The Decade of Declining Heavy Truck Fatalities... A Tribute to the Cooperative Process

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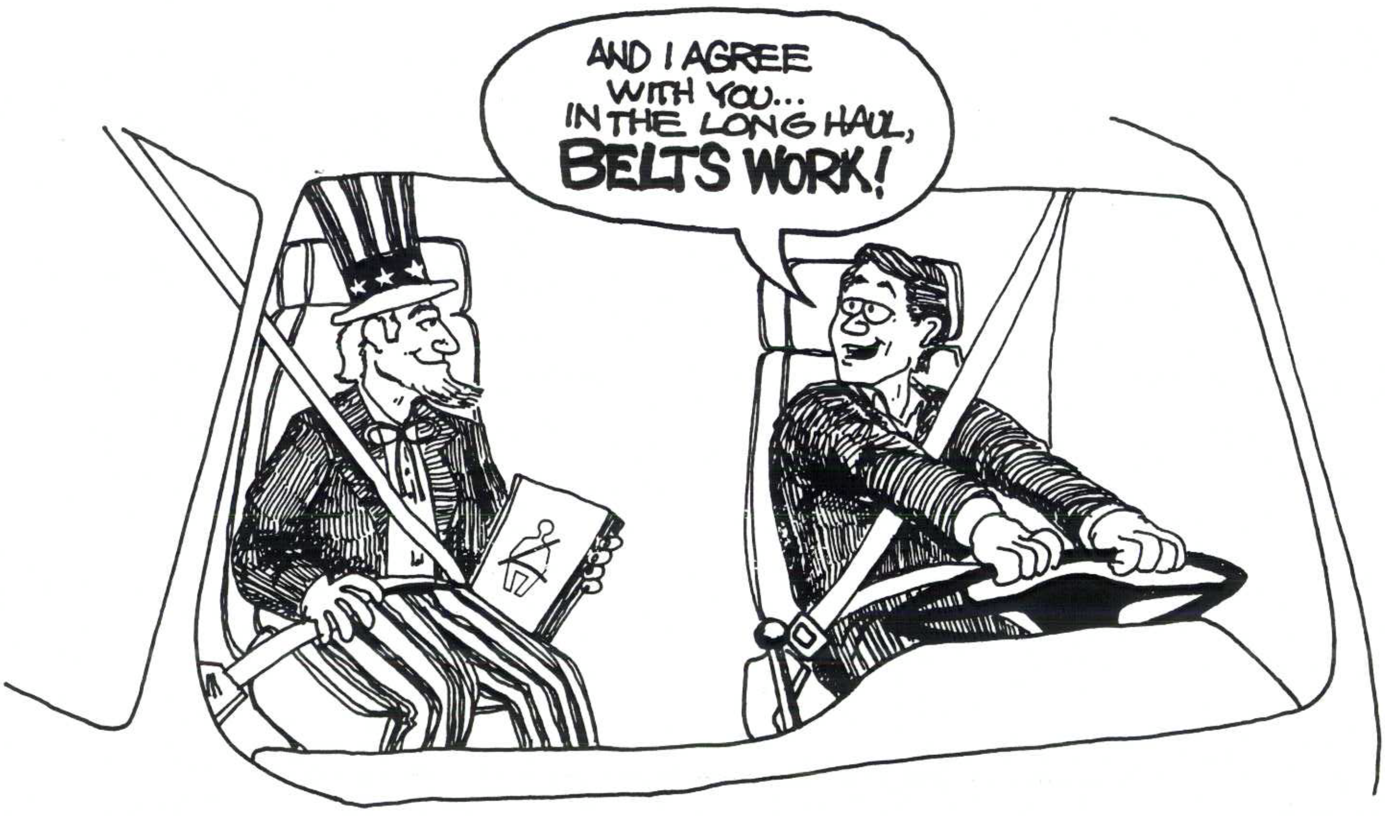

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933058

The Decade of Declining Heavy Truck Fatalities -- A Tribute to the Cooperative Process

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ABSTRACT

This paper provides an overview of the substantial reduction since 1980 in frequency of medium/ heavy truck accidents, injuries, and fatalities. It also reviews concurrent progress achieved by truck manufacturers, the trucking industry in general, and the U.S. Department of Transportation in cooperatively addressing key truck transportation issues.

Single vehicle truck crashes continue to be the largest contributor to truck occupant fatalities; fewer than 13% of all fatal truck crash involvements account for two-thirds of the total number of in-cab fatalities. The majority of fatally injured truck occupants involve ejection and/or rollover.

Increasing use of seat belts is the single largest contributor to the declining number of truck occupant fatalities. The occupant fatality rate for medium/heavy trucks improved 60% from 1980 to 1991.

A decrease in the overall crash involvement rate for medium/heavy trucks is cited as a second reason for declining heavy truck fatal crash involvements and in-cab fatalities. The paper also compares heavy truck crash involvement and occupant fatality rates with other classes of vehicles.

Section **1.0** of the paper deals with truck accident data analysis, **2.0** discusses and provides examples of the cooperative working relationship that have evolved between government and the trucking industry, and **3.0** offers a resume of coordinated truck safety research studies that have been implemented to identify and resolve priority issues. Section **4.0** contains a list of conclusions drawn from the information presented in the paper.

