Truck Crashworthiness in the United States
"A Historical Perspective"

SAE Heavy Vehicle Rollover TOPTEC
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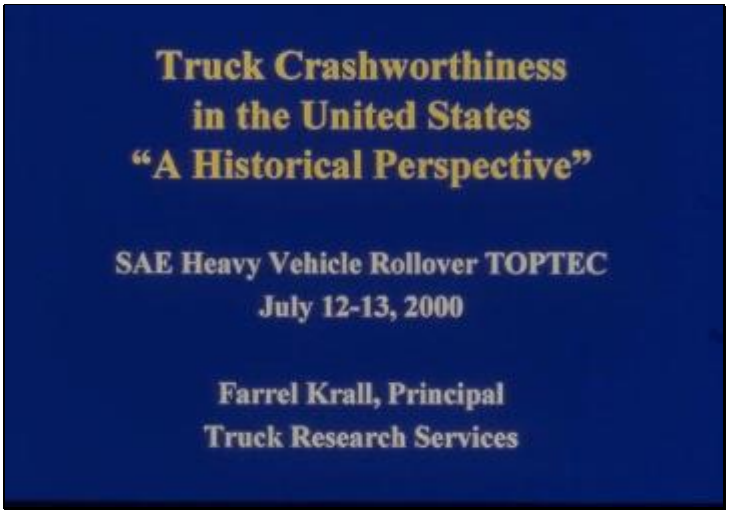


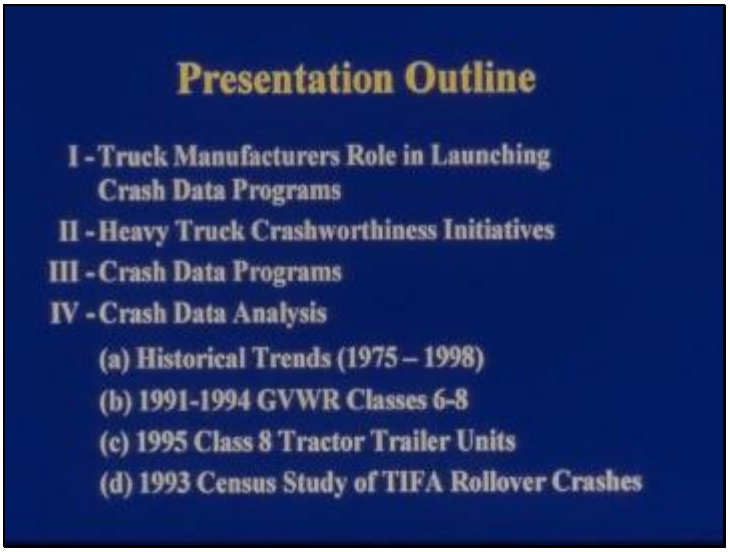
Slide No. 1

Significant progress has been made by U.S. truck manufacturers and the USDOT during the past couple of decades in researching and upgrading crashworthiness design and performance of heavy trucks. I am pleased to have the opportunity to overview the history of these developments with you today as part of this SAE TOPTEC Session. The majority of my 40-year engineering career in the trucking industry has been devoted to the field of truck safety. I joined International Harvester Co. (now Navistar International) in 1960 and worked in vehicle design and test engineering for six years. I then transferred to the *Engineering Vehicle Safety Group* shortly after the U.S. Congress enacted the *National Traffic and Motor Vehicle Safety Act* in September 1966.

I was later promoted to the position of Manager Technical Legislation and held that position until retiring from Navistar in 1996. I feel privileged to have had the opportunity to be directly involved in the advancement of truck crash-injury protection as overviewed in this presentation.

SAE has also played a significant leadership role in advancing the state-of-the-art of truck crashworthiness. In view of this, I believe it is highly appropriate that *heavy vehicle rollover* is the topic of this SAE TOPTEC SESSION. As you will hear later in the presentation, an effective SAE technical committee structure was organized - on an as-needed basis - to plan, implement, and provide technical oversight of important research, testing and standards development under the *SAE Cooperative Research Program.*

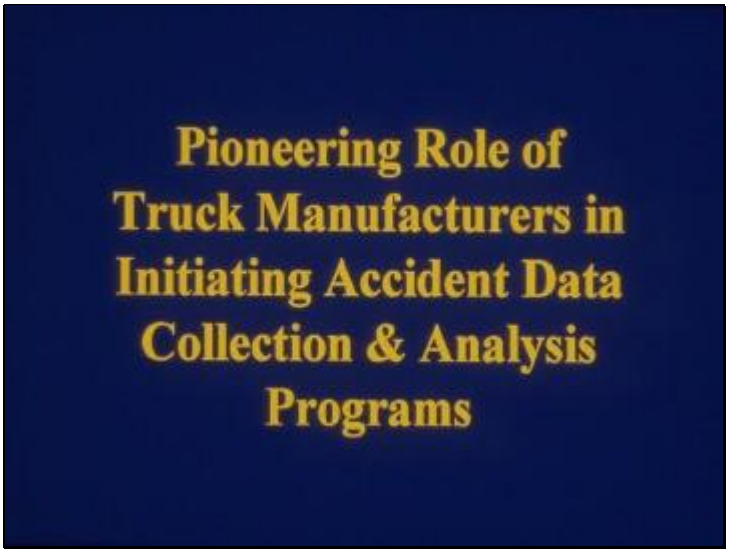
The genesis of this historical overview dates back to the late 1960's. Enactment of the "*1966 Safety Act",* as referenced above, motivated truck manufacturers to collectively pursue many of the safety initiatives discussed in this presentation. Truck manufacturers, via their trade association AMA, decided at that time it was necessary to take a pro-active approach to objectively pursue the research investigation and safety enhancement of commercial vehicles.



Slide No. 2

Since truck accident data were virtually non-existent at the time, truck manufacturers decided to sponsor several accident data collection/analysis studies to investigate emerging safety issues such as truck crashworthiness (i.e.,crash-injury protection). Much of the research and regulatory development work covered in this presentation was coordinated through the *Motor Vehicle Manufacturers Association* (MVMA). As background, MVMA (known as AMA prior to 1972) was later dissolved as the truck manufacturers trade organization in December 1992.

I have selected four sample topics for analysis as a means of illustrating the type and quality of accident data that are generally available in the U.S. I would also like to give credit to Dan Blower of UMTRI for his assistance in interrogating the UMTRI accident -data files in support of the analysis effort presented herein.

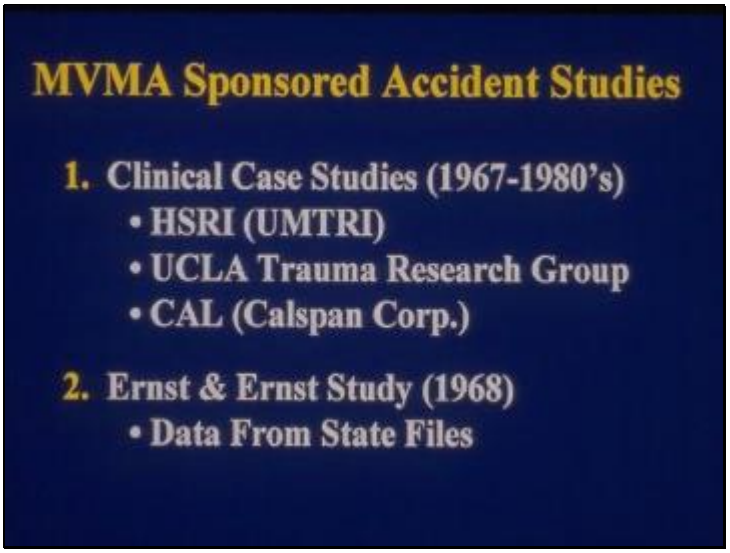


Slide No. 3

Shortly after the U.S. Congress enacted the 1966 Safety Act U.S. truck manufacturers launched an aggressive accident data collection effort via MVMA to assess the highway accident experience of large commercial vehicles. Based on information gained from these early accident studies, MVMA spearheaded the implementation of the *Trucks Involved in Fatal Accidents (TIFA)* Program in 1980 by UMTRI. MVMA continued to fund the TIFA Program until MVMA was dissolved in December 1992.

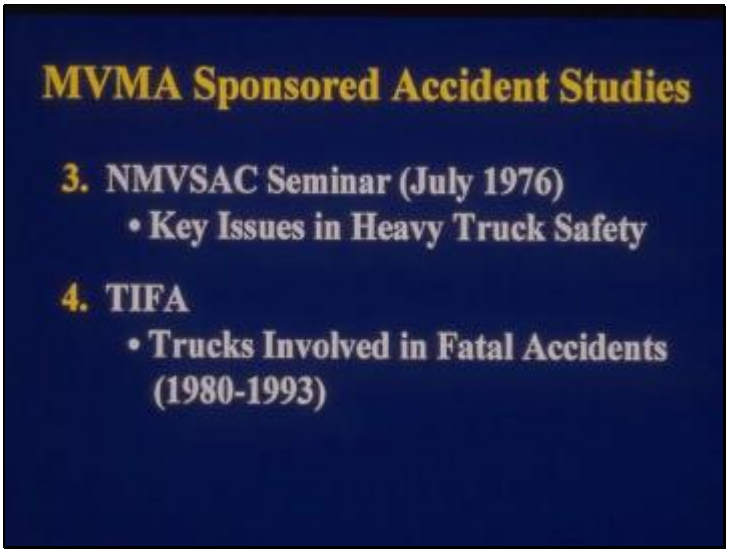
This section of the presentation provides an overview of the numerous accident data program initiatives that were sponsored by MVMA. A complete listing of the studies sponsored by MVMA can be found in *MVMA Sponsored Motor Truck Research (A Bibliography) December 1992.*

This Document is Reference 7 in the Farrel Krall Resource Library: www.kralltrucksafety.com



Slide No. 4

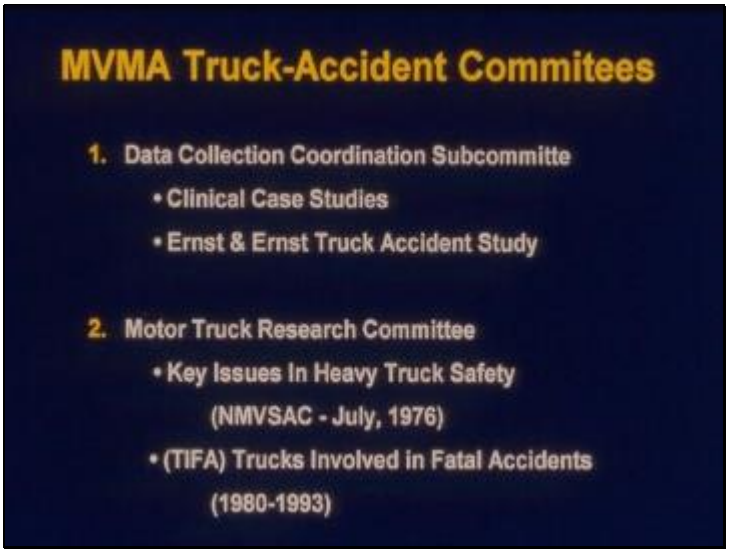
To illustrate the evolutionary development of MVMA's data collection efforts, I will highlight, as examples, four of the early MVMA sponsored studies. The initial approach was to sponsor in depth clinical case studies of a limited number of select truck crashes. The follow-on Ernst & Ernst study was initiated as an attempt to gain a better statistical understanding of truck crashes at the national level. The results of this study clearly revealed that the research quality of state accident data was extremely lacking of pertinent accident information.



