed objects and other large trucks. Although limited to frontal impacts, these earlier findings indicate that the collisions involving cabovers are not more severe and that greater intrusion results. However, this study was not successful in linking either collision severity and intrusion or intrusion and injury severity.

The focus of this study is on the probability of fatality and injury given a collision, vehicle crashworthiness. Hence, the analysis was limited to accident data. However, because only limited information on collision severity was available, fatality rates per mile travelled were calculated in an effort to address the issue of exposure on high speed roads, and possibly more severe collisions in a broader context. These results are presented separately in Appendix B. Driver fatalities per hundred million miles travelled were found to be about 50% higher for cabover drivers as compared to conventional cab drivers. The risk for the cabover driver as compared to the conventional cab was greater in urban areas than in rural. This may be a reflection of a greater likelihood of frontal impact in urban areas. The approximately 50% increase in fatality rates is consistent with the finding in Figure 13 of a 40% increase in the probability of fatality for cabover drivers. Thus, the fatality rates support the conclusion that the differences in the probability of fatality for cabover drivers as compared to conventional cab drivers is related to crashworthiness rather than exposure.

GES DATA - The results presented in the preceding paragraphs were derived from a very severe subset of all accidents, those resulting in at least one fatality. In order to calculate restraint effectiveness for a broader range of collision severity, the NHTSA General Estimates System (GES) files for 1988-89 were analyzed. The GES is a probability-based sample of police-reported accidents in the United States. As such, it includes accidents of all severities, including property-damage-only. Thus, it would be expected to provide the best estimates of probability of injury and restraint effectiveness. However, the information in GES is also taken from the police accident reports, and is subject to bias in the reporting of belt use as discussed above. Clearly, the reported belt use for tractor drivers in GES is too high, as discussed earlier. It would seem that many of those drivers were not, in fact, wearing restraints. However, some tabulations from the GES file were made for comparison.

Figure 14 shows the distribution of injury severity for tractor drivers in the 1988-89 GES files by restraint use. Here, restraint use appears to provide a nearly 50% reduction in injury (including fatality). A similar result is shown for frontal impacts in Figure 15. Figure 16 focuses on rollover. Restraint use makes only a modest reduction in the probability of all injury (including fatality), but the probability of serious (A) and fatal injury is reduced substantially with a corresponding increase in moderate (B and C) injuries. There were too few cases involving fire to analyze in GES, and the GES file does not identify cabstyle.

Perhaps the most striking information is in Figure 16. The probability of injury (including fatality) to the driver is about 50% when the truck rolls over even when the driver is restrained. If the truck does not roll, the probability of injury for the restrained driver drops by a factor of 10 to 4.7%. The probability of fatality when the truck rolls is 6.2% for the unrestrained driver and 2.5% for the restrained driver. The probability of fatality drops by a factor of 25 to 0.1% for the restrained driver if the truck does not roll. Based on the GES data, only about 6% of all tractor combinations involved in a police-reported accident roll, but the high risk of fatality makes rollover the most prevalent impact mode for tractor driver fatalities.

This finding can be contrasted with similar statistics for frontal impacts that were presented in Figure 15. Unlike rollover, frontal impacts are more common. About 21% of the tractors in police-reported accidents were struck in the front. The probability of any injury (14.1%) or fatality (1.9%) is relatively low even for the unrestrained tractor driver. Only frontal impacts with other large trucks, massive fixed objects, or in combination with rollover produce sufficient deceleration levels and/or cab deformation to pose a significant threat to the driver.

A lack of confidence in the reporting of belt use on police accident reports makes it difficult to interpret these results. The GES data clearly indicate the elevated risk of injury in rollover accidents. However, one must presume that the estimates of restraint effectiveness from the GES file are biased. Certainly, the GES figures are substantially higher than the 55% use rate recently observed (6). But how accurate is the reporting of belt use in TIFA? The TIFA file simply incorporates the belt use from the FARS file, which in turn, is taken from the police accident reports. There are some reasons to think that the TIFA/FARS file estimates are more accurate. The TIFA file is limited to severe accidents, by definition. Reported belt use has been shown to be more accurate for injured occupants (10). The belt use rates in TIFA are consistent with the earlier observational survey (5) and the recently observed rate. The TIFA file includes a large amount of data from the years prior to 1984 when the belt use rates correspond more or less to observational information. To some degree, the large sample size for the unrestrained group make these estimates less sensitive to the effects of possible mis-classification in the more recent years. However, since the probability of injury for the restrained drivers necessarily comes from the more recent data, this estimate will still be biased if belt use is overstated.

The trend data show a 20% reduction in the number and proportion of fatally injured tractor drivers. This figure would be consistent with a 40% belt use rate and a 50% effectiveness in preventing fatal injuries. This calculation is clearly an over-simplification. There are, undoubtedly, other factors influencing the probability of injury. Overall, the estimates from the TIFA file indicated that restraint use reduces the probability of injury (including fatality) by about 24%, and the probability of fatality by 77%. The estimate of the reduction in the risk of injury is somewhat lower in more severe accidents such as rollover, but the reduction in the risk of fatality is greater in these accidents. The reader has been cautioned about the uncertainty in these estimates of restraint effectiveness. The available information suggests that these estimates overstate the true effectiveness of restraint use.

NTSB Data

The NTSB study investigated 182 fatal-to-the-driver accidents involving 186 heavy trucks in eight states (California, Colorado, Georgia, Maryland, New Jersey, North Carolina, Tennessee and Wisconsin) during the period October, 1987 to September, 1988 (7). The study defined "heavy trucks" as those with a GVWR over 10,000 pounds and "fatal injury" as dead at the scene or within four hours of the accident. Before these accidents could be analyzed the investigators' files were reviewed and data regarding the vehicle, accident and injuries were coded and computerized. This data was linked to the Fatal Accident Reporting System (FARS) and Trucks Involved in Fatal Accidents (TIFA) files for this study. Fifteen of the 186 trucks in the NTSB study could not be matched in the FARS files. In ten of these unmatched cases the truck drivers died of cardiac failure, two of the case vehicles were legally parked, and two of the accidents occurred on private property. Each of these situations does not meet FARS criteria for inclusion. Reasons for not matching the remaining NTSB truck are not apparent. Conversely, FARS includes 209 truck driver fatal records in the eight states during the study period. Six of these were drivers of trucks with a GVWR under 10,000 pounds. One-hundred-seventy-one NTSB case vehicles were matched with the FARS records in the TIFA file. The remaining 32 (nine in 1987 and 23 in 1988) are assumed to be fatalities occurring more than four hours after the accident. Due to the sampling process used in the TIFA survey since 1987, twenty cases lack the TIFA data elements. The analysis file used includes NTSB vehicles with matching FARS records and the available TIFA data for those vehicles. Cases reported as "heart attacks" or "driver jumped from vehicle" not already excluded were omitted from the analysis.

A second file with *all* heavy-truck driver fatalities during the period October, 1987 to September, 1988 was taken from the TIFA files and used for a national comparison. The national file included a total of 774 heavy truck driver fatalities. Thus, the 171 NTSB case vehicles meeting the FARS reporting criteria represent 22% of all heavy-truck driver fatalities reported in FARS during the NTSB study time period. The most striking difference between the NTSB sample and the national file was the preponderance of California cases in the NTSB study. While California cases accounted for 9.8% of the national file, they were 41.8% of the NTSB cases. There were seventeen doubles involved in fatal-to-the-driver accidents in California during the study period. These accounted for 42.5% of the doubles in the national file and 81% of the doubles in the NTSB sample. Consequently the percentage of doubles in NTSB, 12.9%, is almost twice the national total of 6.6%. There was a higher proportion of older (pre-1982 model year) tractors in the NTSB sample than in the national file, 60.3% versus 46.9%. The majority of these older tractors were cabover. In the national sample 61.7% of the older tractors were cabovers and in the NTSB sample 72.2% of the older tractors were cabovers. Looking at tractors of all model years with driver fatalities, the proportion of cabovers in the national file is 57.6%. In the NTSB study, 64.9% of the tractors were cabovers.

Carrier type was another difference between NTSB cases and the national sample. While 65.4% of the vehicles represented in the national file were interstate ICC Authorized (Common or

Contract) carriers, only 46.5% of the NTSB vehicles were in that category. On the other hand, there was a much higher percentage of intrastate for-hire vehicles in the NTSB states, 11.4%, than in the national file, which had 5%. These differences in vehicle configuration, age and cabstyle, and in carrier type between the NTSB cases and the national file can be attributed to the domination of the California cases in the NTSB sample. Comparisons of accident type, rollovers, ejections, fires and extrication did not show any bias between the NTSB subset and the national population.

In order to be comparable with the preceding sections, the remainder of this section will focus on the 131 tractor or tractor combinations in the NTSB study.

CAB DAMAGE - The NTSB case materials were reviewed for information on cab intrusion and other factors related to occupant survival. Rollover occurred in 63% of the NTSB tractor cases, essentially the same as the national percentage. The direction of roll was divided almost exactly between left and right, with 12% unknown direction. An effort was also made to determine the number of quarter turns in the roll. This effort was less successful. The distribution was 25% one quarter-turn, 27% two quarter-turns, 8% more than two quarters, and 40% unknown. Some of the rollovers occurred on relatively steep embankments in mountainous terrain, so it is difficult to judge whether rollovers of two or more quarter-turns are as frequent nationally as in the NTSB sample. Rollover onto the roof was generally responsible for the loss of occupant survival space in rollovers.

Overall, the tractor driver was ejected in 39% of the NTSB cases, a little higher than the national percentage of 34% (shown in Table 2). Three-fourths of the ejections in the NTSB study are from cabover tractors. This figure is consistent with the finding presented earlier that 69% of the fatally injured tractor drivers were ejected from cabover tractors, based on the 1980-86 TIFA data. Area of ejection could not be determined for 44% of these. However, the remainder was distributed as 68% windshield, 21% door, and 11% side window. Windshield retention could not be determined for 32 of the 131 tractors. However, the windshield was not retained in 95 of the remaining 99 tractors. While there was substantial cab deformation in the majority of these, the windshield was not retained in some cases with minimal cab damage.

A subjective estimate of the potential for survival was made for each of the NTSB cases. A primary consideration was cab deformation. Reduction in the occupant compartment space was estimated from photographs and the description of the cab damage. If the left one-third of the occupant compartment was reduced in space by 50% or more, a coding of "not sufficient survival space" was made. Then possible countermeasures were considered such as restraint use, prevention of ejection, prevention of fire, and improved cab structure. The relevant countermeasures were recorded. If the collision was so severe that none of the countermeasures seemed capable of preventing the fatality, then the case was classified as "not survivable." The relationship of available survival space and collision severity is summarized in Table 4 below for the 121 tractors where there was sufficient information on cab deformation.