BACKGROUND

The frequency of heavy truck accidents, injuries, and fatalities has been steadily declining since 1980. Truck manufacturers, the trucking industry in general, and the U.S. Department of Transportation have, since 1980, made great strides in addressing key issues on a cooperative and coordinated basis. This represents a significant turnaround in contrast to the truck accident experience in the late '70s.

The number of truck crashes and fatalities peaked in 1979. Based on the best statistical information available at that time, the number of truck occupant fatalities had been steadily increasing by over 50% from 1975 to 1979. A corresponding increase in the number of truck-related passenger vehicle fatalities was also reported.

Out of the concern for the increasing number of truck accidents and fatalities, in July 1976 the National Motor Vehicle Safety Advisory Council (NMVSAC) convened a Motor Vehicle Safety Seminar to explore key issues in heavy truck safety. The agenda for this seminar identified 21 hypotheses indicating over-involvement of heavy commercial vehicles in fatal crashes.

In preparation for the NMVSAC-sponsored seminar, the Motor Vehicle Manufacturers Association (MVMA) (subsequently renamed American Automobile Manufacturers Association - AAMA) engaged two independent research organizations--Calspan Corporation and Southwest Research Institute--to evaluate and comment constructively on the truck safety issues put forward by the Advisory Council.

Based on the two independent contractors' review, evaluation, and critique of the 21 hypotheses against available research findings, the MVMA concluded in its report to the Advisory Council, *Key Issues in Heavy Truck Safety,* that "information and analysis of available data fail to establish heavy trucks as grossly disproportionate contributors to the incidence of death and injury in motor vehicle transportation."

Expressing continuing commitment to heavy truck safety, the MVMA, in behalf of member truck manufacturers, pledged full support to improve knowledge and understanding of truck crashes. To that end, MVMA offered the following recommended action plan:

> "MVMA suggests a coordinated heavy truck safety research and information gathering program involving government, industry, and the academic and scientific communities. Subjects to be explored include: the development of better accident

involvement reporting and evaluating procedures that segregate large from small truck data; development and maintenance of in-depth large truck accident studies, including the collection of better exposure information, data on the effects of speed differentials, and data on the effects of various vehicle designs; studies and analyses on methods for improving police reporting and collection techniques on large truck accident involvements; the development of more effective motor truck inspection procedures; and the development of comprehensive training, registration and licensing procedures for truck drivers."

In retrospect, there is a high degree of consistency between the above action plan recommended by MVMA and what has subsequently transpired in the truck safety field.

In October 1980, a paper entitled, *"Heavy Truck Safety - The Need to Know,"* was co-authored by the current author and Gary W. Rossow, who at the time was Manager, Technical Services, for the MVMA Motor Truck Manufacturers Division (MTMD). The paper was first presented by Krall in October 1980 before the annual conference of the American Association for Automotive Medicine (AAAM). It was later presented by Rossow at the SAE West Coast International Meeting in August 1981.

The thesis of the *"Need to Know"* paper was to present what was known and not known about truck crashes and to review current and past issue-oriented research studies. In recognition of the limited scope of available truck accident data, the paper identified a need and recommendation for implementing a comprehensive study covering truck accident data collection and analysis.

The current paper is being offered as a sequel to the 1980 paper. It reviews the significant progress that has since materialized in the quality of accident data and identifies the dramatic decline in frequency of heavy truck fatal crashes since 1980. The paper also overviews the effective working relationship that has developed between government and the truck industry in addressing key issues. Finally, it offers a resume of pertinent truck research studies being cooperatively coordinated by private and public sector organizations.

1.0 TRUCK ACCIDENT DATA ANALYSIS

One of the recommendations included in the 1980 *Heavy Truck Safety - The Need To Know* (1)* identified the need for development of a comprehensive continuing heavy truck accident data collection and analysis program. Substantial progress has been made in this regard beginning with the 1980 implementation of the TIFA (Trucks Involved in Fatal Accidents) Program at UMTRI (University of Michigan Transportation Research Institute). In addition to TIFA, this paper will also reference NHTSA's Fatal Accident Reporting System (FARS), NHTSA's General Estimate's System (GES), and the Federal Highway Administration's Highway Performance Monitoring System's Vehicle Miles of Travel (VMT). The *TIFA Factbook 1990* (2) was the primary reference document utilized for the author's initial interrogation of the TIFA file.

One other reference for the analysis conducted and reported in this paper is the *Heavy Truck Cab Safety Study* by Campbell & Sullivan, November 1991 (3). That study presented an analysis of existing accident data to describe the number and nature of truck-occupant fatal accidents. This author's report is intended to expand on that study and will additionally review TIFA 1989-1992 data not included in the above-referenced 1991 study.

One difference in the analytical methodology and accident data base employed in Campbell's 1991 study versus the current paper is perhaps worth noting. The findings in this paper are derived from a macro analysis of the total TIFA accident data base which includes census data for all fatal crashes (1980-1992) in the U.S. with heavy truck involvement. Part of the analysis in the Campbell 1991 study was based on a one-year study (by the National Transportation Safety Board) (4) of fatal truck accidents occurring in eight states (California, Colorado, Georgia, Maryland, New Jersey, North Carolina, Tennessee, Wisconsin). A subset of the TIFA files was then created and utilized to extrapolate national accident experience based upon the NTSB sample.