Slide No. 5

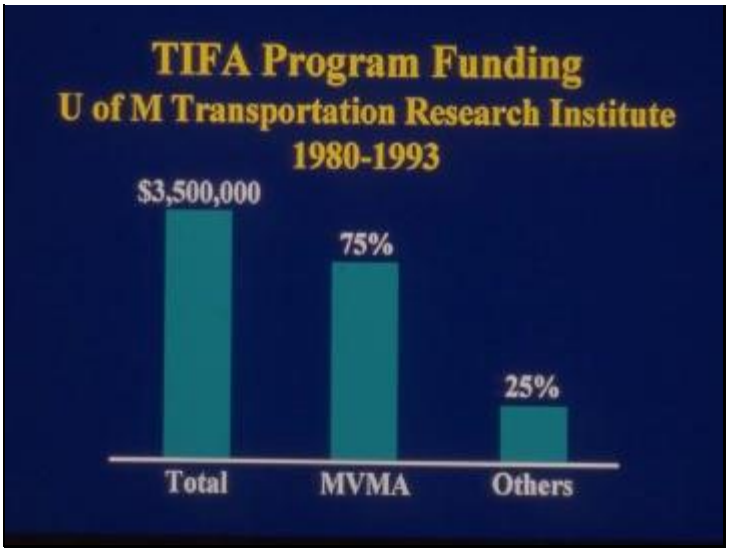
As a third generation initiative, MVMA retained two leading independent research institutions, namely Calspan Corporation & Southwest Research Institute, to analyze their respective accident data bases. The purpose of these studies was to seek information to respond to a report that was authored by a member of DOT's *National Motor Vehicle Safety Advisory Committee*. The results of these two analyses, in support of the Ernst & Ernst study, substantiated the fact that the quality of available accident data is grossly lacking. As a next step, MVMA retained the services of the University of Michigan Highway Safety Research Institute (later renamed the University of Michigan *Transportation Research Institute*) to develop and implement the national TIFA Program.

TIFA has earned the reputation as being the leading source of quality data on fatal truck involvements in the U.S. Most of the data analysis included in this presentation is derived from the TIFA data base.



Slide No. 6

Shown here are the two MVMA committees that had primary responsibility for developing and monitoring MVMA sponsored crash data programs. This author served as a charter truck member of the *Data Collection Coordination Subcommittee* and also as a member of the *Motor Truck Research Committee* from 1966 through 1992, at which time the MVMA organization was dissolved.

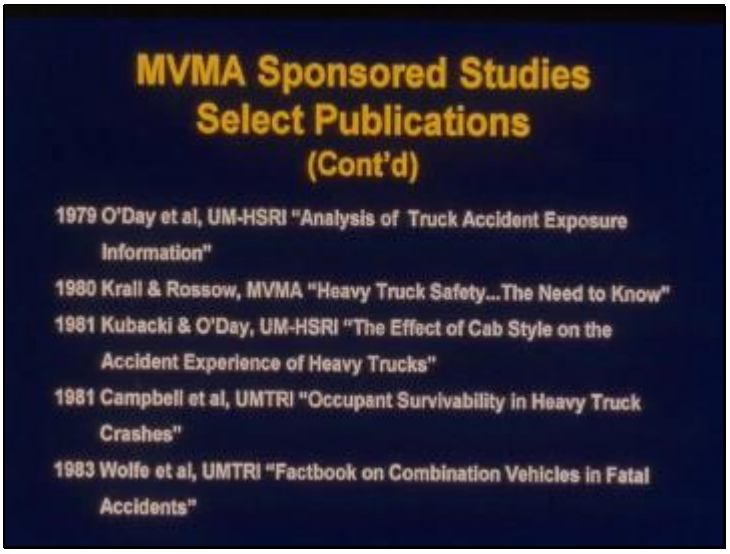


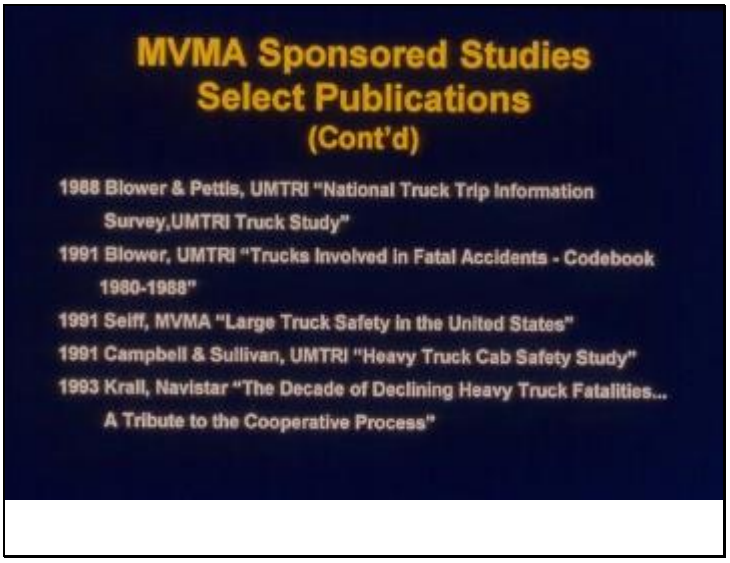
Slide No. 7

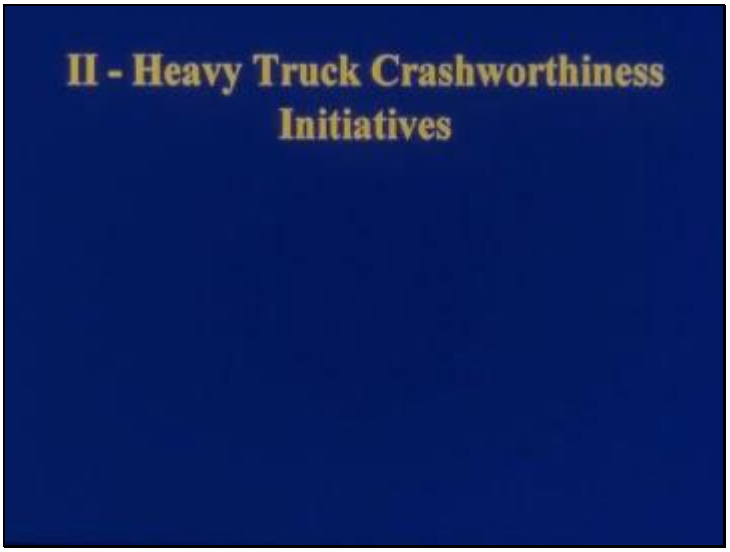
MVMA provided 75% of the $3,500,000 to support the TIFA Program from 1980 thru 1993; the remaining 25% was furnished by the U.S. government and other trucking organizations.

Slide No. 8

Shown on this slide and the next two slides is a select listing of 15 study reports that were generated from MVMA sponsored accident data programs.

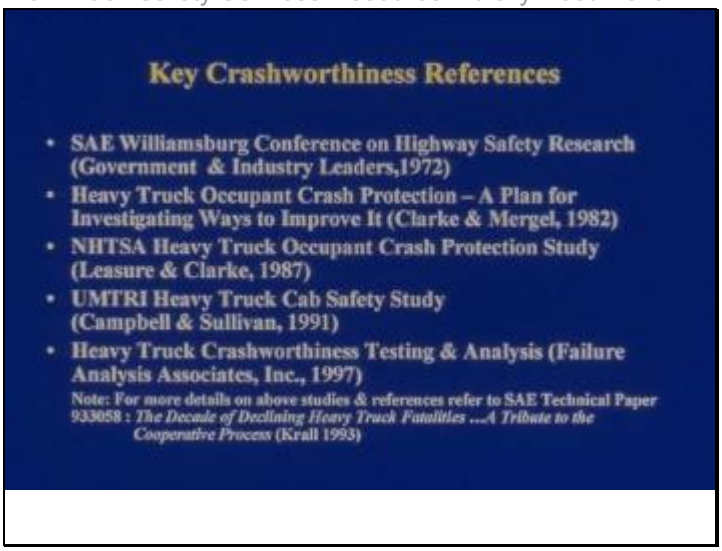

MVMA Sponsored Studies
Select Publications
(Cont'd)
1979 O'Day et al, UM-HSRI "Analysis of Truck Accident Exposure Information"
1980 Krall & Rossow, MVMA "Heavy Truck Safety...The Need to Know"
1981 Kubacki & O'Day, UM-HSRI "The Effect of Cab Style on the Accident Experience of Heavy Trucks"
1981 Campbell et al, UMTRI "Occupant Survivability in Heavy Truck Crashes"
1983 Wolfe et al, UMTRI "Factbook on Combination Vehicles in Fatal Accidents"


MVMA Sponsored Studies
Select Publications
(Cont'd)
1988 Blower & Pettis, UMTRI "National Truck Trip Information Survey,UMTRI Truck Study"
1991 Blower, UMTRI "Trucks Involved in Fatal Accidents - Codebook 1980-1988"
1991 Seiff, MVMA "Large Truck Safety in the United States"
1991 Campbell & Sullivan, UMTRI "Heavy Truck Cab Safety Study"
1993 Krall, Navistar "The Decade of Declining Heavy Truck Fatalities... A Tribute to the Cooperative Process"



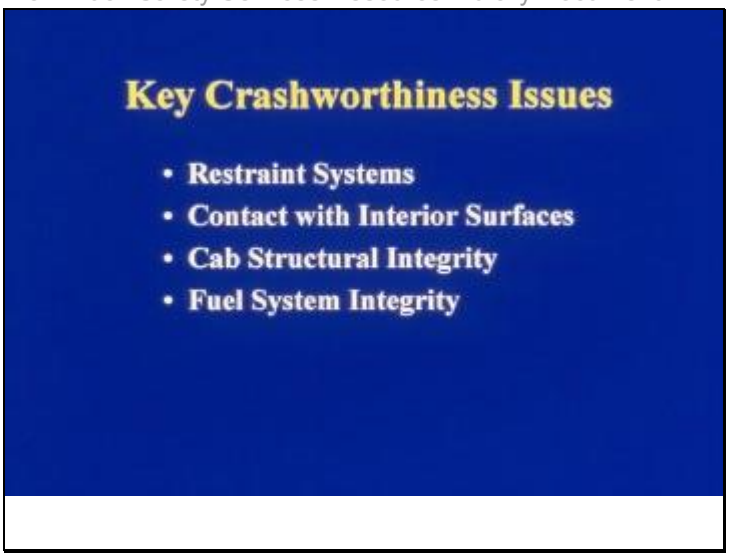
Slide No. 11

As noted earlier, the issue of truck crashworthiness has received considerable longstanding attention by truck manufacturers and other organizations. This section of the paper provides an overview of the many crashworthiness initiatives that have been undertaken by truck manufacturers, the USDOT, and the trucking community at large.