TABLE 4

Survival Space and Collision Severity
NTSB Tractor Drivers

	Collision Severity	
Occupant Space	Survivable	Not Survivable
Sufficient	42 (35%)	-
Not Sufficient	28 (23%)	51 (42%)

Overall, sufficient survival space was not maintained in 65% of the tractors. Forty-two percent were judged to be not survivable with any countermeasure, including improved cab integrity. Since these judgments were made on the rather limited evidence in the case materials, they should be regarded as approximations at best. The intent was to be conservative in estimating the potential for survival. While some of the frontal impacts seemed clearly to be catastrophic, it was very difficult to speculate on the force levels in the rollovers that frequently involved many glancing or sliding impacts over the course of several hundred feet.

Mergel in 1982 (2) used an event tree to estimate the potential benefits of restraint use, improved cab structure, and improved steering assemblies. Using his most optimistic estimates, 40.4% were not preventable. About the same time, Ranney (1) used data on combination vehicles with driver fatalities in Texas, 1978-79, to estimate that about 70% of the fatal involvements involved catastrophic damage and that the remaining 30% did not. Ranney's 30% appears to be comparable to the finding from review of the NTSB cases that sufficient survival space was maintained in about 35% of the cases. In a paper on the limits of crash protection for passenger cars, Viano (11) describes several analyses that lead to the conclusion that as many as 50% of passenger car occupant fatalities are not preventable by foreseeable crashworthiness countermeasures due to the severity of the collisions. Although subjective, the finding that there was not sufficient occupant survival space in 65% of the tractors in the NTSB study and that about 40% were in collisions too severe to be survivable with any of the countermeasures considered are consistent with previous studies.

Some differences are evident in the relationship of survival space and collision severity for ejected tractor drivers as compared to non-ejected drivers. As shown in Table 5 below, there was sufficient survival space for 44% of the ejected drivers, but only 29% of the fatally injured drivers that stayed in the cab had sufficient survival space. This result implies that some drivers are ejected in collisions that produced only moderate damage to the cab. For these ejected drivers, the primary benefits will come from preventing the ejection.

The first row in Table 5 shows cases with sufficient occupant survival space, while the second includes cases with *in*sufficient space in collisions that were judged to be of survivable collision severity. Collisions that were too severe to be survivable (and had insufficient occupant survival space) are in the third row. Looking at the cases where the survival space was not sufficient (the second and third rows), the collision severity is appreciably different for the ejected versus non-ejected drivers. For the ejected drivers, when there was not sufficient survival space already, most (22/27, or 81%) of the collisions did not appear to be survivable. For the drivers that were not ejected and did not have sufficient survival space, only 56% (29/52) did not appear to be survivable collisions.

TABLE 5

Survival Space by Ejection
Tractors Drivers—NTSB Study

Survival Space	Ejected	Not Ejected	Total
Sufficient	21 (44%)	21 (29%)	42 (35%)
Insufficient	5 (10%)	23 (31%)	28 (23%)
Not Survivable	22 (46%)	29 (40%)	51 (42%)
TOTAL	48 (100%)	73 (100%)	121 (100%)

Survival space and collision severity are also shown by collision type in Table 6. Collisions resulting in fire on the truck are shown separately in the first column. The "other" collision type shown in the third column is primarily frontal impacts. The severity of the rollover accidents in the NTSB cases is reflected in the percentage that appeared to not be survivable, 41%, only a little lower than the non-rollovers, 47%.

The fire so completely destroyed the truck in 4 of the cases that available survival space and collision severity could not be estimated. In the remaining 16 cases shown in Table 6, sufficient survival space appeared to be available in 10 (63%). The remaining 6 (37%) collisions were felt to be too severe for survival.

The relationship between survival space and extrication was also examined, since extrication has been used as a surrogate for lack of survival space in previous studies (1,2,4). Omitting ejected occupants and looking at the FARS coding for extrication, only about half of the drivers with insufficient survival space were coded as requiring extrication, 33% versus 71%. NTSB separately recorded whether the driver was entrapped or not. This coding did correspond fairly well with the authors determination of lack of survival space. In other words, NTSB identified entrapment about twice as often as the FARS file indicated that extrication was required.

TABLE 6

Survival Space by Collision Type
Tractors Drivers—NTSB Study

Survival Space	Fire	Rollover	Other	Total
Sufficient	10 (63%)	23 (33%)	9 (25%)	42 (35%)
Insufficient	0 (0%)	18 (26%)	10 (28%)	28 (23%)
Not Survivable	6 (37%)	28 (41%)	17 (47%)	51 (42%)
TOTAL	16 (100%)	69 (100%)	36 (100%)	121 (100%)

Apparently, extrication and entrapment are not the same. When extrication is required, it is likely that there was entrapment. Based on the comparison of NTSB coding of entrapment and the FARS coding of extrication, extrication is only required in about half of cases involving entrapment. The assessment of survival space made for this study focused on the space around the driver's seat. Thus, some situations occurred where there was adequate space for the driver, had he/she stayed in the seat, but the unrestrained driver moved out of position to an area of the cab where intrusion/entrapment occurred. Survival space was also compared for conventional and cabover tractors. Omitting ejected drivers, 35% of the conventional cab tractors maintained sufficient survival space as compared to 20% of the cabover tractors.

COUNTERMEASURES - The preceding material has focused on the relationship of collision severity and occupant survival space to ejection and collision type. Some of the findings with regard to countermeasures follow directly from these results. Countermeasures were not identified for the 51 cases (42%) judged to be too severe to be survivable with any of the countermeasures considered. For the collisions judged to be of survivable collision severity, the countermeasures considered included: restraint use, prevention of ejection, prevention of fire, improved cab structure, improved interior surfaces, and prevention of load shift. Because of the information in the literature cited earlier (3,4) that demonstrates the elevated probability of injury and death for ejected occupants, prevention of ejection is identified as the most important countermeasure for all ejected occupants from collisions that were judged to be of survivable collision severity. As shown in Table 5, a little over half of the ejected occupants were involved in survivable collisions, and 44% had sufficient survival space had they stayed in the cab.

The discussion of countermeasures is organized by the available survival space for the driver. Table 7 shows only the 42 cases with sufficient occupant survival space classified by ejection and collision type. These cases are 35% of the total.

TABLE 7

Survivable Collisions with Sufficient Space
Collision Type by Ejection
Tractors Drivers—NTSB Study

Collision Type	Ejected	Not Ejected	Total
Fire	2	8	10
Rollover	13	10	23
Other	6	3	9
TOTAL	21	21	42

Prevention of ejection is clearly the top priority here, since half (21/42) are ejections, and only two of these also had a fire on the truck. Looking at the drivers that were not ejected in Table 7, the next priority is the collisions not resulting in fire. Most of these are rollovers. The typical situation here is a rollover to the right that produced minimal damage to the driver's side of the truck. However, the unrestrained driver was thrown to the right and received fatal injuries when the cab struck the ground. This type of collision sometimes resulted in the positional asphyxia described by Clarke and Leasure (4) and frequently mentioned in the NTSB case materials. Restraint use is clearly the countermeasure of choice, addressing about 75% of the collisions in Table 7 (32/42), or about 27% of the total (32/121). The remainder of Table 7 requires prevention of the fire, addressing another 8% of the total (10/121).

The other group amenable to countermeasures are those where there was not sufficient survival space for the driver, but it was felt that cab structural modifications could provide sufficient space. These collisions were 23% of the total, and are classified by ejection and collision type in Table 8. The majority of these, about two-thirds, are rollovers, very few were ejections, and none were fires. In this group, the rollover is more likely to be more than a quarter roll producing extensive roof crush, sometimes to the level of the dash. The essential countermeasure to address this group is improved cab structural integrity in rollover.

An effort was also made to examine limited information that NTSB obtained from the truck manufacturers on the materials used in the cab construction of 33 tractors that involved a half-turn roll or more. All of the cabovers were aluminum, while there were both aluminum and steel conventional cabs. All of these cabs sustained substantial roof crush. Based on our review, three-fourths did not provide sufficient survival space. The proportion providing sufficient survival space was essentially the same for steel and non-steel cabs. This information is presented in Appendix C. In the authors' view, these data do not support any conclusion regarding the relationship of the materials used in cab construction and the resulting structural performance in a collision. The issue here is not so much the materials used, but the structural strength specified for the design. If specific performance levels were identified, it is likely that designs using a variety of materials could satisfy the requirements. What is needed then, to address this issue, is to establish structural performance levels for truck cabs.

TABLE 8

Survivable Collisions without Sufficient Space
Collision Type by Ejection
Tractors Drivers—NTSB Study

Collision Type	Ejected	Not Ejected	Total
Fire	0	0	0
Rollover	3	15	18
Other	2	8	10
TOTAL	5	23	28

The remaining third of this group are primarily frontal impacts. Here there are two mechanisms contributing to lack of adequate survival space. The more frequent mechanism is penetration by the steering column, particularly with cabover tractors. The other mechanism is deformation of the back of the cab due to load shift during the impact.

Information from the Truck Driver Injury Survey (12) indicates that the steering wheel is the most frequent contact for the chest and upper extremities, and is second only to the windshield for head contact. These results were obtained for tractor drivers that were not ejected in frontal impacts. Looking only at steering wheel contacts causing fatal or serious injuries, the head and chest are the most frequent body region contacted. For less serious injuries, the upper extremities are involved more. Based on an analysis of the CPIR-B data, Ranney (1) also identifies the steering wheel as the most frequent contact point for serious injuries to heavy-truck drivers. Ranney also identifies the steering column as the most frequent cause of entrapment. Thus, there are two important countermeasure objectives for the steering column. The first is to prevent penetration, and the second is to minimize injuries associated with occupant contact.

The potential benefits of the various countermeasures considered are summarized in Table 9. This table is organized in the same way as the preceding discussion. The first group shown in Table 9 is the collisions where sufficient survival space was provided by the cab. This group was also shown in Table 7. Prevention of ejection, for example, is estimated to save 16% of the tractor driver fatalities. The columns of Table 9 show the number of NTSB cases affected by each countermeasure and the corresponding percentage of the total. The last column is a projected annual number of fatalities calculated by multiplying the percentage from the NTSB cases by 587, the national total number of tractor driver fatalities during the 12-months of the NTSB study, October 1987 - September 1988. Assuming the effectiveness estimates are nationally representative, prevention of ejection would be expected to prevent 92 tractor driver fatalities per year nationwide.

TABLE 9

Tractor Driver Fatalities by Countermeasure
NTSB Cases and Annual Projection

Countermeasure	NTSB	%	Annual
Cabs with Sufficient Space			
Prevent Ejection	19	16%	92
Restraint Use	13	11%	63
Prevent Fire	8	7%	39
Subtotal	42	35%	204
Improved Structure in Survivable Collisions			
(Assuming Countermeasures Above)			
Rollover	18	15%	87
Frontal	10	8%	49
Subtotal	28	23%	136
Not Survivable	51	42%	247
Total	121	100%	587

Recall from Table 2 that 34% of the fatally injured tractor drivers are ejected. The review of the NTSB cases indicates that there was sufficient survival space in the cab so that about half of the ejection fatalities, 16% of all driver fatalities, would be prevented if the ejection were prevented. The NTSB data also show that the windshield was not retained in nearly all of these cases and that the ejection was usually through the windshield opening. Windshield retention would, therefore, prevent many of the ejections. Bonded windshields and impact resistant door latches have contributed to the integrity of the passenger car occupant compartment. If windshield mounting techniques that provide improved retention can be developed for large trucks, there is the potential to eliminate the leading cause of tractor driver fatality, ejection.