The next section, **1.1**, offers a general characterization of heavy truck crashes, fatalities, and involvement by truck classification. Sections **1.2** and **1.3** will respectively address crash and injury causation attributes associated with heavy truck crashes. It is pertinent to note that the analysis in this study is confined to trucks with a gross vehicle weight rating in excess of 19,500 lbs., i.e., GVWR classes 6,7, and 8.

1.1 Characterization of Truck Crashes - Figure 1 shows the number of truck fatal crash involvements and the resulting number of truck occupant fatalities from 1980 to 1992. Estimates for 1992 are from a preliminary version of the 1992 TIFA file. Total fatalities involving heavy trucks were rather constant from 1980 to 1988 (average per year 5686), but experienced a 21.5% decline from 1988 to 1992 (5905 vs. 4638). However, the reduction in truck occupant fatalities has been significantly more dramatic with a steady decline from 1141 in 1980 to 574 in 1992. This represents a reduction of over 50% in truck occupant fatalities from 1980 to 1992, and a 57% reduction from the peak year of 1979. More significantly, from 1980 to 1992, the annual vehicle miles traveled by heavy trucks increased over 40% (per FHWA Highway Statistics) (5).

* Numbers in parentheses designate references listed at the end of the report.

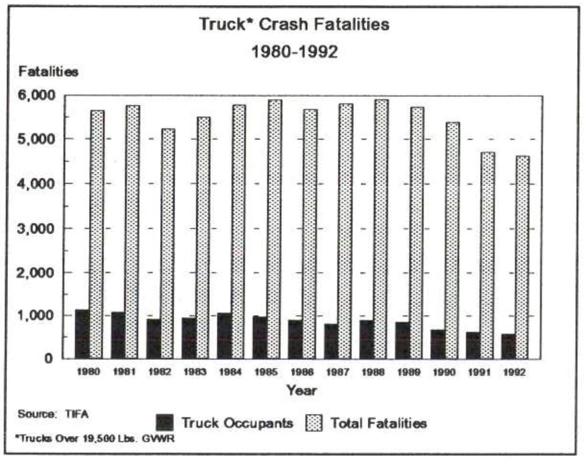

Figure 1

<u>1.1.1 Driver vs. Passenger Fatalities</u> - The majority of the analyses presented in this paper covers the 1980-1990 time period, but in some instances, 1991 and 1992 data are also included. Figure 2 shows a further breakdown of truck occupant fatalities into driver and passenger categories. Of the total number of 11,458 truck occupant fatalities from 1980 to 1992, 9,559 (83.4%) were drivers. Ninety-five percent of trucks with occupant fatalities had only one on-board fatality. The number of fatalities per truck are shown below:

1980-1990
<u>Occupant Fatalities Per Truck</u>

9167	Trucks with 1 Fatalities
493	Trucks with 2 Fatalities
32	Trucks with 3 Fatalities
7	Trucks with 4 Fatalities
9699	Total

Refer to Appendix A for a detailed breakdown by year of (1) truck involvements, (2) truck crash fatalities, (3) truck occupant fatalities, (4) truck driver fatalities, and (5) non-truck fatalities.

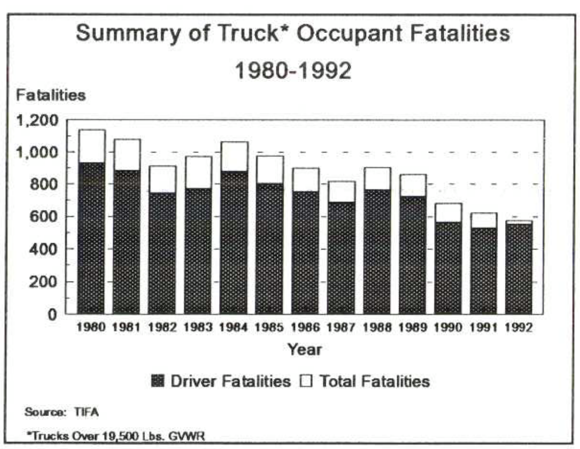

Figure 2

<u>1.1.2 Comparison of Occupant Fatality Rates</u> - Figure 3 displays occupant fatality rates for trucks above 19,500 GVWR and passenger vehicles, i.e., passenger cars, vans and light trucks. As indicated in Figure 3, passenger vehicle fatalities resulting from collisions with heavy trucks have been eliminated from the passenger vehicle fatality count. Therefore, the number of passenger vehicle fatalities shown in Figure 3 includes only those involved with other passenger vehicles or single vehicle crashes. In fact, the actual fatality rate for passenger vehicles is slightly higher than shown because the total number of "non-truck" fatalities subtracted from passenger vehicle fatalities included pedestrian and pedal cyclist fatalities--the number of which averages over 500 per year since 1980 (refer to the 1991 FARS Report).