Slide No. 12

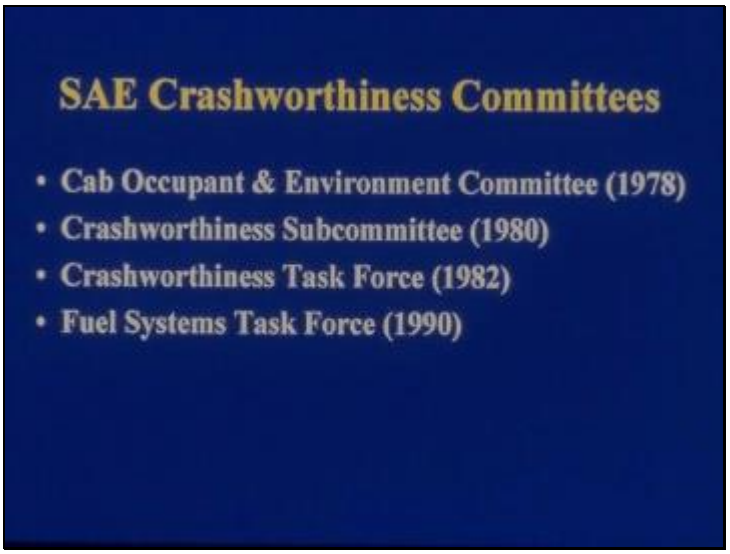
This is a list of key activities and events that contributed to the crashworthiness developments mentioned earlier. I will call your attention to the 3rd and 5th bullets. The 1987 NHTSA study, which became known as the Section 217 Study, was authorized by the U.S. Congress and carried out by Bill Leasure and Bob Clarke of NHTSA. This was a highly recognized broad-based cooperative effort by government, industry and academia. It identified the top priority vehicle crashworthiness issues that warranted further study. The research priorities outlined in the S.217 report lead to an in -depth testing and analysis effort conducted by Failure Analysis Associates, now known as Exponent, Inc. The results of this study will be presented later as part of the TOPTEC program.



Slide No. 13

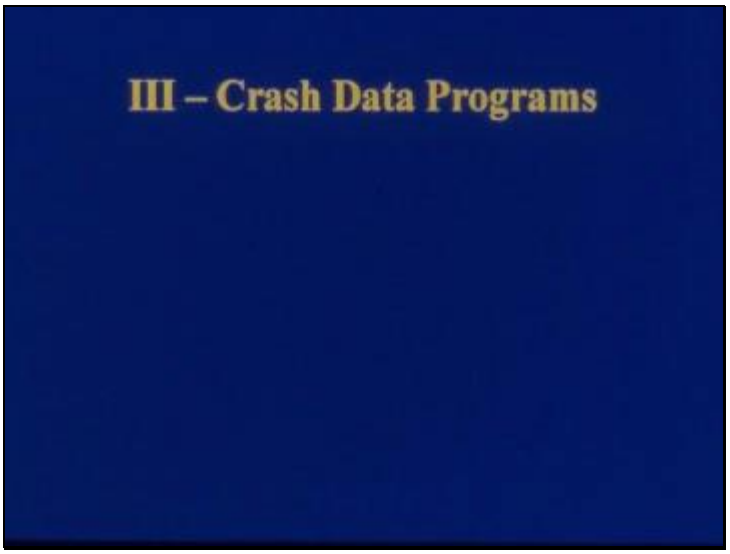
Here are the top four priority issues identified in the S.217 report that became the focus of further study. The first three items were addressed by the FaAA crashworthiness project; and fuel system integrity became part of further in-depth study by the government and vehicle manufacturers. It is also pertinent to note that shortly thereafter all U.S. truck manufacturers voluntarily installed 3-point restraint systems as standard equipment in all large trucks.

Slide 14



Slide No. 14

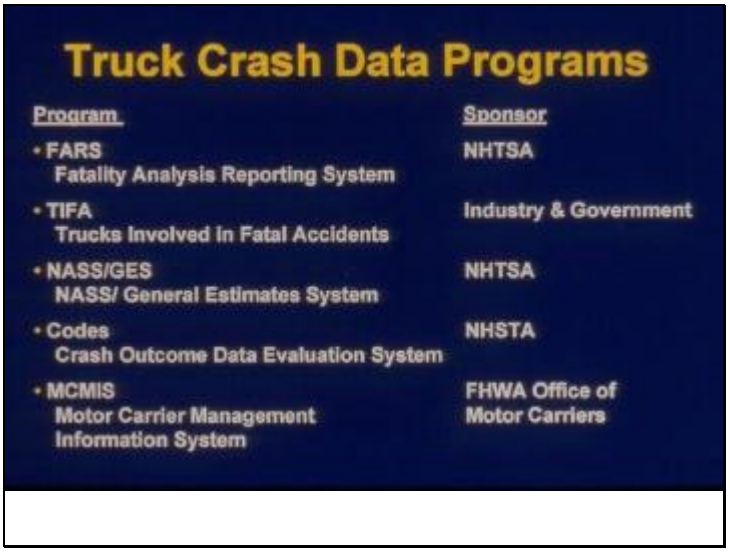
The *SAE Cab Occupant & Environment Committee* was formed in 1978 to focus attention on coordinating improvements in cab/driver environment and comfort, including crashworthiness; i.e. occupant crash protection. Three additional subcommittees and task forces were formed at later dates to carry out specific task assignments. The author is a charter member of each of the above four committees.



Slide No. 15

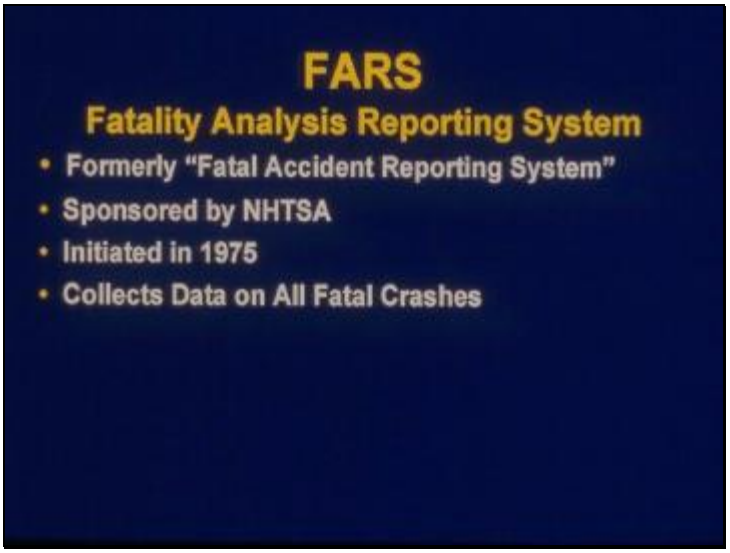
This section of the presentation highlights the various crash data programs that are currently sponsored by the USDOT and the trucking industry.