Still focusing on the collisions where sufficient survival space was provided by the cab, restraint use is the essential countermeasure for 11%, or 63, of the driver fatalities annually. This group (11%) is limited to drivers that were *not* ejected. Of course, restraint use is also effective in preventing ejection. Thus, the estimated benefits of restraint use, in the absence of other countermeasures, is a 27% reduction in driver fatalities (16% + 11%). Prevention of fire, without other countermeasures, would save another 7%, or 39 annually. The subtotal shown for this group includes an additional 2 cases (2%) that require both prevention of fire and ejection. Otherwise, only the countermeasure identified appeared necessary to prevent the fatality in this group (cabs with sufficient space).

The second group in Table 9 is the collisions that were judged to be of survivable collision severity, but adequate survival space was not provided by the cab. These were previously shown in Table 8. Prevention of these fatalities requires improved cab structure in addition to restraint use and prevention of ejection and fire. Rollover is the dominant collision situation in this group, accounting for 15% of the total as compared to 8% that are frontal impacts.

Restraint use, prevention of ejection, improved cab structure, improved steering assembly, and prevention of fire have all been identified in the literature previously as heavy-truck crashworthiness countermeasures (1,2,3,4). This study used the NTSB case materials to better define the situations where each countermeasure is applicable, to estimate the potential benefits of each countermeasure, and to identify those collisions that appear to be too severe for survival with any of these countermeasures. Not surprisingly, prevention of ejection and improved cab structure in rollover emerge as the top priorities because these are the most prevalent injury mechanism and collision type, respectively, associated with truck driver fatalities.

Conclusions

Rollover is identified as the primary impact mode associated with about 60% of all tractor driver fatalities. Furthermore, the GES data indicate that the probability of injury to a *restrained* tractor driver in a police-reported rollover accident is still 50%. If the truck does not roll, the probability of injury for the restrained driver drops by a factor of 10 to 4.7%. The probability of fatality drops by a factor of 25 to 0.1% for the restrained driver if the truck does not roll. Based on the GES data, only about 6% of all tractor combinations involved in a police-reported accident roll, but the high risk of fatality makes rollover the most prevalent impact mode for tractor driver fatalities.

Frontal impact is identified as the next most prevalent impact mode for tractor driver fatalities. Unlike rollover, frontal impacts are more common and the probability of injury (14.1%) or fatality (1.9%) is relatively low even for the unrestrained tractor driver. Only frontal impacts with other large trucks, massive fixed objects, or in combination with rollover produce sufficient deceleration levels and/or cab deformation to pose a significant threat to the driver.

The primary injury mechanism for tractor drivers is ejection. One-third of all fatally injured tractor drivers are ejected. Ejection occurs in both rollover and frontal impacts. Extrication, coded for 21.5% of all fatally injured tractor drivers, and fire, associated with 16.2%, are the other factors identified that are suggestive of injury mechanisms. This statistical description of the impact modes and injury mechanisms associated with heavy truck occupant fatalities has remained essentially the same over the past decade. Tabulations prepared by Ranney (1) from the 1979 FARS file provided essentially the same information. Some new information has emerged as well.

More than two-thirds of all ejected occupants came from cabover tractors. In frontal impacts resulting in fatal injuries to the driver, the percentage of drivers ejected is 50% higher for cabover tractors. Data from the TIFA files shows that for restrained drivers in severe impacts, the probability of injury is 20% higher in a cabover as compared to a conventional cab, and the probability of fatality is 40% higher. Estimates from the NTSB case materials indicated that there was sufficient survival space in 35% of the conventional cab tractors as compared to 20% of the cabovers. Thus, the cabover tractor is associated with both higher incidence of ejection and higher probabilities of injury and death for drivers that are not ejected.

Current yearly trends show a decrease in tractor driver fatalities and increased restraint use. A recent observational survey confirms increased restraint use by heavy truck drivers. However, the estimation of restraint effectiveness from existing accident data is problematic because of the suspected bias in the reporting of restraint use. Limiting the estimates to fatal accidents reduces the bias. Based on the TIFA file, restraint use reduces the probability of injury (including fatality) by 24% and the probability of fatality by 77%. The authors believe that these estimates still overstate restraint effectiveness.

The review of the NTSB cases provided some information on the potential benefits of crashworthiness countermeasures in large trucks. Prevention of ejection appears to have the greatest potential for preventing tractor driver fatalities. Prevention of ejection by itself is estimated to prevent 16% of all tractor drivers fatalities, or 92 fatalities per year nationwide. Restraint use has been shown to be effective in preventing ejection. However, windshield retention would also prevent the majority of ejections. Based on the NTSB cases, restraint use would prevent an additional 11%, or 63 fatalities per year, in addition to the 16% that were ejected. Prevention of post-crash fire on the truck would save 7%, or 39 fatalities per year.

The next focus must be on maintaining sufficient survival space for the occupant, particularly in rollover. This is the next countermeasure area identified as having the potential to prevent occupant fatalities. Existing cab structures above the plane of the dash are not sufficient to withstand the forces produced during rollover. Improved cab structure would also facilitate improved windshield retention. However, it will probably be necessary to improve the interior of the occupant compartment as well, particularly the steering column. Restraint use is likely to be necessary for the occupant to benefit from improved structural integrity. The interior surfaces of current cabs pose a significant threat of injury to the unrestrained occupant.

Estimates of the potential for survival from the NTSB cases are appreciably less than estimates of restraint effectiveness derived from the TIFA file. Based on the TIFA file, restraint use appeared to reduce the probability of fatality by 77%. The NTSB review found only 27% that would be prevented by restraint use alone. The estimates from the NTSB cases were deliberately conservative. The actual benefits of restraint use for tractor drivers probably are somewhere between the estimates presented here. However, prevention of ejection and improved cab structure in rollover are the top priorities. These problems must be addressed in order to make appreciable reductions in the number of large truck occupant fatalities in traffic accidents.

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Figures

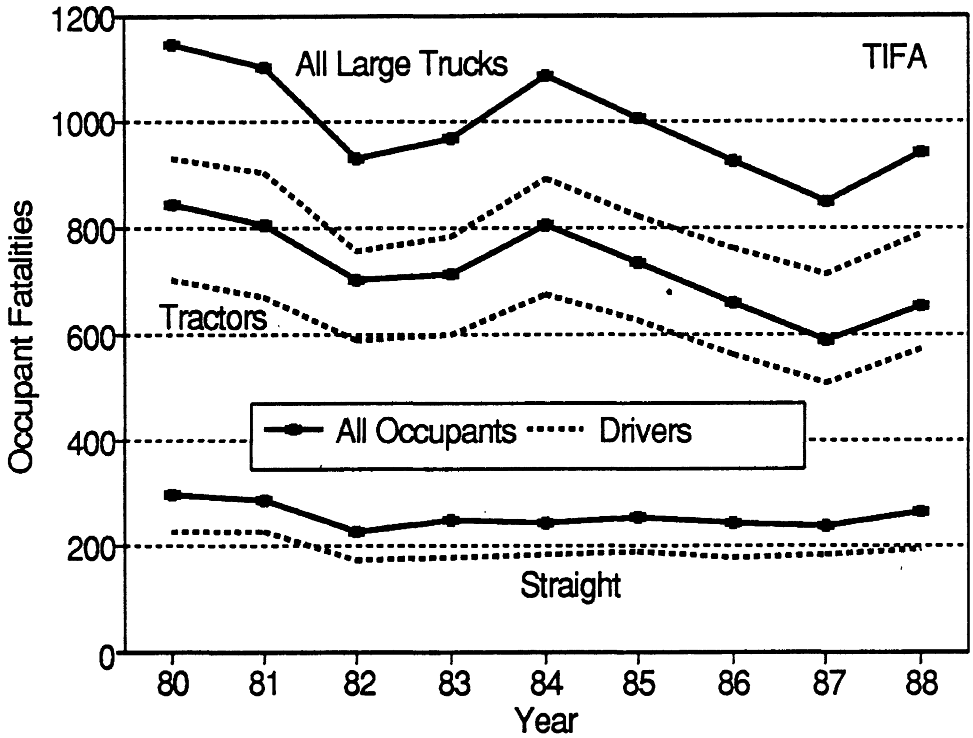

Figure 1: Yearly Large Truck Occupant Fatalities in the United States

TABLE F-1

Occupant Fatalities by Power Unit Type
And as a Percent of All Trucks in Fatal Accidents
1980–88 TIFA

Year	Straight N	Straight %	Tractor N	Tractor %	Total N	Total %
1980	299	22.1	840	23.0	1,146	22.7
1981	288	20.0	804	21.4	1,099	21.0
1982	227	17.9	699	20.3	926	19.6
1983	248	18.9	713	19.8	966	19.5
1984	242	17.6	801	21.5	1,082	20.4
1985	255	17.6	734	19.0	1,003	18.6
1986	241	17.0	659	17.8	920	17.5
1987	235	15.5	588	16.1	848	16.1
1988	263	17.2	652	17.0	937	17.1
TOTAL	2,298	18.2	6,490	19.5	8,927	19.1

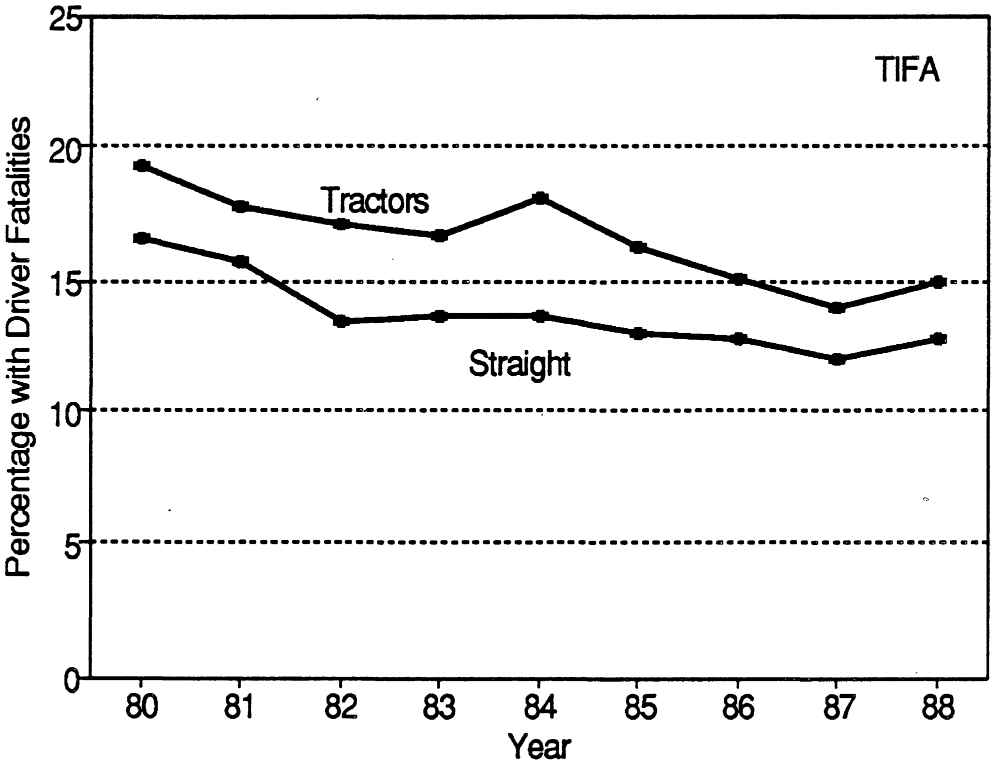

Figure 2: Driver Fatalities as a Percentage of All Trucks Involved in Fatal Accidents