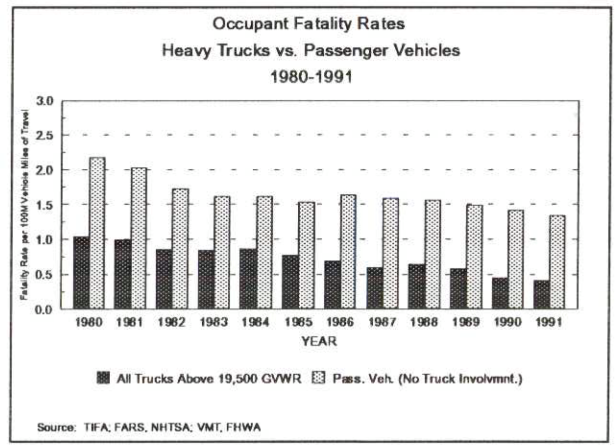

Figure 3

The occupant fatality rate for heavy trucks has declined 60% from 1980 to 1991 (from 1.04 to 0.413 fatalities per 100 million vehicle miles of travel). During this same time, the occupant fatality rate for passenger vehicles has declined 38% (from 2.17 to 1.34 fatalities per 100 million VMT).

As a further comparison, from 1980 to 1991 the average occupant fatality rate for passenger vehicles is 225% higher than for heavy trucks. This rate differential increased to 268% for the period 1986 to 1991, and for 1991 it is 325% (1.34 vs. .41 fatalities per 100 million vehicle miles of travel).

<u>1.1.3 Fatalities By Truck Type</u> - Figure 4 shows the number of truck occupant fatalities associated with various classes of heavy trucks. Combination vehicles account for about 75% of the fatalities and straight trucks for about 25%. The fact that twin trailer combinations and bobtail tractors are equally represented in fatal crashes would appear to support previous findings (6) regarding over involvement of bobtail tractors. A more detailed comparison of crash involvement of tractors and straight trucks is discussed later in the paper.

Truck* Occupant Fatalities
By Type of Truck
(1981-1991)

	Total	Percent	Avg. No. Per Year
Tractor & Semi	6382	65.3	580
Tractor & Doubles	360	3.7	33
Tractor Bobtail	364	3.7	33
Straight Truck	2205	22.6	200
Straight Truck & Trailer	189	1.9	17
Other & Unknown	269	2.8	24
	9769	100.0	888

Source: TIFA (Breakdown by above vehicle classes not available prior to 1981)
*Trucks Over 19,500 lbs. GVWR

Figure 4

1.1.4 Twin-Trailer Fatalities - Figure 5 shows the number of occupant fatalities for twin-trailer combination vehicles. "Doubles" tractor occupant fatalities increased by 30.4% from 1981 (32) to 1986 (46)* and then experienced a steady decline of 58.7% to a low of 19 fatalities in 1991. The downward trend in fatalities should indicate the development of a positive trend regarding crash involvement of twin combination units.

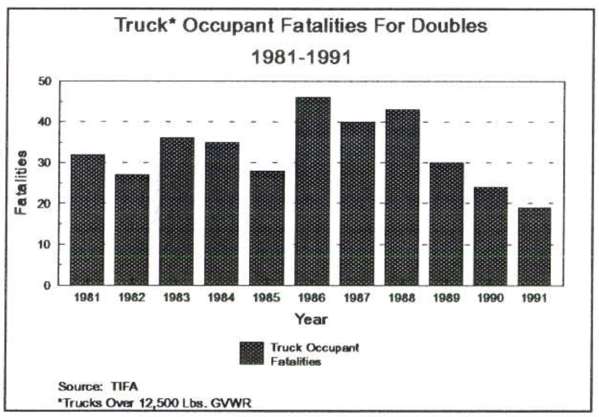

Figure 5

1.1.5 Trucks by GVWR Classification - Figure 6 shows a breakdown of straight trucks and tractors by GVWR class. As noted earlier, only trucks above 19,500 lbs. are included in this analysis. About half of the straight trucks fall into GVWR classes 6 and 7 (19,501 to 33,000 lbs.) with the other half being Class 8 (33,001 lbs. and up).

Truck tractors involved in fatal crashes are predominantly Class 8 (33,001 lbs. and up). Collectively, 84% of straight trucks and tractors included in the TIFA file are in GVWR Class 8.

TRUCKS BY GVWR CLASSIFICATION
Fatal Crash Involvement
1980-1991

	GVWR Class* 6	7	8	Unknown	Total
	(Percent)				
Straight Trucks	26.0	17.0	45.0	12.0	100%
Tractors	0.6	4.1	90.6	4.7	100%

Source: TIFA

*GVWR Class 6: 19,501 - 26,000 lbs.
Class 7: 26,001 - 33,000 lbs.
Class 8: 33,001 lbs. & Up

Figure 6

1.1.6 Single Vehicle Vs. Multi-vehicle Crashes - Of the 55,813 truck fatal involvements occurring between 1980 and 1990, 11,708 (21%) were involved in single vehicle crashes. Of the 11,708 vehicles, 59.4% had a fatality in the truck. The remaining 40.6% of reported single vehicle crashes are included in the TIFA file as a result of a pedestrian or pedal cyclist fatality in the crash.