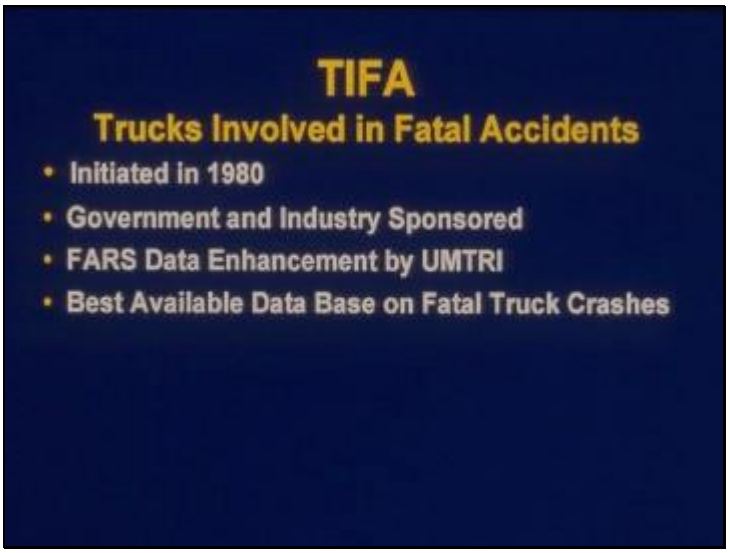
Slide 16

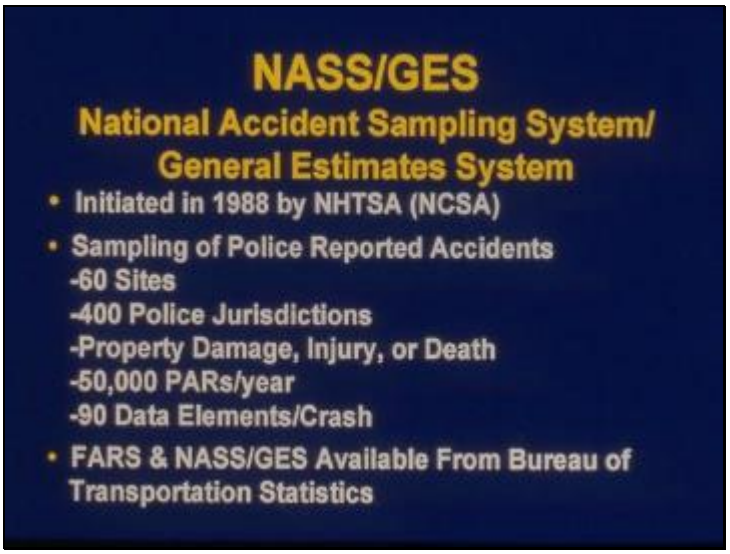


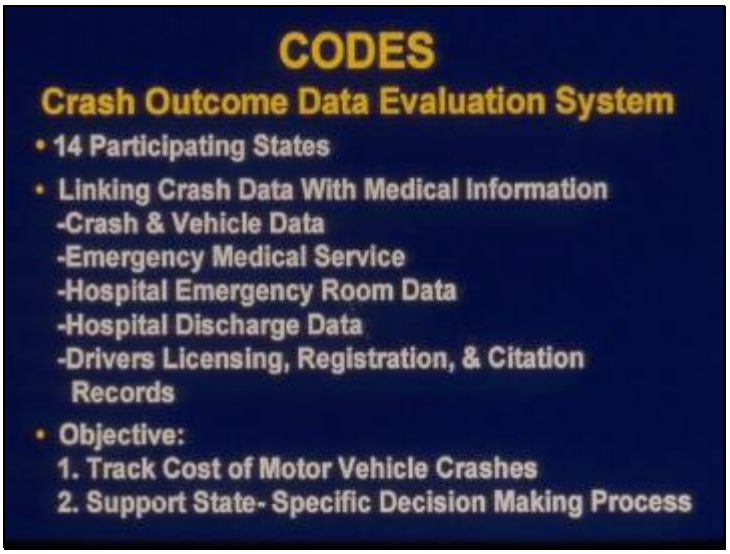
Slide No. 16

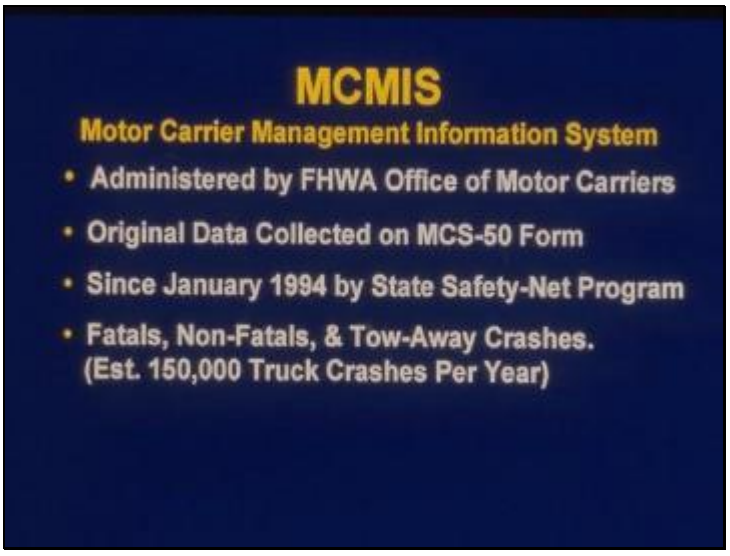
Shown here is a list of five accident data programs and their sponsors. The next five individual slides highlight pertinent details for each of the programs.

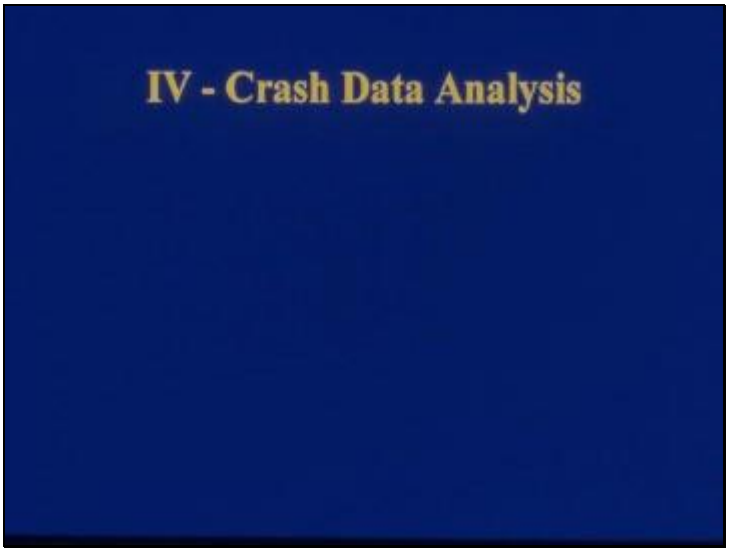

FARS
Fatality Analysis Reporting System
• Formerly "Fatal Accident Reporting System"
• Sponsored by NHTSA
• Initiated in 1975
• Collects Data on All Fatal Crashes


TIFA
Trucks Involved in Fatal Accidents
• Initiated in 1980
• Government and Industry Sponsored
• FARS Data Enhancement by UMTRI
• Best Available Data Base on Fatal Truck Crashes


NASS/GES
National Accident Sampling System/
General Estimates System
• Initiated in 1988 by NHTSA (NCSA)
• Sampling of Police Reported Accidents
-60 Sites
-400 Police Jurisdictions
-Property Damage, Injury, or Death
-50,000 PARs/year
-90 Data Elements/Crash
• FARS & NASS/GES Available From Bureau of Transportation Statistics


CODES
Crash Outcome Data Evaluation System
• 14 Participating States
• Linking Crash Data With Medical Information
-Crash & Vehicle Data
-Emergency Medical Service
-Hospital Emergency Room Data
-Hospital Discharge Data
-Drivers Licensing, Registration, & Citation Records
• Objective:
1. Track Cost of Motor Vehicle Crashes
2. Support State- Specific Decision Making Process


MCMIS
Motor Carrier Management Information System
• Administered by FHWA Office of Motor Carriers
• Original Data Collected on MCS-50 Form
• Since January 1994 by State Safety-Net Program
• Fatals, Non-Fatals, & Tow-Away Crashes.
(Est. 150,000 Truck Crashes Per Year)

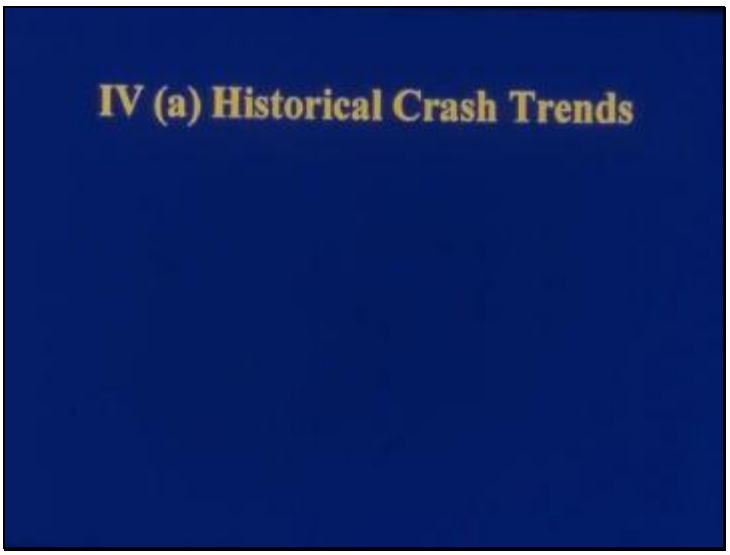


Slide No. 22

The final segment of this presentation provides an analysis of several existing accident data bases. The analysis covers the following two basic vehicle categories that comprise the range of GVWR Classes 6 thru 8 vehicles:

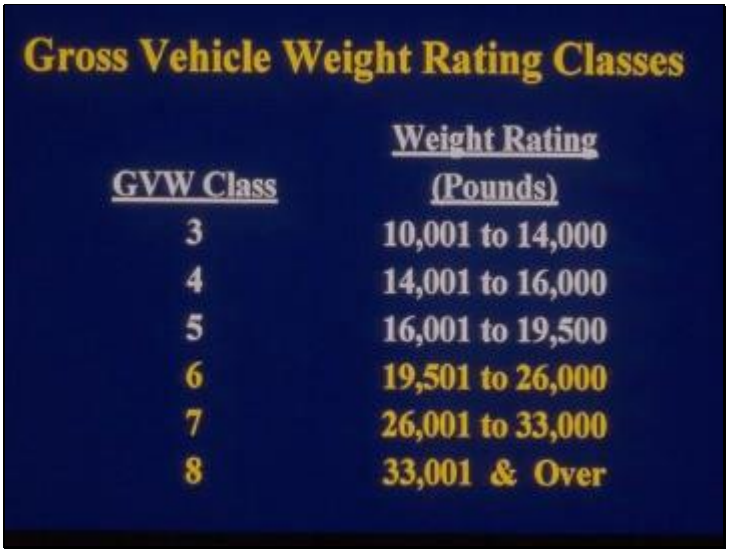
1) All GVWR 6-8 vehicles including single-unit trucks and tractor trailers

2) tractor trailers as a subset of above category 1)



Slide No. 23

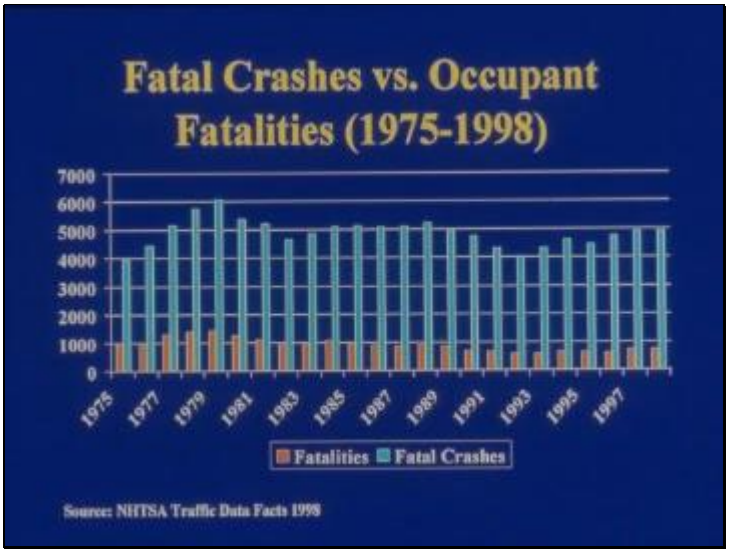
This section provides a historical summary of accident statistics for all single-unit trucks and truck tractors in GVWR Classes 6-8 (19,501 pounds and above).



Slide No. 24

Most U.S. accident data programs collect and combine, as one group, information on all trucks with a GVWR rating above 10,000 pounds (Classes 3 thru 8). However, the analysis included in this presentation covers only those vehicles above 19,500 (classes 6 thru 8). This category is typically referred to as medium/heavy trucks and normally share a common cab design. In other words, a given manufacturer such as Navistar that produces GV WR 6-8 Classes will likely use the same basic cab design for all three GVWR Classes.

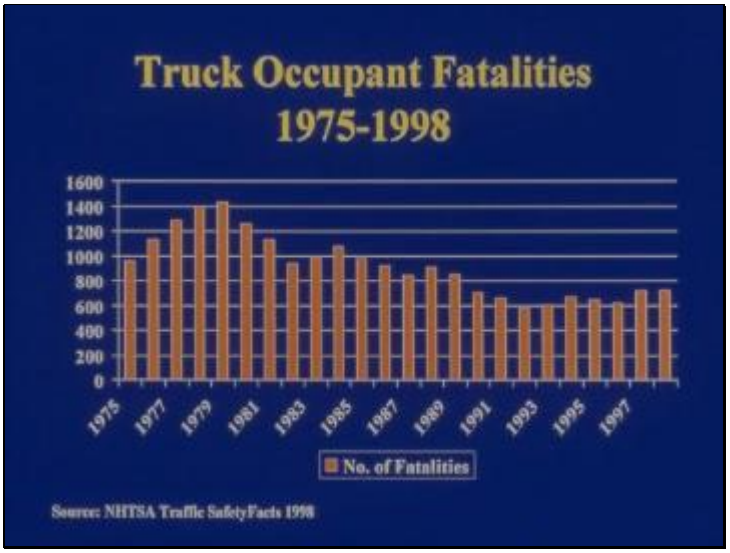
Since Class-8 trucks comprise the vast majority of accidents in the Classes 3-8 category, I have also performed a select analysis confined to Class-8 tractor trailer combination vehicles.