TABLE F-2

**Driver Fatalities by Power Unit Type
And as a Percent of All Trucks in Fatal Accidents
1980–88 TIFA**

	Straight		Tractor		Unknown		Total	
Year	N	%	N	%	N	%	N	%
1980	224	16.6	702	19.2	4	7.1	930	18.4
1981	227	15.7	671	17.8	4	11.1	902	17.2
1982	170	13.4	588	17.1	0	0.0	758	16.1
1983	179	13.7	599	16.6	3	8.3	781	15.8
1984	186	13.6	674	18.1	31	14.2	891	16.8
1985	188	12.9	625	16.2	9	11.0	822	15.2
1986	181	12.8	560	15.1	20	16.4	761	14.5
1987	182	12.0	508	13.9	20	17.9	710	13.5
1988	196	12.8	571	14.9	20	18.3	787	14.4
TOTAL	1,733	13.7	5,498	16.6	111	14.0	7,342	15.7

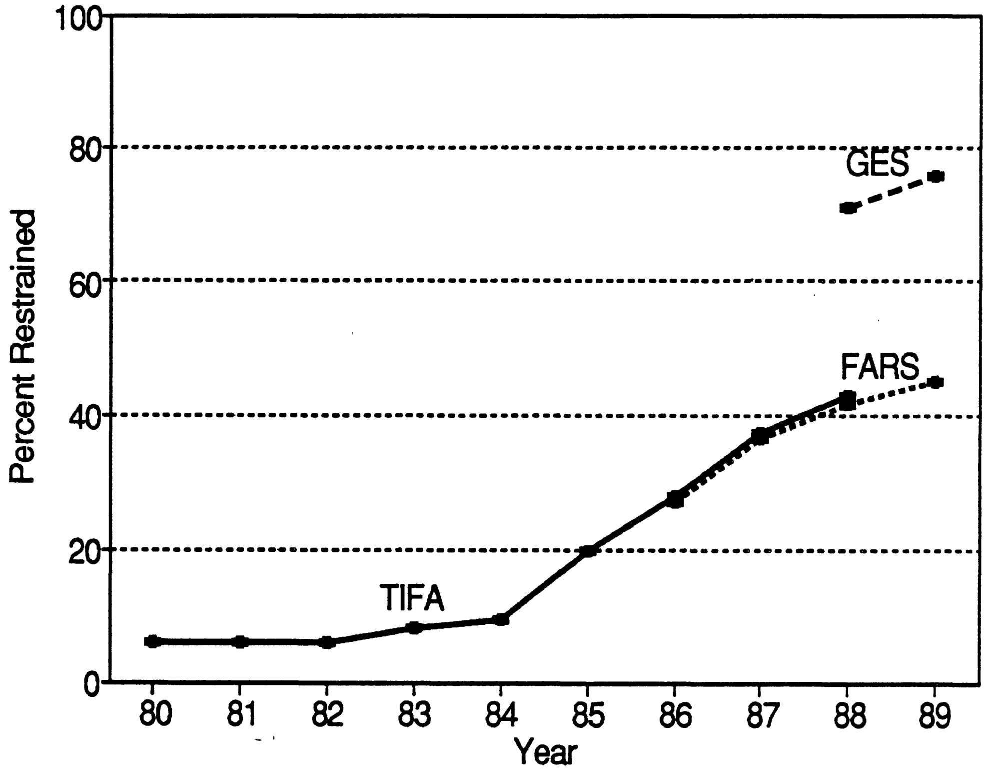

Figure 3: Tractor Driver Restraint Use

TABLE F-3

Restraint Use by Tractor Drivers
1980–1988

Source	1980	1981	1982	1983	1984	1985	1986	1987	1988
TIFA	6.1%	6.1%	6.0%	8.1%	9.6%	19.6%	27.9%	37.3%	43.2%
FARS							27.2	36.6	41.8
GES									70.9

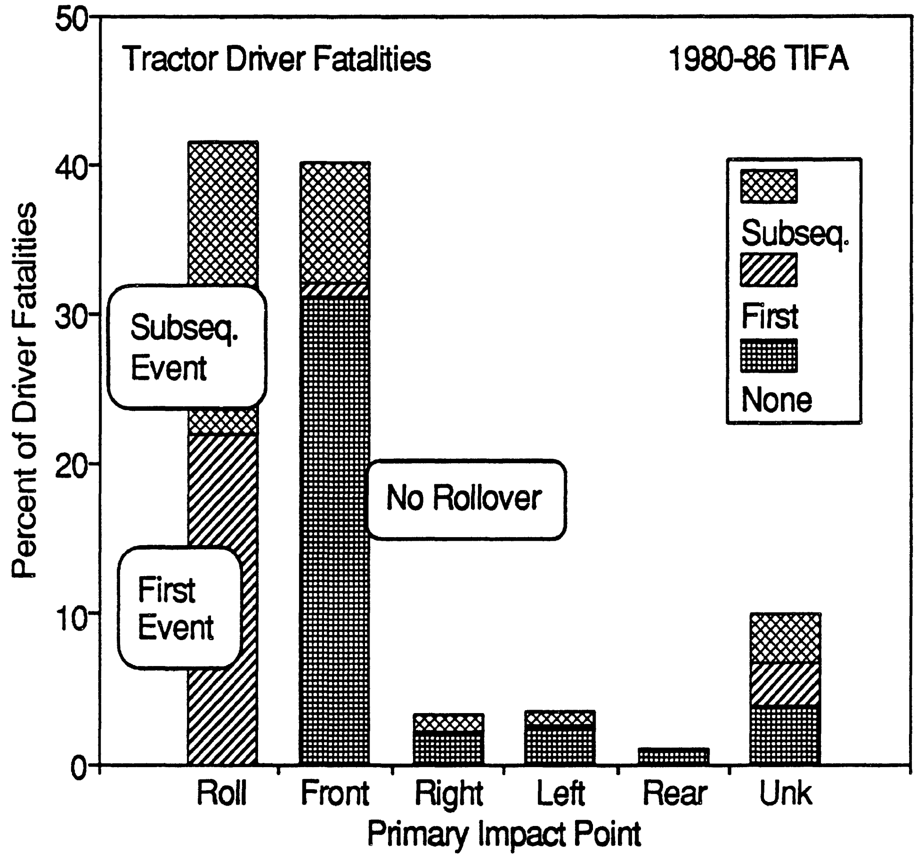

Figure 4: Rollover by Primary Impact Point

TABLE F-4

Rollover by Primary Impact Point
Tractor Drivers Involved in Fatal Accidents
1980–86 TIFA

Primary Impact Point	No Rollover		First Event		Subsequent Event		Total	
	N	%	N	%	N	%	N	%
Roll	0	0.0	966	21.9	864	19.6	1,830	41.4
Front	1,374	31.1	49	1.1	360	8.1	1,783	40.3
Right	86	1.9	10	0.2	57	1.3	153	3.5
Left	107	2.4	7	0.2	41	0.9	155	3.5
Rear	33	0.7	2	0.0	13	0.3	48	1.1
Unknown	173	3.9	131	3.0	146	3.3	450	10.2
TOTAL	2,853	40.1	1,165	26.4	1,481	33.5	4,419	100.0

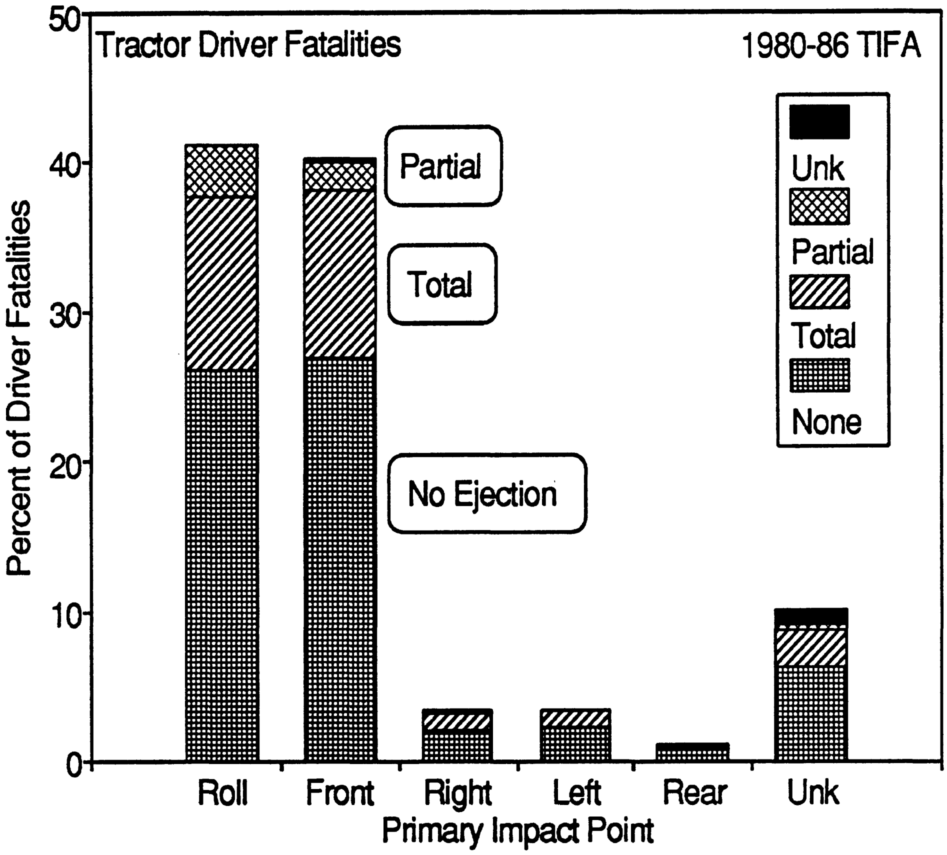

Figure 5: Ejection by Primary Impact Point

TABLE F-5

Ejection by Primary Impact Point
Tractor Drivers Involved in Fatal Accidents
1980–86 TIFA

Primary Impact Point	No Ejection		Total Ejection		Partial Ejection		Unknown		Total	
	N	%	N	%	N	%	N	%	N	%
Roll	1,162	26.3	512	11.6	150	3.4	6	0.1	1,830	41.4
Front	1,196	27.1	490	11.1	86	1.9	11	0.2	1,783	40.3
Right	85	1.9	56	1.3	11	0.2	1	0.0	153	3.5
Left	98	2.2	50	1.1	7	0.2	0	0.0	155	3.5
Rear	37	0.8	9	0.2	2	0.0	0	0.0	48	1.1
Unknown	275	6.2	109	2.5	24	0.5	42	1.0	450	10.2
TOTAL	2,853	64.6	1,226	27.7	280	6.3	60	1.4	4,419	100.0