Consequently, 6954 (12.5%) of the 55,813 total crash involvements for years 1980 to 1990 involved a single vehicle crash with a fatality in the truck. This 12.5% vehicle involvement accounted for 66.8% (5668) of the total number of driver fatalities (8481). Clearly, prevention of single vehicle truck crashes represents the top priority countermeasure opportunity for reducing truck-occupant fatalities. Single vehicle crashes account for 67% of driver fatalities for both straight trucks and tractors. As shown in Figure 7, a larger percentage of tractor drivers were fatally injured in single vehicle crashes than were drivers of straight trucks (53.8% versus 37.8%). Non-fatal injuries were about the same but more straight truck drivers than tractor drivers were uninjured (54.9% versus 38.4%).

INJURY SEVERITY
SINGLE VEHICLE* COLLISIONS
(1980-1990)

	STRAIGHT TRUCKS	TRACTORS
	(PERCENT)	
FATAL INJURY	37.8	53.8
NON-FATAL INJURY	7.3	7.8
NO INJURY	54.9	38.4
	100.0	100.0

Source: TIFA
*Trucks Over 19,500 Lbs. GVWR

Figure 7

* Twin trailers were granted nationwide operation by the 1982 Surface Transportation Assistance Act.

Multi-vehicle crashes accounted for 44,105 (79%) of the total 55,813 involvements during 1980-1990. Figure 8 displays a breakdown by type of crash and percentage of truck occupant fatalities resulting from each for straight trucks and tractors. Angle collisions account for the largest portion of fatalities with head-on being the second highest. Straight trucks have a higher proportion of in-vehicle fatalities in head-on and angle collisions than tractors. A much higher proportion of tractor fatalities occur in rear-end collisions, particularly where the tractor is the striking vehicle. In an attempt to better understand crash interaction between passenger vehicles and trucks, it would be of interest to know how many passenger vehicle fatalities are associated with each crash type shown in Figure 8. However, TIFA data do not permit this type of analysis.

MULTI-VEHICLE CRASHES
(1981-1990)

COLLISION TYPE	% OF TRUCK FATAL CRASHES	PERCENT OF TRUCK OCCUPANT FATALITIES: STRAIGHT TRUCK	PERCENT OF TRUCK OCCUPANT FATALITIES: TRACTOR
ANGLE	43.0	40.6	23.9
HEAD-ON	27.0	28.2	23.6
SIDESWIPE	6.0	6.8	10.4
REAR-STRUCK	14.3	7.9	1.7
REAR-STRIKING	9.7	16.5	40.4
	100.0	100.0	100.0

Source: TIFA
*Trucks Over 19,500 Lbs. GVWR

Figure 8

The overall ejection rate experienced in single vehicle crashes is 20.5% versus 4.7% for trucks involved

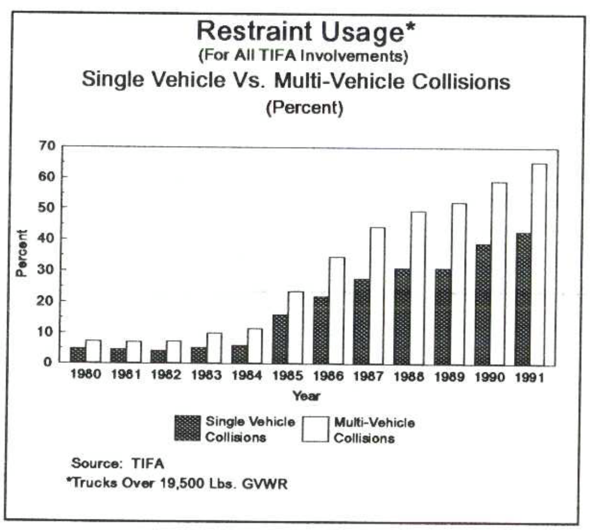

Figure 9

in multi-vehicle crashes. Even though single vehicle crashes tend to be higher severity crashes, the significant difference in seat belt use is also likely to be a factor. As shown in Figure 9, seat belt use is 77% higher (average for 1980-1991) for trucks involved in multi-vehicle crashes than for single vehicle involvements. Since the TIFA file includes only fatal accidents, in order for a single vehicle accident to qualify for the file it is likely that the driver must have been killed. Therefore, the over-representation of the unbelted occupants in single vehicle accidents is an artifact of the file's coverage.

1.1.7 Straight Trucks Vs. Tractors - This section will provide additional comparison of straight truck and tractor experience over and above that discussed in **1.1.6** regarding involvement in single and multi-vehicle crashes.

As noted earlier, straight trucks account for about 25% of all truck occupant fatalities and tractors for the remaining 75%. Given involvement in a fatal accident,

Rollover Crashes*
With Driver Fatality
(1980-1990)

	Straight Trucks (Percent)	Tractors (Percent)
Rollover Only	40.3	56.2
Rollover & Fire	9.8	10.2
Roll/Fire/Ejection	3.0	3.0
Rollover & Ejection	46.9	30.6
	100.0	100.0

Source: TIFA
*Trucks Over 19,500 Lbs. GVWR

Figure 10

both tractors and straight trucks have about the same proportion of involvements where there is a fatality in the cab (12.1% for straight trucks and 14.9% for tractors). When the driver is killed, the proportion of rollovers is similar for both (54.5% for straight trucks and 57.5% for tractors). Ejection in rollover crashes (see Figure 10) where the driver is killed is, however, about 50% higher for straight trucks than tractors (49.9% vs. 33.6%). The higher incidence of ejection in straight trucks is likely a result of considerably lower belt use. As shown in Figure 11, seat belt use (average for 1980-1991) is 57% higher for tractors than straight trucks. In reference to Figure 11, seat belt use shown for 1991 is 56.9% for tractors, 41.8% for straight trucks with an average for all trucks of 52.7%. The topic of rollover crashes will be examined more thoroughly in **1.3.2**.