Slide No. 25

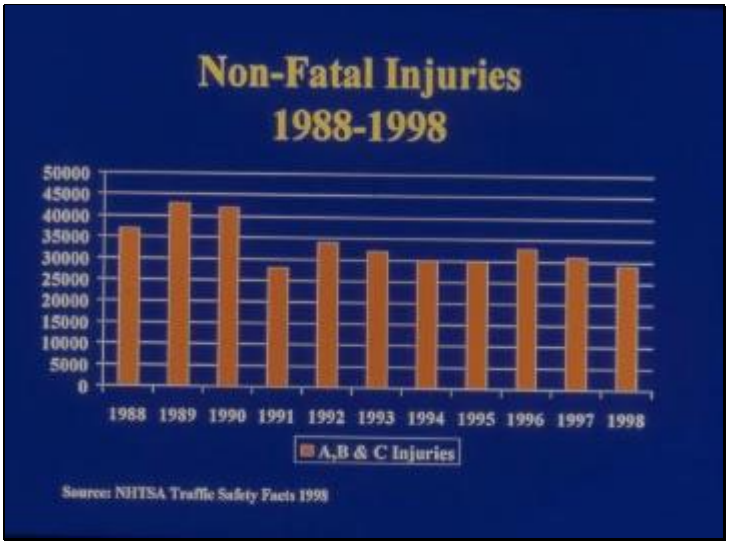
The tallest bars show the total number (ranging from 4000 to 6000) of heavy trucks involved in fatal crashes from 1975 to 1998. This number includes all truck crashes in which there is a fatality in either the truck or in the companion vehicle such as a passenger car. Since some accidents have multiple fatalities the total number of fatalities resulting from truck crashes, including those in companion vehicles, is slightly higher than the total number of involved trucks shown on this graph.

The bottom orange graph shows the number of truck-occupant fatalities resulting from these crashes. The annual distribution of truck occupant fatalities is shown more clearly on the next slide.



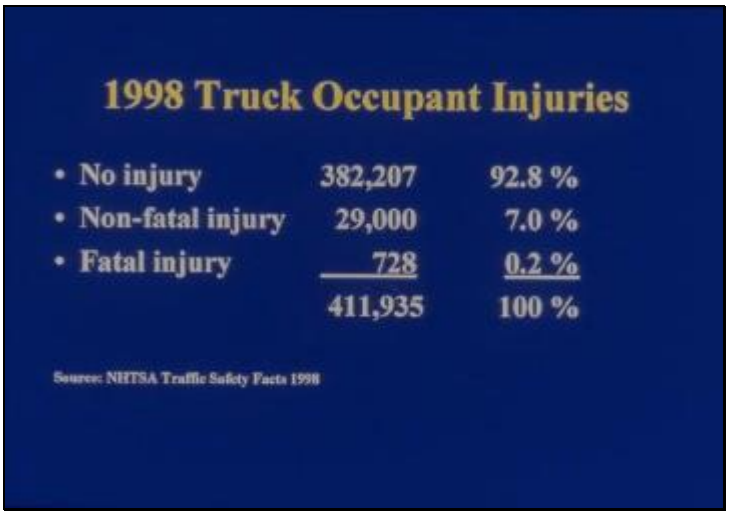
Slide No. 26

As shown here, there has been a steady and dramatic decline in the number of truck occupant fatalities since the peak year of 1979. There were 60 percent fewer fatalities in the early 1990's than in 1979. This 60 percent reduction is even more impressive when one considers that the total annual number of vehicle miles traveled by heavy trucks increased at least 50% during this same time frame. Also, the number of USDOT registered fleets more than doubled during this time period as a result of the 1980 Motor Carrier Act (deregulation).



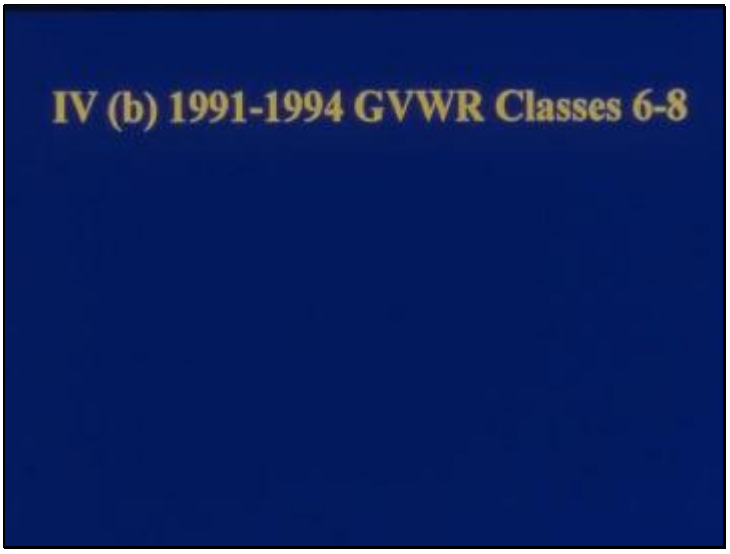
Slide No. 27

In 1988 the U.S. DOT started tracking non-fatal truck occupant injuries as part of its *General Estimates System*. As shown here, there are approximately 30,000 non -fatal truck occupant injuries occurring each year. About half of these are minor injuries and the other half are moderate to serious injuries. Comparing these numbers to the previous slide, there are about 20 times as many moderate-to-serious injuries as fatal occupant injuries.



Slide No. 28

Of the approximate 400,000 police reported accidents in 1998, 0.2% were fatal, 7.0% were nonfatal and approximately 93% of all police reported truck accidents were in the non-injury category.

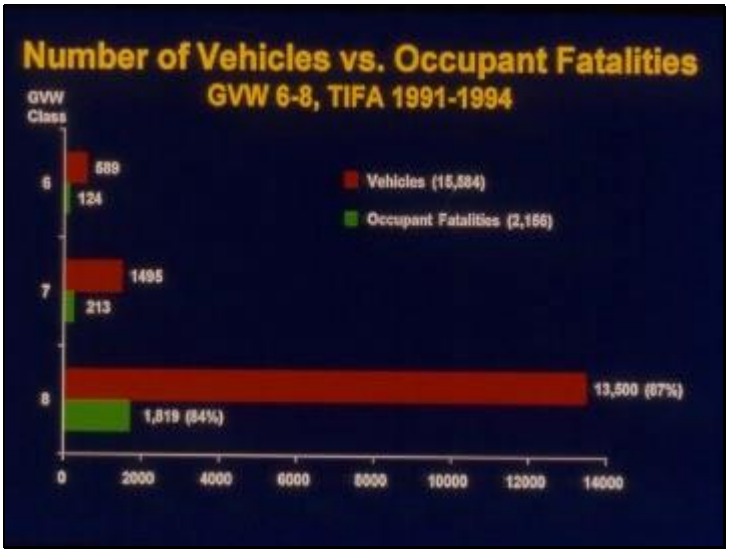


Slide No. 29

This section provides an analysis of GVWR Class 6, 7 and 8 vehicles for years 1991 through 1994.

Slide No. 30

As a way of introducing the GVWR Class 6-8 analysis, this chart shows that even though the number of new trucks sold varies from year to year (blue line), the annual number of vehicle miles traveled (VMT) (yellow line) is on a steady upward trend with VMT increasing over 50% from 1980 to 1994.

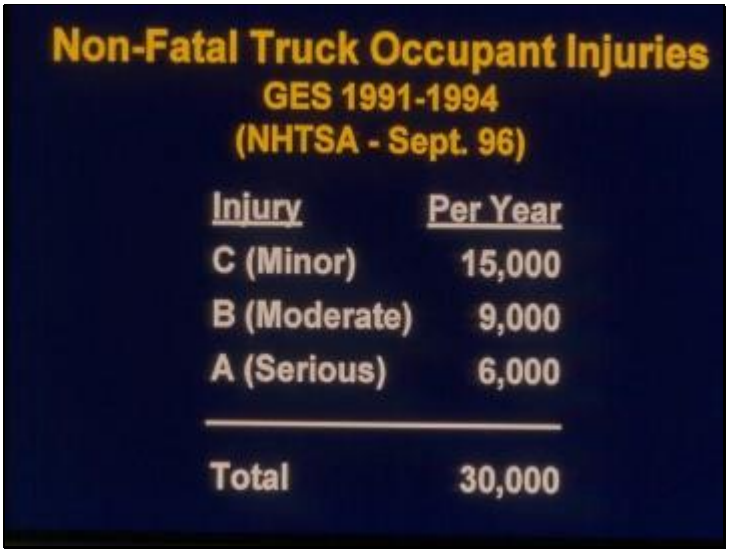


Slide No. 31

This slide shows a breakdown of the TIFA accident file for GVWR Class 6, 7 & 8 vehicles for the 4-year period 1991-1994. Class 8 vehicles account for 87% of the Class 6-8 trucks involved in fatal accidents and 84% of the truck-occupant fatalities.

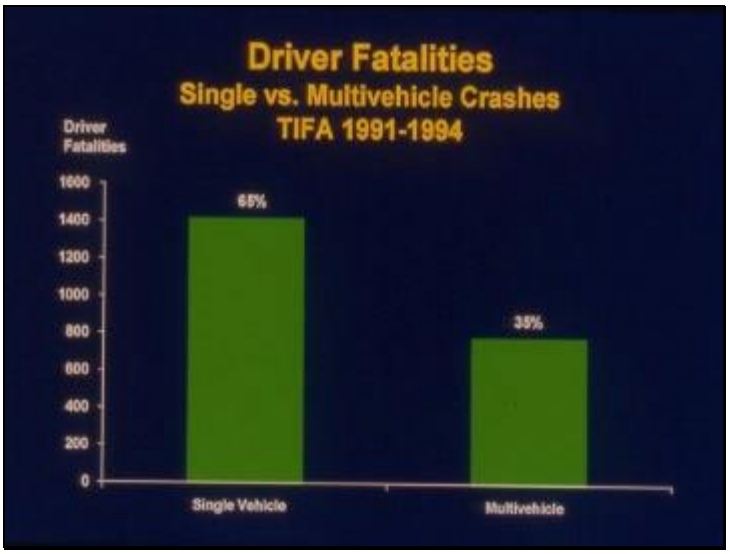
Slide No. 32

For Class 6-8 vehicles, drivers account for 95% of total occupant fatalities and 90% of moderate to serious injuries.