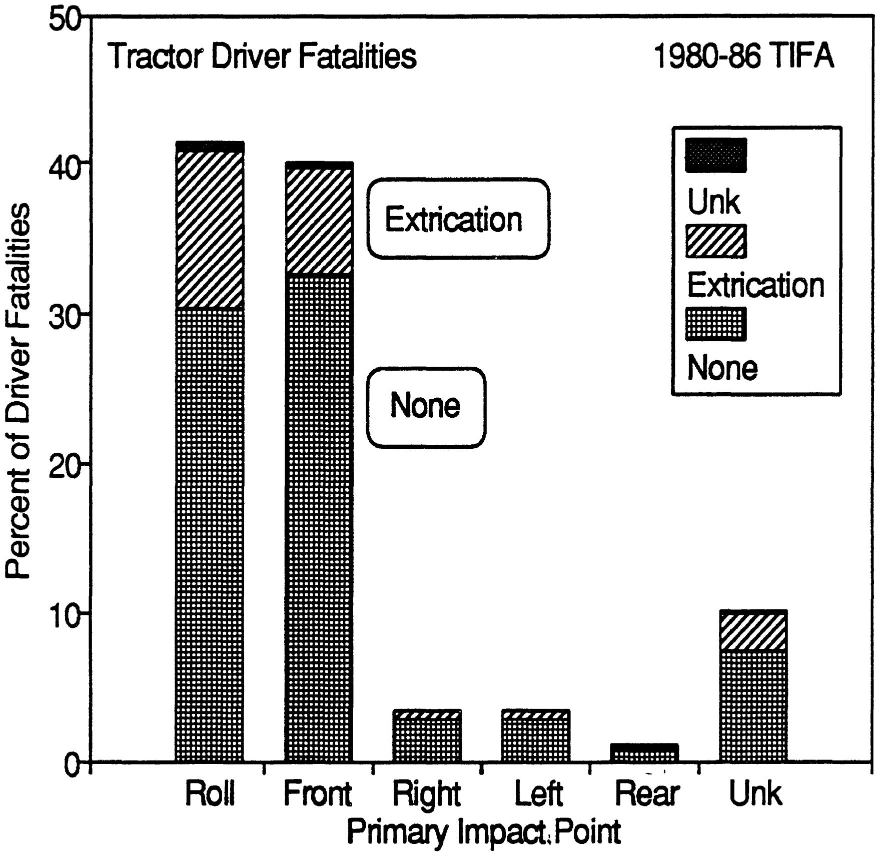

Figure 6: Extrication by Primary Impact Point

TABLE F-6

Extrication by Primary Impact Point
Tractor Drivers Involved in Fatal Accidents
1980–86 TIFA

Primary Impact Point	No Extrication		Extrication		Unknown		Total	
	N	%	N	%	N	%	N	%
Roll	1,336	30.2	466	10.5	28	0.6	1,830	41.4
Front	1,441	32.6	318	7.2	24	0.5	1,783	40.3
Right	131	3.0	20	0.5	2	0.0	153	3.5
Left	130	2.9	25	0.6	0	0.0	155	3.5
Rear	37	0.8	11	0.2	0	0.0	48	1.1
Unknown	329	7.4	111	2.5	10	0.2	450	10.2
TOTAL	3,404	77.0	951	21.5	64	1.4	4,419	100.0

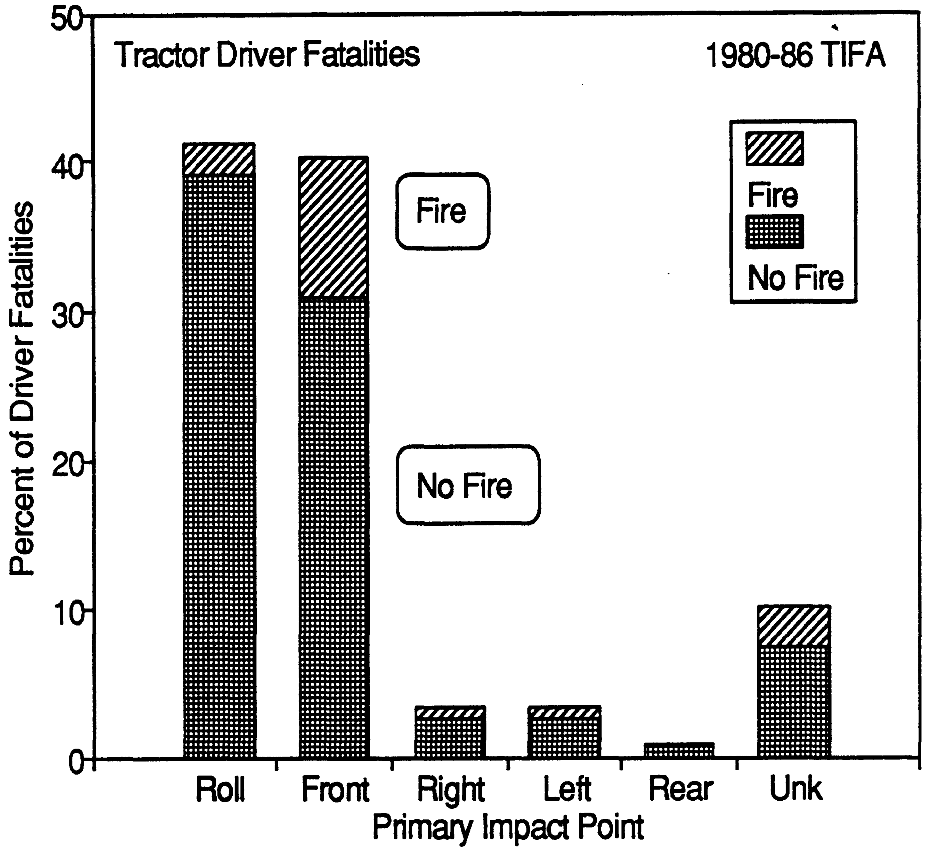

Figure 7: Fire by Primary Impact Point

TABLE F-7

Fire by Primary Impact Point
Tractor Drivers Involved in Fatal Accidents
1980-86 TIFA

Primary Impact Point	No Fire		Fire		Total	
	N	%	N	%	N	%
Roll	1,733	39.2	97	2.2	1,830	41.4
Front	1,362	30.8	421	9.5	1,783	40.3
Right	118	2.7	35	0.8	153	3.5
Left	120	2.7	35	0.8	155	3.5
Rear	40	0.9	8	0.2	48	1.1
Unknown	328	7.4	122	2.8	450	10.2
TOTAL	3,701	83.8	718	16.2	4,419	100.0

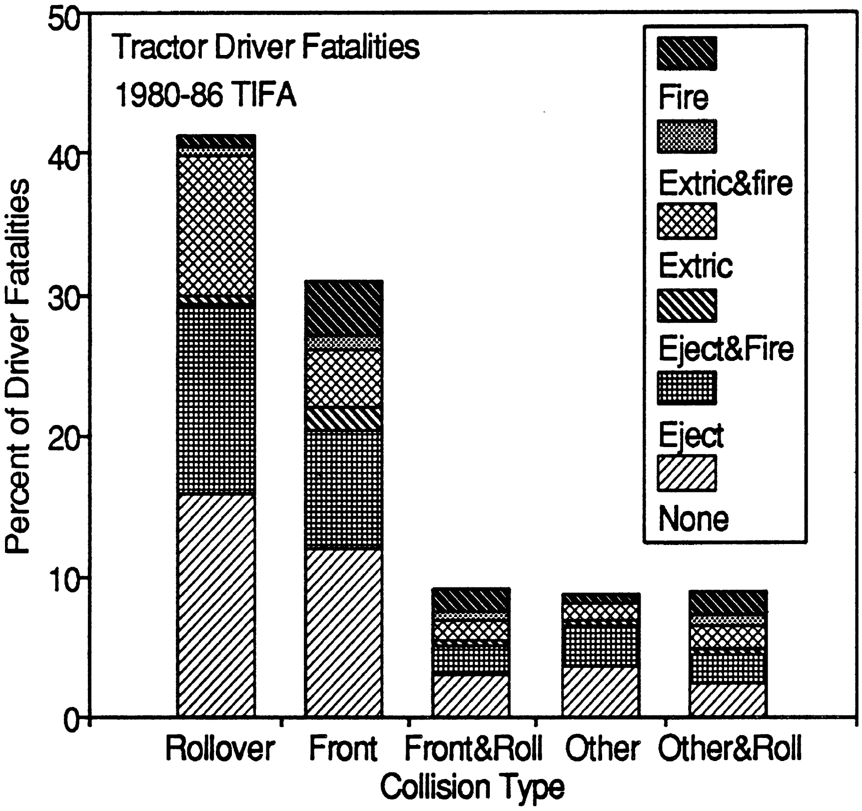

Figure 8: Injury Mechanisms by Collision Type

TABLE F-8

Injury Mechanisms by Collision Type
Tractor Drivers Involved in Fatal Accidents
1980–868 TIFA

Collision Type	Ejection	Ejection & Fire	Entrap	Entrap & Fire	Fire	None	Total
Rollover	590 13.4%	32 0.7%	439 9.9%	27 0.6%	38 0.9%	704 15.9%	1,830 41.4%
Front	367 8.3	76 1.7	177 4.0	47 1.1	174 3.9	533 12.1	1,374 31.1
Front & Roll	90 2.0	21 0.5	61 1.4	33 0.7	70 1.6	134 3.0	409 9.3
Other	131 3.0	21 0.5	47 1.1	7 0.2	31 0.7	162 3.7	399 9.0
Other & Roll	86 1.9	23 0.5	75 1.7	38 0.9	80 1.8	105 2.4	407 9.2
TOTAL	1,264 28.6	173 3.9	799 18.1	152 3.4	393 8.9	1,638 37.1	4,419 100.0