1.2 Crash Causation Attributes - The fact that the truck crash statistics examined in this paper relate primarily to truck occupant fatalities/injuries should in no way be construed to de-emphasize the importance of truck accident causation and prevention considerations. The

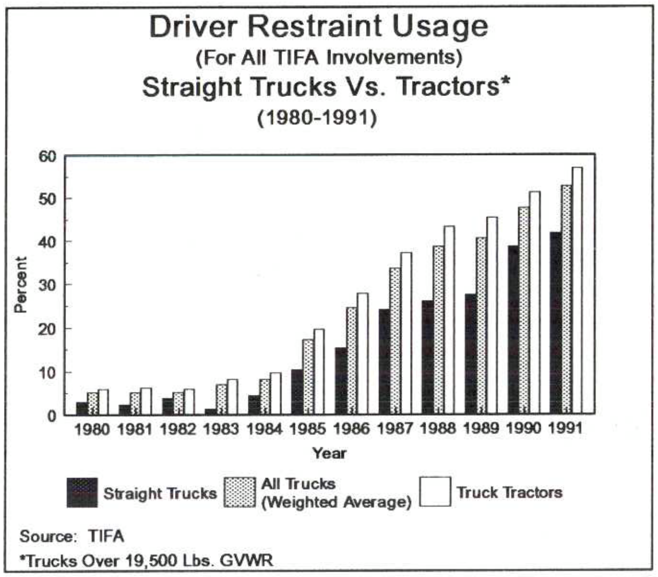

Figure 11

latter topic has been of utmost importance to vehicle manufacturers and the trucking industry, particularly as it relates to truck involvement with passenger vehicle crash injuries. Many of the truck research initiatives discussed in **3.0** address crash causation countermeasures. What follows are a few statistics that will provide some degree of insight on the topic of truck crash causation.

1.2.1 Comparison of Crash Involvement Rates - Figure 12, shows overall crash involvement rates (1989 to 1991) for passenger vehicles (columns 1 and 2) and medium/heavy trucks. As shown, the involvement rate for medium/heavy trucks is less than half that of passenger vehicles. The crash involvement rate for medium/heavy trucks has declined 21.8% from 1989 to 1991 (from 2.8 to 2.19 crashes per 100 million VMT). This 21.8% decline for trucks compares to a 6.6% decline for passenger vehicles. In summary, the crash involvement rate for medium/heavy trucks improved 7% annually from 1989 to 1991. This improvement is 330% higher than that experienced by passenger vehicles.

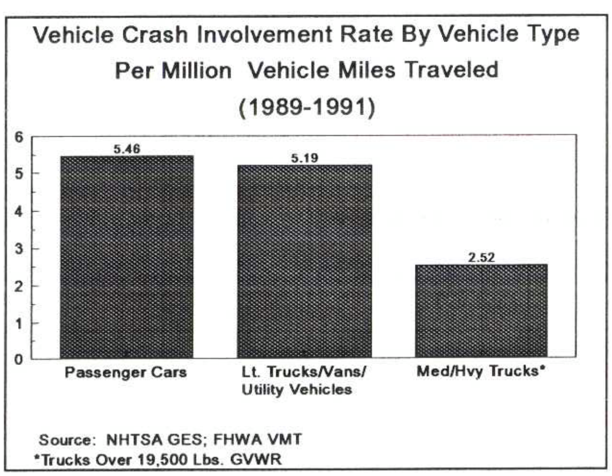

Figure 12

Driver Traffic Violations

	Medium/Heavy Trucks	Passenger Vehicles
Fatal Crashes	16%	19%
Injury Crashes	28%	33%

Source: NHTSA (5)

Figure 13

Frequency of driver violation and intoxication are considered to be indicators of crash culpability. As shown in Figure 13, heavy trucks have fewer traffic violations than passenger vehicles for both fatal and injury crashes.

Driver Intoxication In Fatal Crashes (1992)

	Percent
Medium/Heavy Trucks	1.4
Passenger Cars	21.7
Light Trucks	25.5
Motorcycles	35.6

Source: 1992 Traffic Safety Facts - NHTSA

Figure 14

Figure 14 shows frequency of driver intoxication in fatal crashes (ranging from 1.4% to 35.6%) as reported by NHTSA (7) for various classes of vehicles in 1992. These data would imply that even though use of alcohol is a significant contributing factor for fatal crashes in general, the relative contribution on the part of heavy truck drivers is rather minor.