Slide No. 33

This slide shows the per -year breakdown of non -fatal injuries over the four -year period. Fifty percent of non-fatal injuries are minor and the other half are in the moderate to serious injury category.



Slide No. 34

Approximately two-thirds of all driver fatalities occur in single vehicle crashes and one-third in multi-vehicle crashes. This percent breakdown has remained consistent for many years.

Slide No. 35

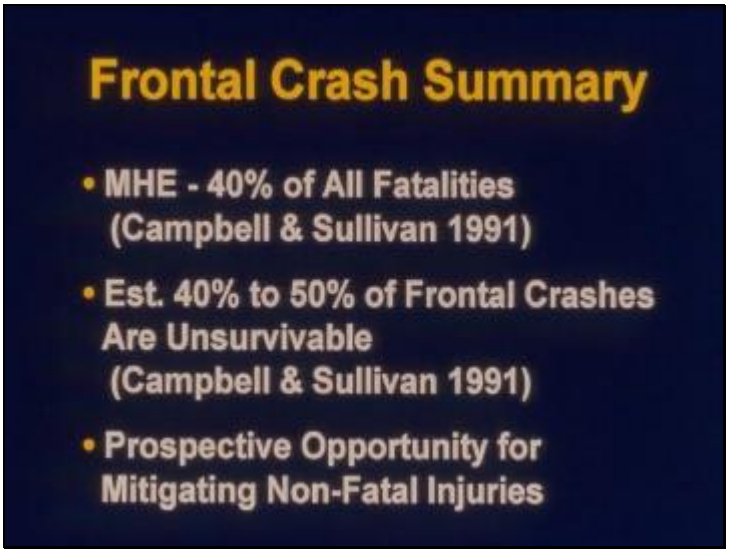
In single vehicle crashes, rollover is considered to be the most harmful event (MHE) in over half of the driver fatalities and impact with a fixed object is the MHE about 25% of the time.

Slide No. 36

Trucks involved in fatal multi -vehicle crashes collide more frequently with another truck (42%)than with a passenger car (29%). Rollover is the most harmful event in 13% of multi-vehicle crashes.

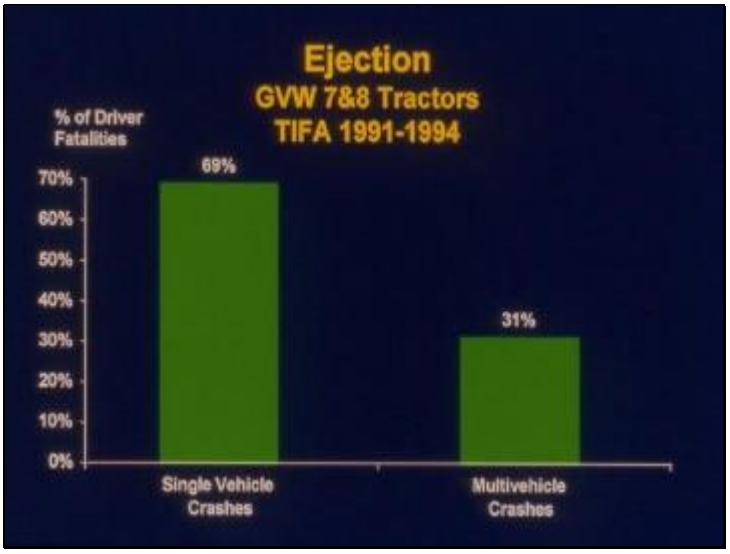
Slide No. 37

The following slides provide results of additional analysis for each of the above four topics.



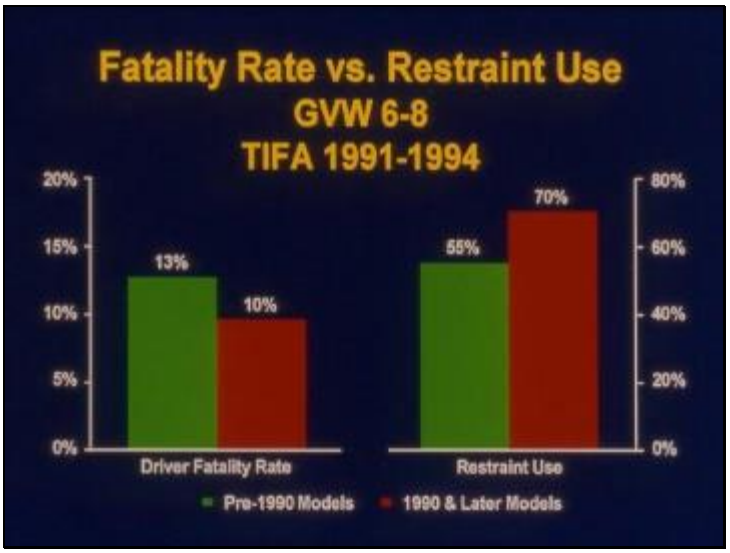
Slide No. 38

The Campbell & Sullivan Study concluded that frontal crashes represent the Most Harmful Event in about 40% of all fatalities. The study further estimated that 40% to 50% of frontal crashes are not survivable.



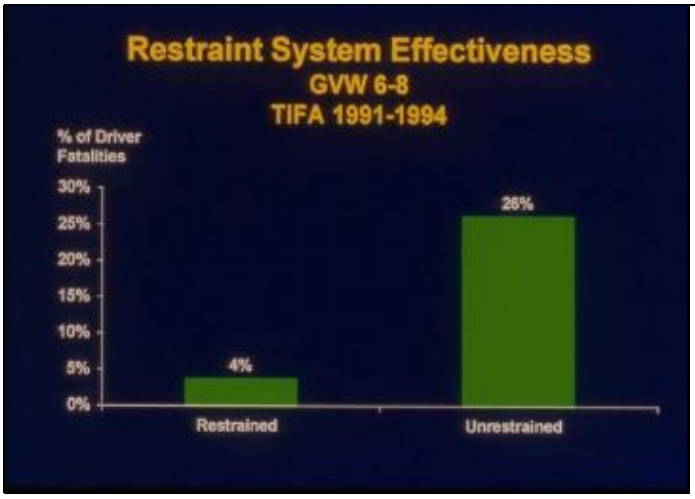
Slide No. 39

For the four-year period, over two-thirds of the ejected tractor -semi driver fatalities occurred in single-vehicle crashes and the other one-third in multi-vehicle crashes.



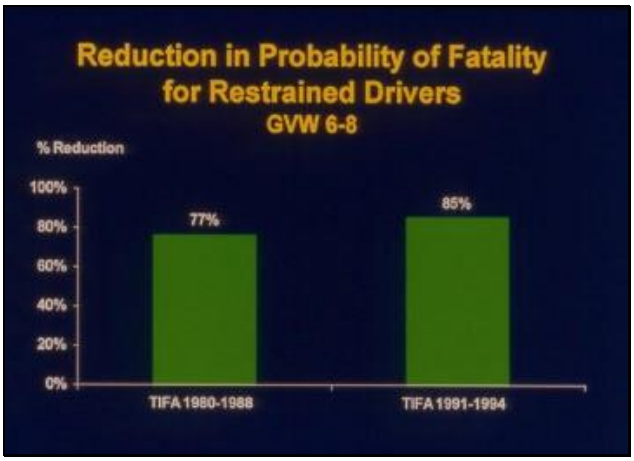
Slide No. 40

This slide compares the fatality rate and restraint use for pre -1990 versus 1990 -1992 model trucks. The later models experienced a 25% lower fatality rate while belt usage increased from 55% to 70%. It is pertinent to note that the later model vehicles were equipped with upgraded 3-point restraint systems while the vast majority of the pre -1990 models were equipped with lap belts.



Slide No. 41

Here is another indicator of restraint -use effectiveness. For the four -year period, only 4% of the restrained drivers were killed while 26% of the unrestrained drivers were killed. This would indicate that unbelted drivers are over 6 times as likely to be killed as are belted drivers. As shown on the next slide, the probability of fatality is significantly lower for restrained drivers.

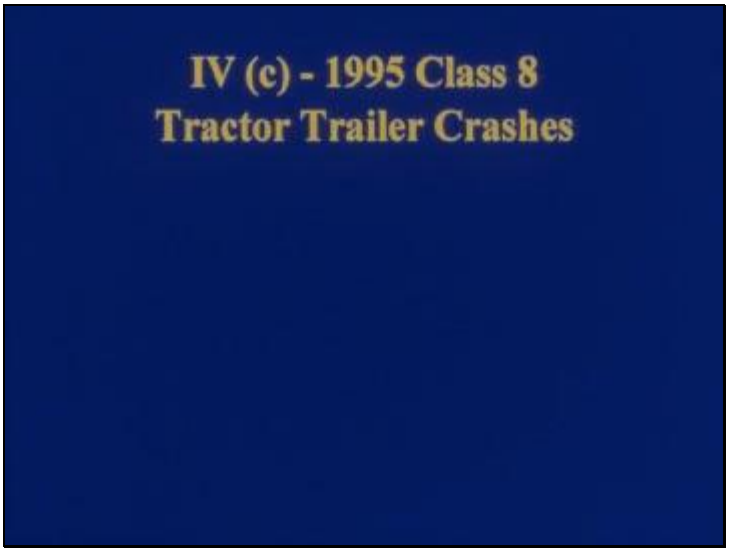


Slide No. 42 The Campbell 1991 Cab Safety Study reported that for 1980-1988 "the probability of fatality is 77% lower for restrained drivers."

For 1991-1994 models the probability of fatality is 85% lower for restrained drivers. As mentioned earlier, this significant improvement for the newer truck models is most likely attributable to the increased usage and improved performance of the upgraded 3-point restraint systems.

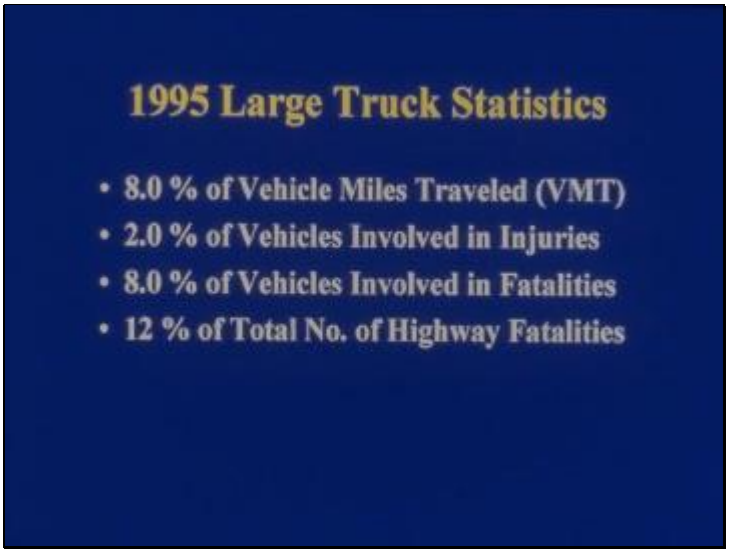
Slide No. 43

This slide graphically depicts the reduction in the number of truck occupant fatalities (blue line) and increased belt usage (yellow line) that occurred from 1980 to 1994. As reported belt use increased from a low of 5% in the early 1980's to over 60% in 1994, the frequency of fatalities decreased 60%. Even though statistical correlation does not necessarily demonstrate causality, this graph presents rather compelling evidence to substantiate the efficacy of seat belts in mitigating truck-occupant injuries.