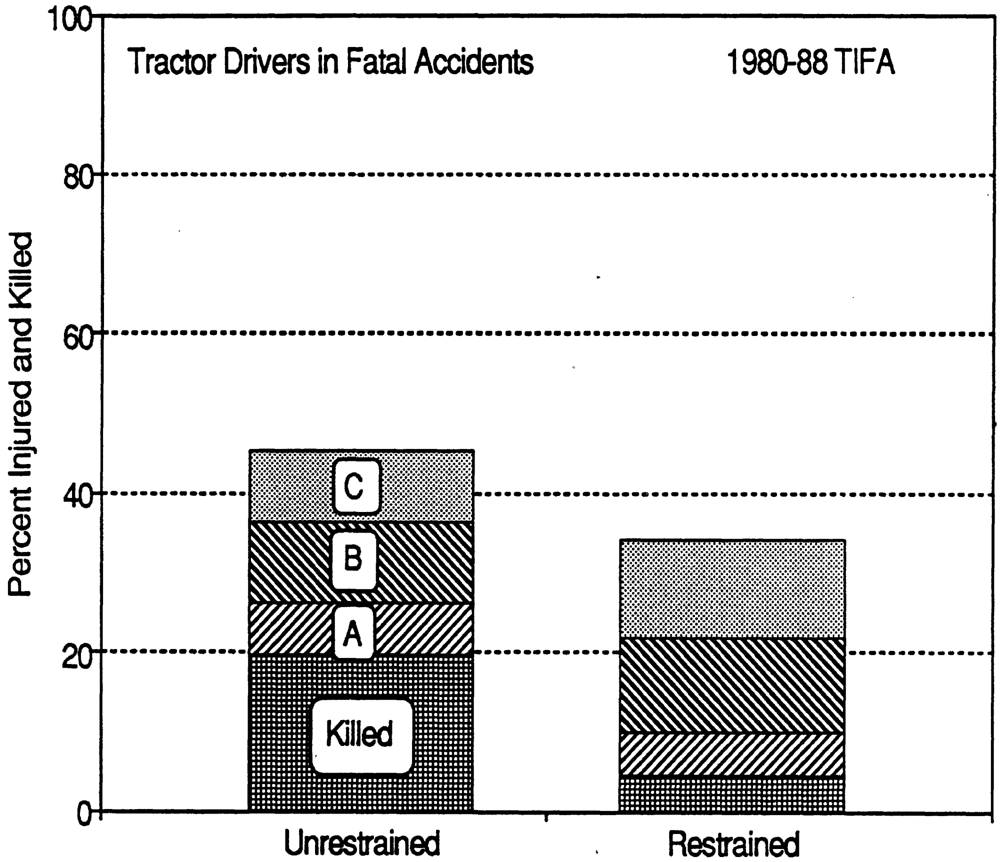

Figure 9: Probability of Injury by Restraint Use (TIFA)

TABLE F-9

Probability of Injury by Restraint Use
Tractor Drivers Involved in Fatal Accidents
1980–88 TIFA

Injury Severity	Unrestrained		Restrained	
	N	%	N	%
Not Injured	14,424	54.4	3,944	65.5
C Injury	2,494	9.4	750	12.5
B Injury	2,688	10.1	721	12.0
A Injury	1,707	6.4	333	5.5
Fatal Injury	5,222	19.7	276	4.6
TOTAL	26,535	100.0	6,024	100.0

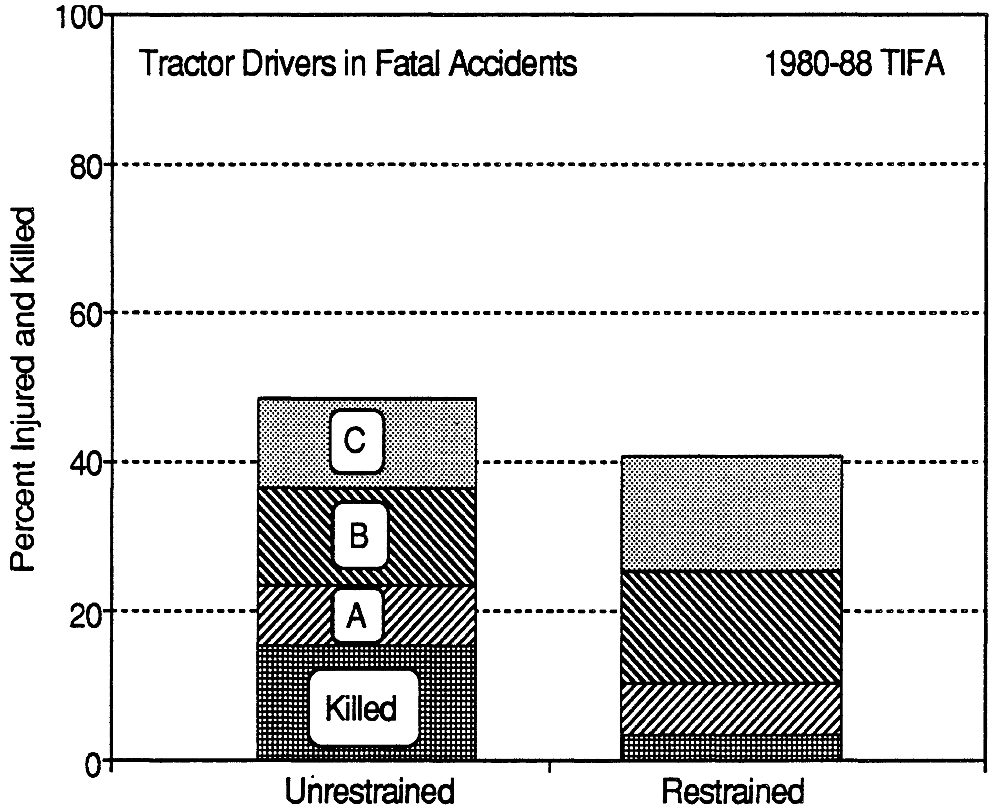

Figure 10: Restraint Effectiveness in Frontal Impacts (TIFA)

TABLE F-10

Restraint Effectiveness in Frontal Impacts
Tractor Drivers Involved in Fatal Accidents
1980–88 TIFA

Injury Severity	Unrestrained		Restrained	
	N	%	N	%
Not Injured	7,264	51.4	2,026	59.0
C Injury	1,693	12.0	525	15.3
B Injury	1,833	13.0	524	15.3
A Injury	1,170	8.3	234	6.8
Fatal Injury	2,160	15.3	1,23	3.6
TOTAL	14,120	100.0	3,432	100.0

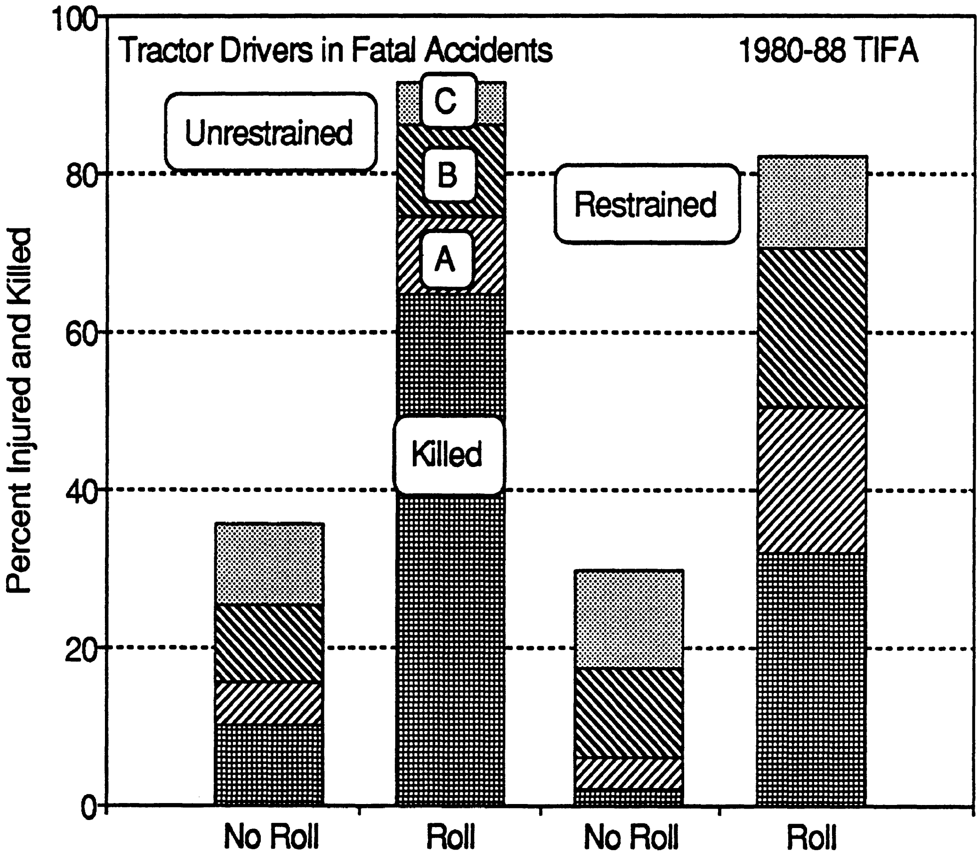

Figure 11: Restraint Effectiveness in Rollover (TIFA)

TABLE F-11

Restraint Effectiveness with Rollover
Tractor Drivers Involved in Fatal Accidents
1980–88 TIFA

Injury Severity	Unrestrained				Restrained			
	No Roll		Roll		No Roll		Roll	
	N	%	N	%	N	%	N	%
Not Injured	14,036	64.4	388	8.2	3,853	69.9	91	17.8
C Injury	2,232	10.2	262	5.5	690	12.5	60	11.7
B Injury	2,133	9.8	555	11.7	620	11.2	101	19.8
A Injury	1,232	5.7	475	10.0	238	4.3	95	18.6
Fatal Injury	2,159	9.9	3,063	64.6	112	2.0	164	32.1
TOTAL	21,792	100.0	4,743	100.0	5,513	100.0	511	100.0

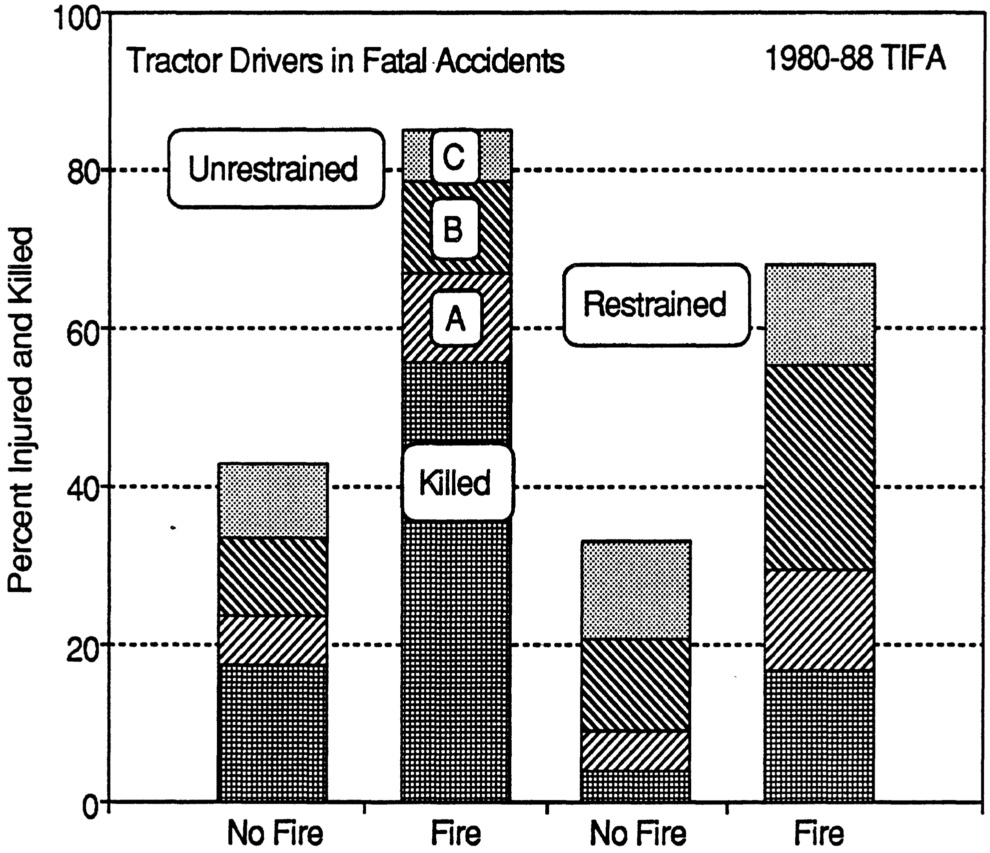

Figure 12: Restraint Effectiveness with Fire (TIFA)