The National Transportation Safety Board (NTSB) study referred to earlier (4) analyzed all heavy truck accidents involving a driver fatality in eight states from October 1, 1987, to September 30, 1988. One aspect of this study was to establish "probable cause" for each of the 182 accidents. The following frequency of probable causes was found:

No. of Cases	Probable Cause
57	Impairment due to fatigue
39	Impairment due to drugs
25	Misjudgment of safe speed
22	Impairment due to alcohol
19	Physical incapacitation
13	Failure to yield, perceive, observe
11	Unsafe movement
*11	Mechanical Maintenance
9	Driver inexperience
*9	Conspicuity
*8	Brake adjustment/deficiencies
5	Disregard of warnings or signs
*5	Load/load shift/center of gravity

Vehicle causal factors as identified with an asterisk (*) represent 14% of the causal factors identified while the remaining 86% pertain to driver performance factors. "Impairment due to alcohol" was found in 12% of the 182 NTSB cases compared to the 1.4% "intoxicated" drivers shown in Figure 14. This disparity could, in part, be due to the thorough drug screening done by NTSB, or, it may be accounted for by the difference in blood-alcohol concentration levels (or other impairment criteria) established by FARS and NTSB for the two studies. The difference may also be a positive indication that use of alcohol and drugs has diminished considerably between the 1987 NTSB and 1992 NHTSA studies as a result of the following countermeasure initiatives: random drug testing of motor carrier fleets beginning November 1991, drug testing required as part of the hiring procedure and during the biennial physical evaluation, and for "reasonable cause." The disparity may also relate to the fundamental issue of "representativeness" of the NTSB data base.

At any rate, it is indeed encouraging to note that several government/industry initiatives have been implemented to address many of the above issues. Some recognized examples are noted below:

1. Commercial Drivers License (CDL)
2. Commercial Vehicle Safety Alliance (CVSA)
3. Driver Fatigue Research
4. Professional Truck Driver's Institute of American (PTDIA)
5. Random Drug Testing
6. Seat Belt Promotional Programs
7. Vehicle Inspection and Enforcement

A 1991 paper by Seiff (8) is listed as a reference for additional information on the above listed counter-measure programs.

1.3 Occupant Injury Attributes - Section **1.1** provided information on total number of injuries and fatalities in heavy trucks including distribution in single and multi-vehicle crashes, straight trucks versus tractors, etc. This section will address additional specific aspects of steering wheel injuries, rollover crashes and seat belt effectiveness in fatal crashes.

1.3.1 Steering Wheel Injuries - The *Truck Driver Injury Survey* (TDIS) by UMTRI (9) examined driver injuries and fatalities in truck crashes with frontal impacts in which there was no ejection, no rollover, and no fire. The data in this study provided an opportunity to assess contact with the steering wheel as a driver injury mechanism as summarized below:

Primary Injury From Steering Wheel Contact

Body Area	Fatal	Non-Fatal
Chest/Ribs	71.0%	39.5%
Head	13.0%	29.0%
Abdominal	4.5%	7.9%
Neck	4.5%	2.6%
Entire Body	4.5%	0.0%
Upper Extremities	0.0%	10.5%
Lower Extremities	0.0%	7.9%
Back	0.0%	0.0%
Undetermined	2.5%	2.6%
	100.0%	100.0%

Two observations can be drawn from the above data: (1) a low incidence of steering wheel induced abdominal injuries, and (2) a high incidence of injuries to the upper body regions for which three-point shoulder belts should be an effective countermeasure.

1.3.2 Rollover Collisions - Of the 55,813 heavy trucks included in the TIFA file from 1980-1990, 8494 (15.2%) were involved in a rollover collision with rollover reported as either the primary event or subsequent event. The 8494 rollover collisions resulted in 4837 driver fatalities (57% of all driver fatalities). Restraint usage for fatally injured drivers in rollover crashes is shown below:

Restrained	285	(5.9%)
Unrestrained	3653	(75.5%)
Unknown	899	(18.6%)
	4837	(100.0%)

Figure 15 shows belt use and corresponding number of driver fatalities and non-fatalities in rollover crashes. The probability of a driver fatality in a rollover if restrained is 29.5% and if unrestrained 61%.

Cab roof contact was reported as the principal impact point for 817 rollovers (9.6% of all rollovers) of which 558 resulted in a driver fatality (11.5% of rollover fatalities). The 817 vehicles represent the number of vehicles involved in either a 180° or greater rollover or those vehicles experiencing a 90° rollover with subsequent roof contact as a result of sliding into another obstacle. Of the 558 fatalities occurring in rollovers with cab roof as the primary impact point, 27 (4.8%) were restrained (compared to 5.9% for all fatal rollovers), 431 (77.2%) were unrestrained, and restraint use was unknown for 100 (17.9%). Straight trucks and tractors were equally represented in rollover crashes involving roof contact. Given a rollover (with 4.8% belted occupants), the probability of an occupant fatality when roof contact occurs (i.e., 180 degree rollover) is 20% higher than for rollovers where the roof is not the principal collision impact point. Of the approximate 4% of belted truck drivers in the TIFA file who were killed, 41% were non-rollover and 59% involved rollover.