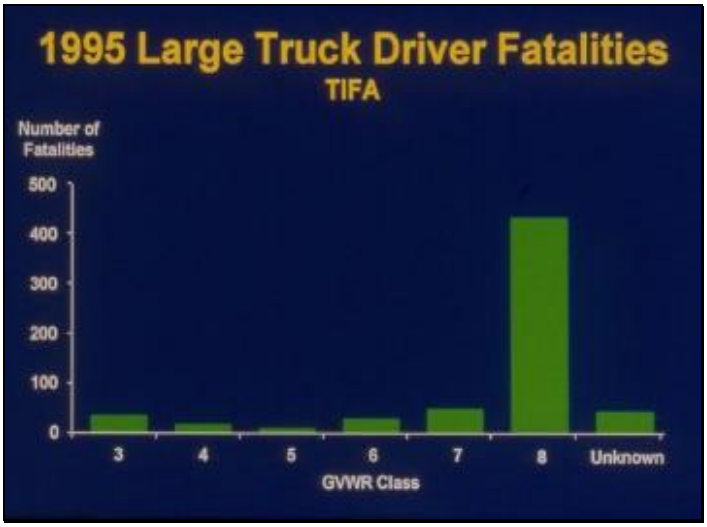
Slide No. 44

This section of the presentation provides an analysis of tractor-trailer accidents. The category of tractor-trailers is a statistical subset of the GVWR Class 6 thru 8 heavy trucks shown on the next slide.



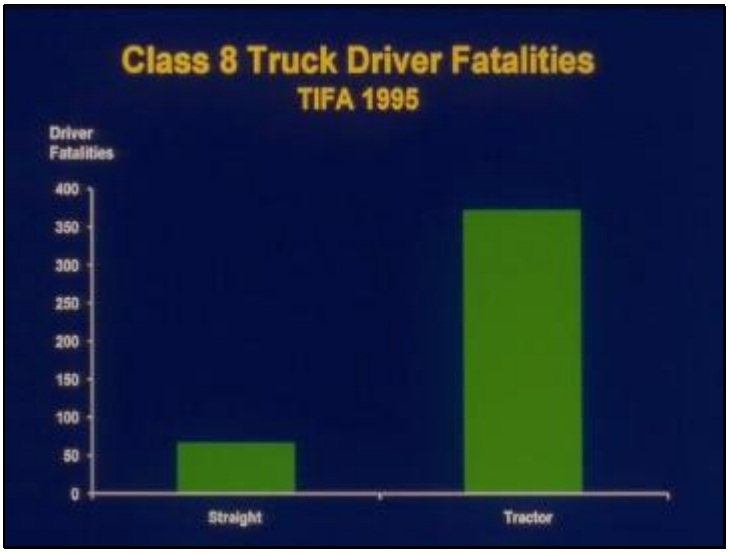
Slide No. 45

Class 6-8 heavy vehicles represent 8% of the nation's vehicle miles traveled (VMT) and also 8% of the number of vehicles involved in fatal crashes. However, crashes involving this 8% of vehicles account for 12% of all highway fatalities. The higher 12% of fatalities results from the higher number of fatalities per accident associated with smaller passenger-carrying vehicles involved in truck crashes as companion vehicles.



Slide No. 46

As noted earlier, the vast majority of driver fatalities in GV WR Classes 3 thru 8 occur in GVWR Class-8 (above 33,000) vehicles.



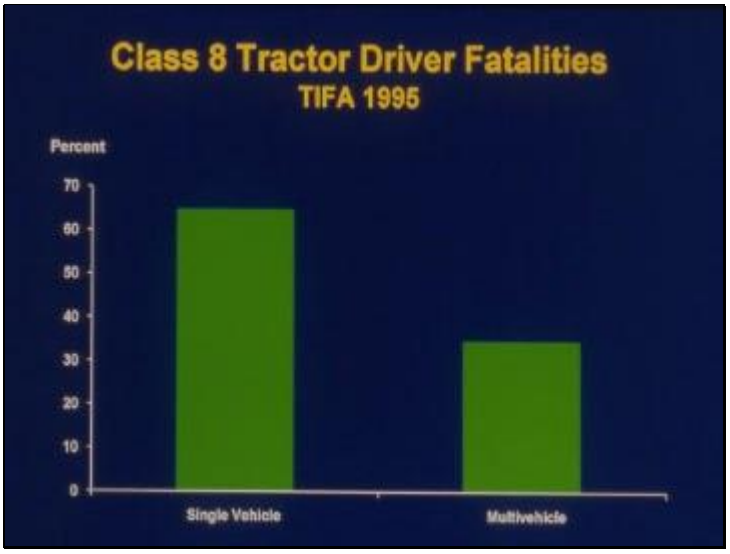
Slide No. 47

Approximately 85% of Class -8 driver fatalities occur in tractor -trailer combination vehicles and 15% in single-unit trucks.

Slide 48

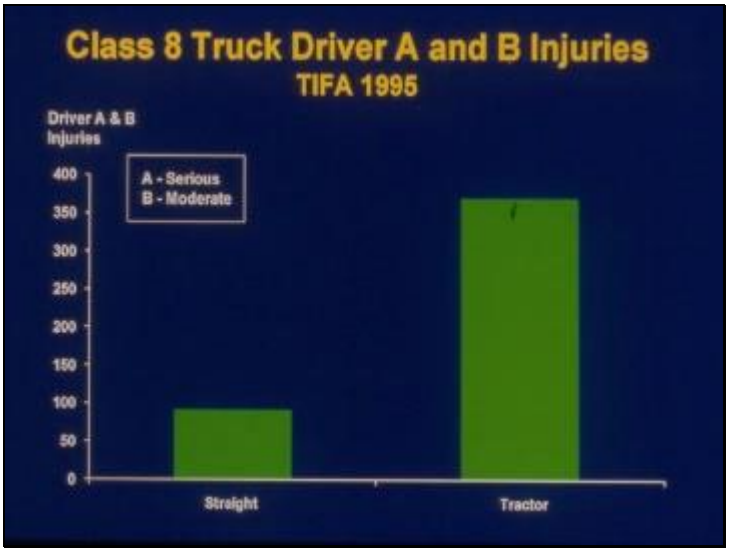
Slide No. 48

Approximately 90% of tractor driver fatalities occur in tractor-semis (single trailer) and the remaining 10% with double trailers and bobtails. There were no driver fatalities recorded for triple trailers in 1995.



Slide 49

Approximately two thirds of Class -8 tractor driver fatalities occur in single-vehicle accidents with the remaining one third in multi -vehicle accidents. This is the same as for all GVWR Class 6-8 vehicles including single-unit trucks.



Slide No. 50

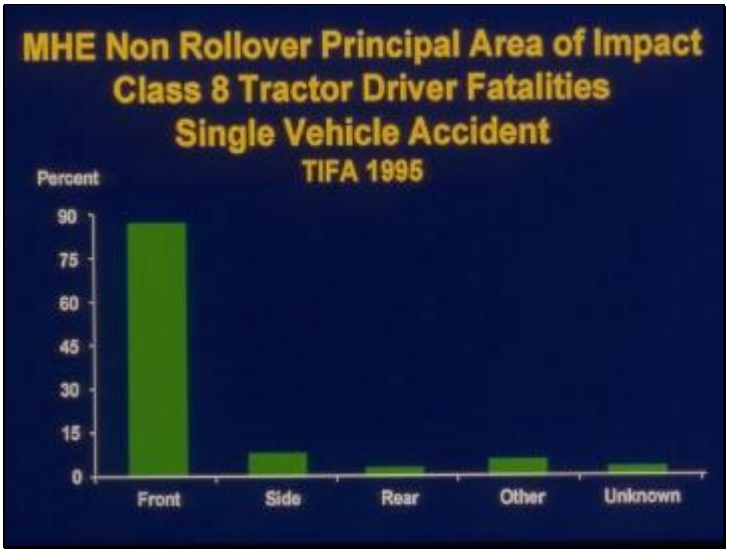
Approximately 80% of serious and moderate injuries occur in tractor -trailer units and 20% in single-unit trucks.

Slide 51

Approximately 90% of serious and moderate injuries to tractor-trailer drivers occur in tractor semis (single trailer), 5% in double trailers and 5% in bobtails.

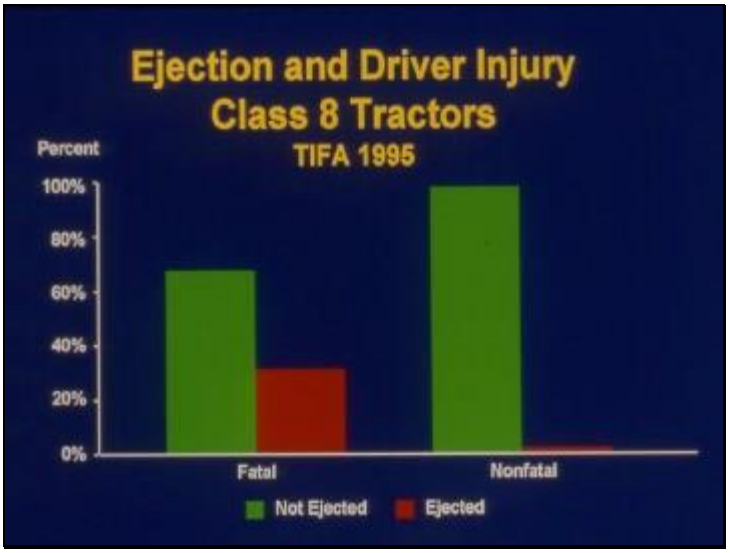
Slide No. 52

In single-vehicle crashes, rollover is the “most harmful event” in approximately 45% of tractor driver fatalities, in comparison to 53% for all Class 6-8 trucks. Contact with fixed objects accounts for approximately 30% of fatal single-vehicle tractor accidents.



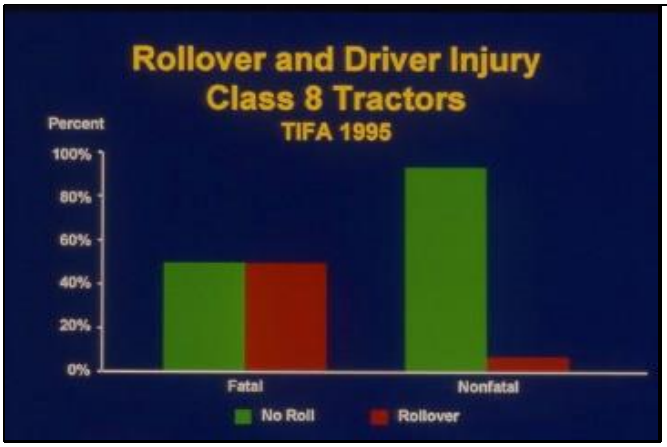
Slide No. 53

Frontal crashes are the most harmful event (MHE) in approximately 90% of fatal non-rollover single-vehicle crashes.