TABLE F-12

Restraint Effectiveness with Fire
Tractor Drivers Involved in Fatal Accidents
1980–88 TIFA

Injury Severity	Unrestrained				Restrained			
	No Fire		Fire		No Fire		Fire	
	N	%	N	%	N	%	N	%
Not Injured	14,201	56.8	223	14.7	3,881	66.6	63	31.8
C Injury	2,396	9.6	98	6.5	725	12.4	25	12.6
B Injury	2,509	10.0	179	11.8	670	11.5	51	25.8
A Injury	1,534	6.1	173	11.4	307	5.3	26	13.1
Fatal Injury	4,379	17.5	843	55.6	243	4.2	33	16.7
TOTAL	25,019	100.0	1,516	100.0	5,826	100.0	198	100.0

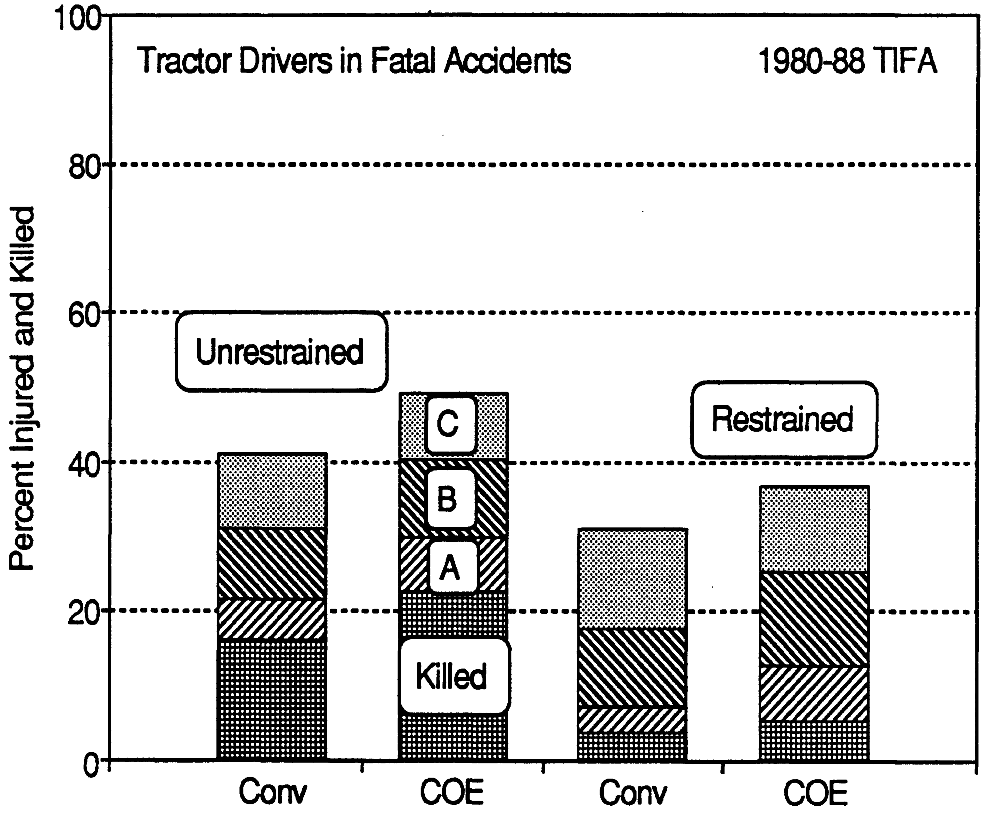

Figure 13: Restraint Effectiveness by Cabstyle (TIFA)

TABLE F-13

Restraint Effectiveness by Cabstyle
Tractor Drivers Involved in Fatal Accidents
1980–88 TIFA

Injury Severity	Unrestrained				Restrained			
	Conventional		Cabover		Conventional		Cabover	
	N	%	N	%	N	%	N	%
Not Injured	6,861	58.9	6,883	50.5	1,970	68.5	1,903	62.8
C Injury	1,171	10.0	1,212	8.9	385	13.4	348	11.5
B Injury	1,120	9.6	1,452	10.6	307	10.7	396	13.1
A Injury	626	5.4	1,010	7.4	104	3.6	223	7.4
Fatal Injury	1,877	16.1	3,084	22.6	109	3.8	161	5.3
TOTAL	11,655	100.0	13,641	100.0	2,875	100.0	3,031	100.0

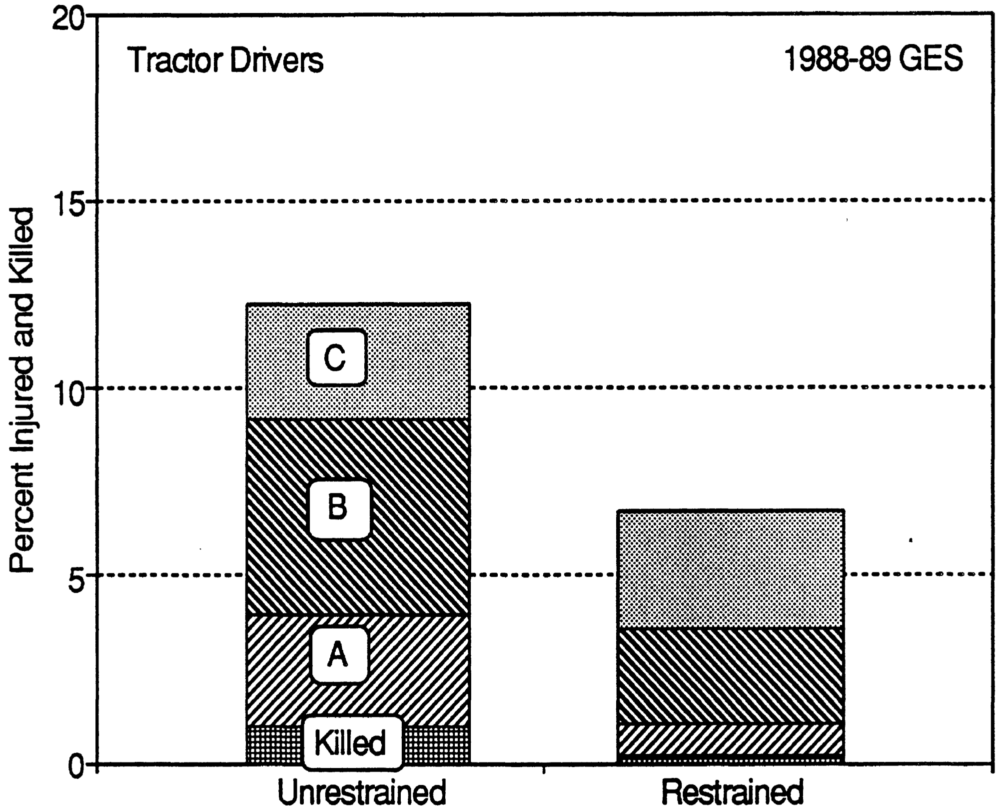

Figure 14: Probability of Injury by Restraint Use (GES)

TABLE F-14

Probability of Injury by Restraint Use
1988–89 GES

Injury Severity	Unrestrained		Restrained	
	N	%	N	%
Not Injured	72,214	87.7	212,121	93.3
C Injury	2,564	3.1	7,142	3.1
B Injury	4,331	5.3	5,808	2.6
A Injury	2,445	3.0	1,908	0.8
Fatal Injury	791	1.0	388	0.2
TOTAL	82,345	100.0	227,367	100.0

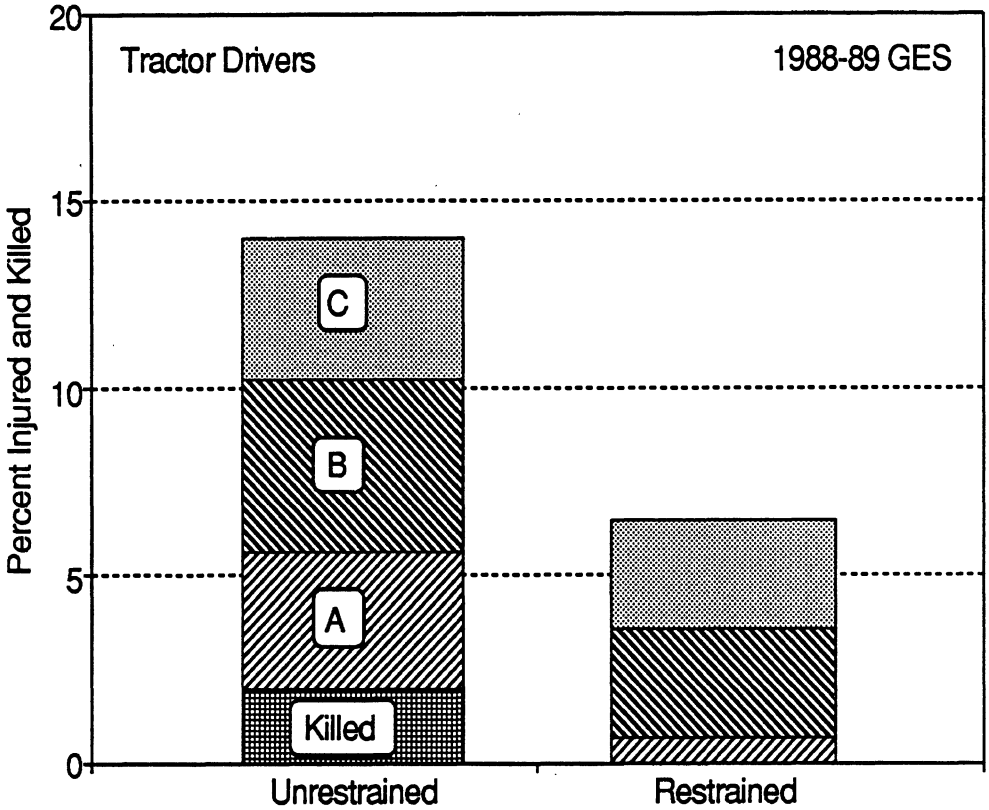

Figure 15: Restraint Effectiveness in Frontal Impacts (GES)

TABLE F-15

Restraint Effectiveness in Frontal Impacts
1988–89 GES

Injury Severity	Unrestrained		Restrained	
	N	%	N	%
Not Injured	12,992	85.9	46,367	93.5
C Injury	572	3.8	14,50	2.9
B Injury	706	4.7	1,457	2.9
A Injury	563	3.7	300	0.6
Fatal Injury	290	1.9	0	0.0
TOTAL	15,123	100.0	49,574	100.0