Slide No. 54

Driver ejection occurs in about one third of all fatal Class-8 tractor accidents, but seldom occurs in non-fatal accidents.

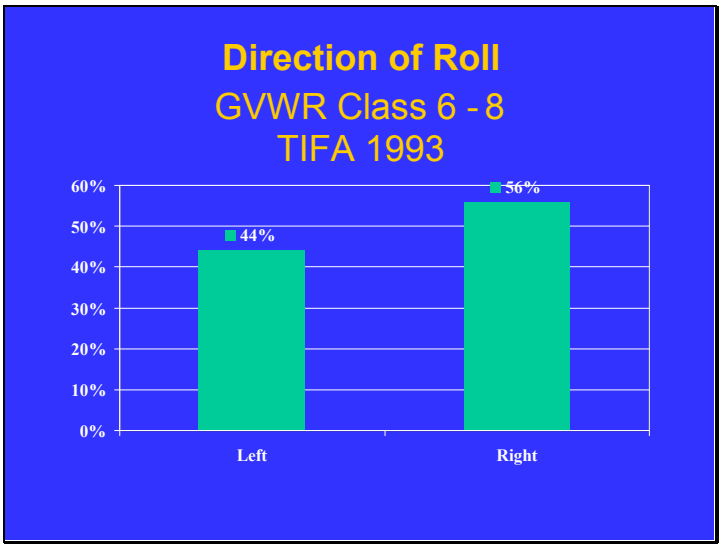


Slide No. 55

About half of fatal tractor accidents involve rollover while non-fatal accidents involve rollover only about seven (7) percent of the time.

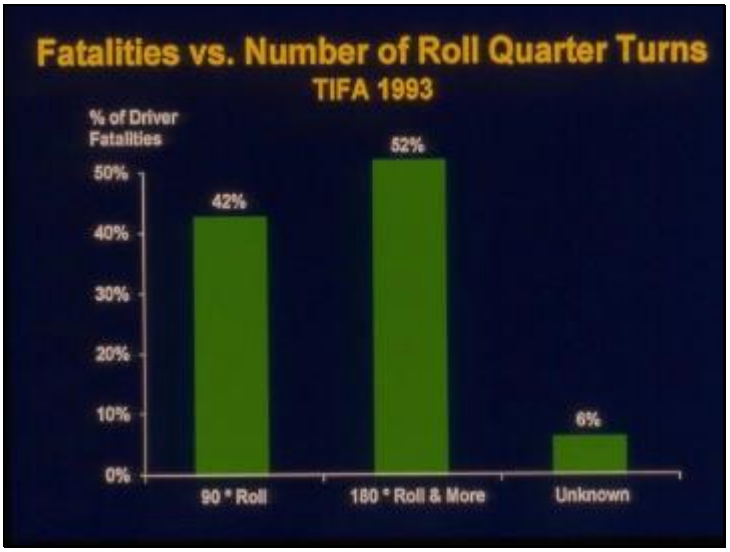
Slide No. 56

The last segment of this presentation covers the author's analysis of a one -time survey of truck rollover accidents conducted by UMTRI. This 1993 TIFA Survey included a special supplementary form to collect the four pertinent data elements shown on this slide. This is the first and only time this type of detailed census information on nation-wide rollover crashes has ever been collected. The current analysis covers all GVWR 6 - 8 single-unit trucks and truck - tractor vehicles.



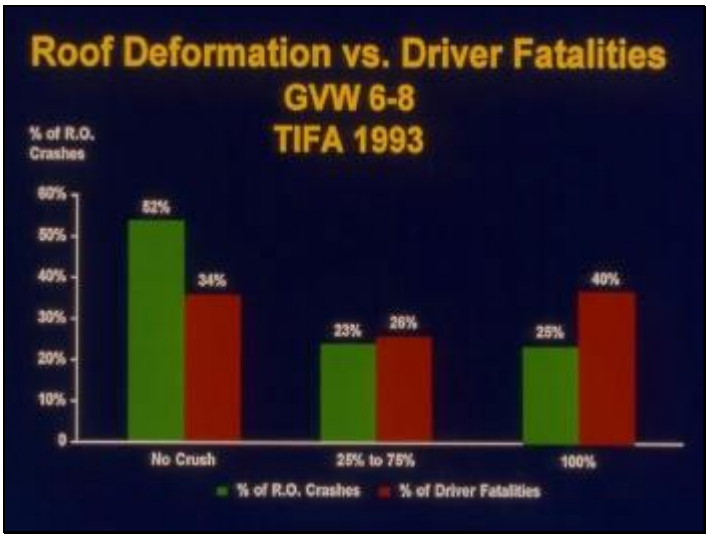
Slide No. 57

Forty-four (44) percent of all Class 6-8 vehicles involved in fatal rollover accidents in 1993 rolled to the left (driver-side rollover) and 56% rolled to the right (passenger side).



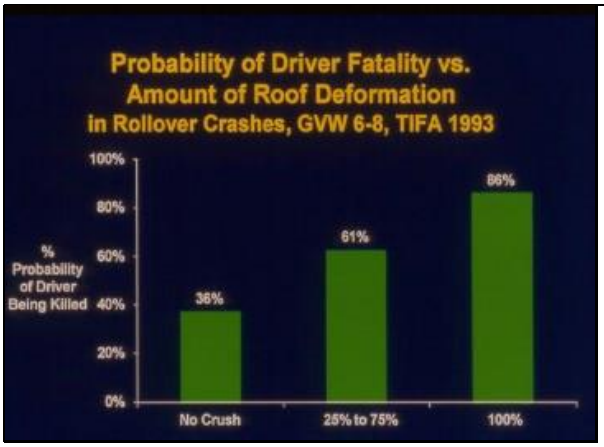
Slide No. 58

Forty-two (42) percent of Class 6-8 rollovers in the 1993 TIFA file rolled 90 degrees (one -quarter turn of roll). Fifty-two (52%) rolled 180 degrees (onto the vehicle roof), or more during the rollover sequence. As noted in later slides, single -unit trucks are much more likely to roll more than 180 degrees (three quarter turns or more) than are tractor-trailer units.



Slide No. 59

This graph shows the percentage of rollover fatalities that occurred in rollover crashes resulting in varying amounts of roof crush. As shown on the left, 52% of vehicles involved in fatal rollover crashes did not experience any vertical roof crush, and 34% of all rollover fatalities occurred in rollover crashes in which there was no roof crush. Twenty-three (23) percent of rollovers experiencing 25-to-75 percent roof crush involved 26% of all rollover fatalities. And, as shown on the right, 25 percent of vehicles experienced 100% roof crush with 40% of all rollover fatalities occurring in vehicles with 100% roof crush.



Slide No. 60

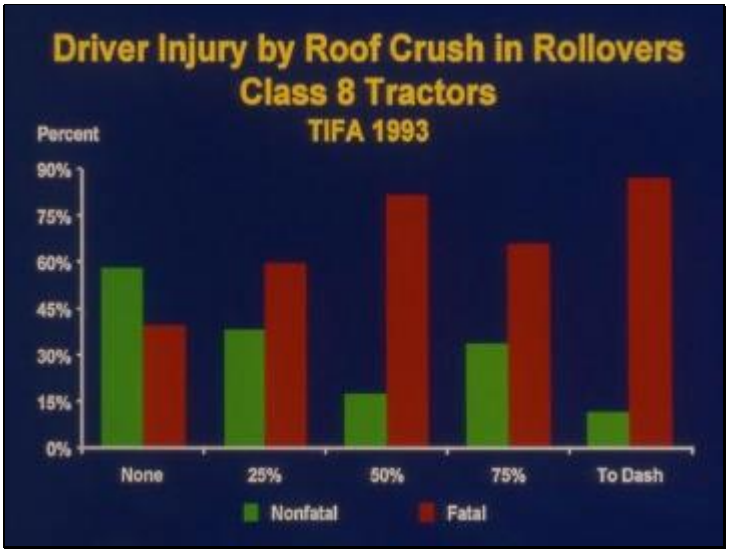
This slide displays the probability of a driver being killed in crashes with varying amounts of roof crush as exhibited on the previous slide. As shown on this slide, the probability of driver fatality in rollover crashes increases as the amount of vertical roof crush increases. However, it is the author's opinion that this statistical correlation does not necessarily provide insight into the age old question as to whether or not roof crush, in itself, is a contributing occupant injury mechanism in rollover crashes. This opinion is based, in part, on findings presented in the previously mentioned FaAA/SAE Heavy Truck Crashworthiness Study Report Further in-depth analysis of rollover crashes is believed necessary to further evaluate the consequences and injury mechanism role of vertical roof crush.

AUTHOR'S SUBSEQUENT ANALYSIS:

Since giving this presentation at the July 2000 SAE TOPTEC, the author has performed further in-depth analyses of the TIFA 1993nationwide census survey of rollover accidents involving GVWR Class 6-8 vehicles.

The results of this subsequent analysis show, for example, that rollover crashes of tractor -trailer vehicles have considerably different rollover characteristics than single-unit trucks; ie, single-unit trucks are about 2½ times more likely to roll more than 180 degrees during the rollover sequence than tractor-trailer vehicles.

As part of this subsequent analysis effort, the author focused on the 1993 U.S. population of single-unit trucks that were involved in rollover crashes. It is concluded from this analysis that roof crush is not the dominate driver-injury mechanism in single-unit trucks involved in driver-side rollovers. It is further concluded from this analysis, that it is more likely than not, that driver injuries sustained during these rollover crashes were not caused by roof crush that occurred during the rollover sequence.



Slide NO. 61

This slide shows roof crush and driver injury information specific to truck -tractor vehicles (as reference, the previous slide #59 covered all Class 6 -8 trucks including truck tractors). As with Class 6-8 vehicles, a tractor driver fatality occurred in about one -third of the rollover s in which there was no roof crush. In comparison, the frequency of fatalities for the other four categories of increasing roof crush ranges from 60 to 85 percent. As noted previously for all Class 6-8 vehicles, additional analysis is likewise believed necessary to determine the injury-mechanism role of roof crush in rollovers involving truck tractors.

Slide No. 62

This slide shows the number of quarter turns of roll by cargo body style for truck-tractor combination units. As expected, van trailers are more likely to roll only one quarter roll (90 degrees) whereas flatbeds, tanks, and bob -tail tractors are much more likely to roll two -or-more quarter turns (180 degrees or more).