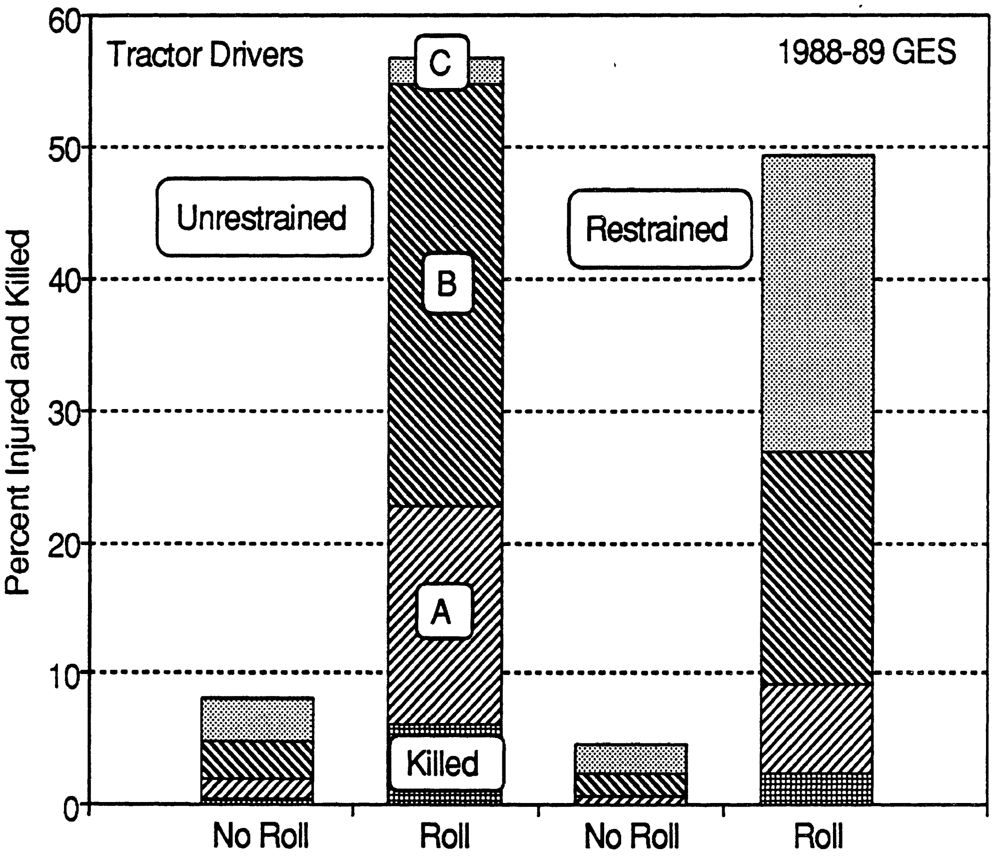

Figure 16: Restraint Effectiveness in Rollover (GES)

TABLE F-16

Restraint Effectiveness in Rollover
1988–89 GES

Injury Severity	Unrestrained				Restrained			
	No Roll		Roll		No Roll		Roll	
	N	%	N	%	N	%	N	%
Not Injured	69,163	91.9	3,051	43.1	206,992	95.3	5,129	50.5
C Injury	2,419	3.2	145	2.1	4,863	2.2	2,279	22.5
B Injury	2,062	2.7	2,269	32.1	3,998	1.8	1,810	17.8
A Injury	1,278	1.7	1,167	16.5	1,230	0.6	678	6.7
Fatal Injury	350	0.5	441	6.2	133	0.1	255	2.5
TOTAL	75,272	100.0	7,073	100.0	217,216	100.0	10,151	100.0

APPENDIX B

Fatality Rates by Cabstyle

One reviewer of this report raised the issue of the exposure of conventional cab versus cabover tractors with regard to the accident statistic presented that indicted that 69% of the fatally injured tractor drivers that were ejected came from cabover tractors. The question raised was whether cabover tractors travel more on high speed roads and are consequently involved in collisions of greater severity. This is a study of vehicle crashworthiness, and the authors approached the study entirely on the basis of accident data. The focus of the study was to compare probabilities of injury and fatality given that a collision has occurred. Generally, this approach effectively separates the issues of interest here, the crashworthiness of the vehicle, from issues associated with the probability of being involved in a collision, the risk of accident involvement. Ideally, the accident data would include good information of the severity of the collisions, so this aspect could be addressed directly. However, the available data on collision severity for tractors is limited to the Truck Driver Injury Survey (12). Since the Center for National Truck Statistics at UMTRI conducted the National Truck Trip Information Survey (NTTIS) a few years ago, exposure data are available by both cabstyle and road type. Tractor-semitrailer driver fatality rates per hundred million miles travelled are presented here. While the rates presented provide some overall information on fatality rates by cabstyle on rural and urban roads, a more comprehensive analysis of the risk of accident involvement is required to address other factors that may be related to the exposure of tractors by cabstyle.

Table B-1 presents fatality rates for drivers of tractor-semitrailers based on the 1986 Trucks Involved in Fatal Accidents (TIFA) file and the 1986 National Truck Trip Information Survey (NTTIS).[B1] Government-owned and 1984 model year or newer trucks were not included in the NTTIS exposure survey conducted during 1986, and are omitted from the 1986 TIFA accident data for consistency. Travel estimates by cabstyle are also available from the 1987 Truck Inventory and Use Survey,[B2] although road type is not distinguished. Driver fatality rates by cabstyle are presented in Table B-2 based on the 1987 TIFA and the 1987 TIUS data. Again, government-owned trucks are not included in TIUS and are excluded from the TIFA accident data for consistency.

[B1] *Analysis of Accident Rates of Heavy-Duty Vehicles.* K.L. Campbell, D.F. Blower, R.G. Gattis, and A.C. Wolfe. Ann Arbor: The University of Michigan Transportation Research Institute. Report No. UMTRI-88-17. April 1988.

[B2] *Census of Transportation, 1987 Truck Inventory and Use Survey Technical Documentation.* Washington, D.C.: Bureau of the Census. 1990.

TABLE B-1

Driver Fatality Rates by Cabstyle for Tractor-Semitrailers 1986 TIFA and NTTIS

Cabstyle & Area Type	Driver Fatals	Hundred Million Miles	Fatal Rate	Relative Risk
Conventional				
Urban	33	58.66	0.56	
Rural	94	108.33	0.87	
All Roads	127	166.99	0.76	
Cabover				
Urban	46	47.61	0.97	1.73
Rural	147	117.67	1.25	1.44
All Roads	193	165.28	1.17	1.54
Overall	320	332.27	0.96	

[a]Excludes government-owned trucks, 1984 and newer model years, and missing data.

TABLE B-2

Driver Fatality Rates by Cabstyle for Tractor-Semitrailers 1987 TIFA and TIUS[a]

Cabstyle & Area Type	Driver Fatals	Hundred Million Miles	Fatal Rate	Relative Risk
Conventional	188	290.21	0.65	
Cabover	250	249.78	1.00	1.54
Overall	438	539.99	0.81	

[a]Excludes government-owned trucks and missing data.

First, it should be noted that the overall driver fatality rates for all tractor-semitrailers estimated from the 1986 TIFA and NTTIS data in the bottom row of Table B-1 as 0.96 fatalities per hundred million vehicle miles is reasonably consistent with the rate of 0.81 in Table B-2 based on the 1987 TIFA and TIUS data. The fatality rates by cabstyle are also quite consistent. The last column of each table shows a "relative risk" to facilitate comparison by cabstyle. The relative risk is calculated by dividing the rate for the cabover drivers by the corresponding rate for conventional cab drivers. In Table B-2, for example, the rate for cabover drivers is 1.00 fatality per hundred million miles. Dividing by the fatality rate for conventional cab drivers, 1.0/.65 = 1.54, the relative increase in the risk of fatality for cabover drivers as compared to conventional cab drivers. In other words, the fatality rate is 54% higher for cabover drivers, based on the data in Table B-2. The comparable relative risk from Table B-1 is 1.54, the same.

Finally, looking at the relative risk on urban as compared to rural roads in an effort to separate high-speed travel from lower speeds in Table B-1, the relative risk for cabover drivers is somewhat higher in urban areas at 1.73 as compared to 1.44 in rural areas. Recall that the differences in the probability of fatality, injury, and ejection by cabstyle were all greater in frontal impacts and more similar in rollover. Rollover is primarily a rural accident event. A greater likelihood of frontal impacts in urban areas may explain the greater relative risk.

These results provide consistent estimates of an approximately 50% increase in the risk of fatality per mile traveled for cabover drivers as compared to conventional cab drivers. While overall risk figures do not distinguish the risk of collision involvement from the risk of fatality given a collision, the 54% increase in the risk of fatality per mile travelled shown here is essentially consistent with the 40% increase in the probability of fatality given a collision that was presented in Figure 13. Hence, these results support the conclusion that the difference is largely in the relative crashworthiness of the respective cabstyles, and not due to differences in use.

APPENDIX C

Cab Materials

The sponsors of the project raised the question as to whether there was any relationship between the materials used in the construction of the truck cab and the structural performance of the cab in a collision. Information provided by the manufacturers to NTSB on cab materials for trucks that rolled onto the roof (a half-turn roll or more) was subsequently obtained from NTSB. To be consistent with previous tabulations of the NTSB data, only tractors are included. The data received on cab materials for 33 of the NTSB cases that involved a tractor rolling one half-turn or more are summarized in Table C-1 below.

TABLE C-1

Cab Materials for Tractors that Rolled onto the Roof

Cab Material	Conventional	Cabover
Steel	8	0
Aluminum	4	18
Fiberglass	3	0
TOTAL	15	18

The entire cab of all 18 cabover tractors is described as being of all aluminum construction. However, a variety of materials are used in conventional cab construction. While the conventional aluminum cabs were also described as being all aluminum in construction, the fiberglass was only used in the roof panel. Also, aluminum doors were noticed as an option on some conventional cabs that were otherwise made of steel, as were aluminum roof panels. Information on door materials was not provided.

All of these cabs sustained substantial roof crush. However, 7 of the cabs did provide marginal to adequate survival space for the driver (2 conventional steel, 1 conventional with a fiberglass roof panel, and 4 aluminum cabovers). In these cases, the fatality occurred because the unrestrained driver was ejected or moved to the area of the cab sustaining the most damage. There was not sufficient survival space for the driver in any of the remaining cases, 25 out the 33 (76%), and 17 (52%) of the collisions were judged to be too severe to be survivable. (Photographs were not available for one of these cases, so no assessment of survival space could be made.)

In the authors' opinion, these data do not support any conclusion regarding the relationship of the materials used in cab construction and the resulting structural performance in a collision. All of the cabovers were aluminum, and some of these did provide adequate survival space. Overall, 25% (2/8) of the steel cabs provided marginal or better survival space, as compared to 20% (5/25) non-steel cabs.

More to the point, all of these cases resulted in fatality. No information on cab materials is available for non-fatal collisions so that the probability of injury could not be estimated for cabs of different materials.