RESTRAINT SYSTEM EFFECTIVENESS *
(1980-1990)

	RESTRAINED DRIVER Killed	RESTRAINED DRIVER Not Killed	UNRESTRAINED DRIVER Killed	UNRESTRAINED DRIVER Not Killed	Total
No Rollover	201 (0.5%)	10,542 (28.3%)	2,636 (7.1%)	23,870 (64.1%)	37,249 (100.0%)
Rollover	285 (4.1%)	680 (9.8%)	3,653 (51.5%)	2,342 (33.6%)	6,960 (100.0%)
	486 1.1%)	11,222 (25.4%)	6,289 (14.2%)	26,212 (59.3%)	44,209 (100.0%)

Source: TIFA
*Trucks Over 19,500 Lbs. GVWR

Figure 15

It was mentioned previously in **1.1.7** that when there is a driver fatality, the proportion of rollovers is similar for tractors and straight trucks (57.5% vs. 54.5%). As shown in Figure 10, for fatally injured tractor drivers in rollovers, one-third are ejected from the cab, and for straight trucks the ejection rate increases to 50%. Shown below are ejection rates for belted vs. unbelted drivers for (1) all TIFA truck involvements, (2) all rollovers, and (3) fatal rollovers. For the three crash modes shown, belt effectiveness in preventing ejection ranges from 94.4% (fatal rollovers) to 99.6% for all fatal crash involvements. Unbelted drivers in fatal rollovers have a 41.5% ejection rate.

DRIVER EJECTION RATE

	Belted	Unbelted
• All TIFA Involvements (55,813 Trucks)	0.43%	9.0%
• All Rollovers (8,494 Trucks)	2.4%	28.1%
• Fatal Rollovers (4,837 Trucks)	5.6%	41.5%

1.3.3 Restraint System Effectiveness - Analysis of the TIFA data as displayed in Figure 15 shows use of restraint systems to be quite effective in preventing truck occupant fatalities. Restraint usage is reported for 44,209 (79.2%) of the 55,813 TIFA reported trucks for 1980-90.

In evaluating seat belt effectiveness, it will be assumed that there is no bias in reporting belt usage that would lead to either under-reporting or over-reporting belt use. Belt use for surviving drivers might be over-reported, since for them belt use often is self-reported rather than observed by the reporting officer. Such over-reporting would inflate estimates of belt effectiveness since the number of belted surviving drivers would be too high. The following observations are offered as support for the contention that restraint usage as shown in Figure 11 appears to be "representative" and does not include an over-reporting bias for non-fatal crashes.

- Seat belt usage reported in TIFA is consistent with findings of belt-use surveys conducted by the U.S. DOT shown below:

	DOT Survey(10)	TIFA
1982	6.25%	5.2% (1980-1982)
1991	54.7%	52.7%

  The above data would strongly suggest that there is no over-reporting of seat belt use by TIFA for years 1982 and 1991. However, the interim period is still in question and will be addressed later.
- As reported by Campbell (3) and others, mandatory seat belt use laws enacted by many states as early as 1985 have been observed to introduce a bias toward elevated reporting of seat belt use, particularly for uninjured occupants. However, rationale for over-reporting does not appear to be applicable to large commercial vehicles. Of the 45 states that have enacted seat belt use laws, only six (Montana, Nebraska, South Carolina, Utah, Washington, and Wisconsin) apply to driver/occupants of medium/heavy trucks. Therefore, it would appear that the inclination for over-reporting seat belt use is, for the most part, confined to passenger vehicles.

Again referring to Figure 15, the probability of survival for belted truck occupants is 96% compared to 80% for unbelted occupants. Thus, if all TIFA truck occupants would have been belted, there would have been a projected 74% reduction in truck occupant fatalities. This appears consistent with the results in the November 1991 Campbell Study (3) which reported that "the probability of fatality is 77% lower for restrained drivers in the TIFA file."

Figure 16 shows positive corresponding trends for increasing belt usage and declining truck occupant fatalities from 1980 to 1991. Progression in belt use is relatively constant from the survey validated usage in the early 1980's to the updated validation referenced above for 1991.

1.3.4 1990-1991 TIFA Analysis - An analysis of the 1990-1991 TIFA file was conducted to compare 1990 and 1991 model year crash performance with pre-1990 models, since 1990 was the first model year in which three-point belts were furnished as standard equipment by

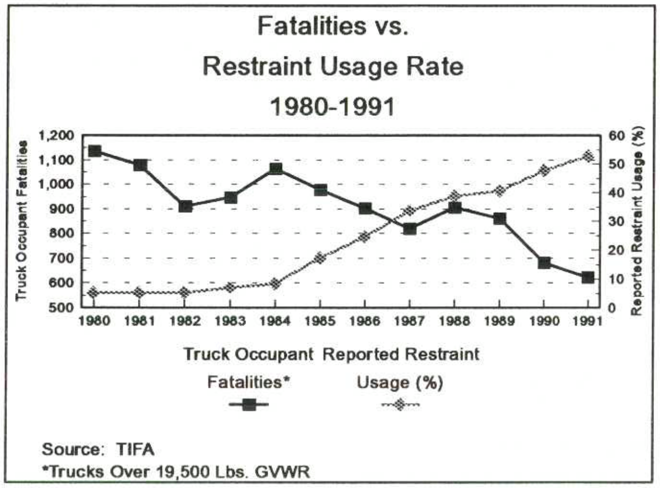

Figure 16

U.S. truck manufacturers. Pertinent observations from the 1990-1991 TIFA file are as follows:

- Of the 8713 involved trucks, 7810 (89.6%) are pre-1990 models and 903 (10.4%) are 1990 and 1991 model trucks.
- Seat belt use is 30.6% higher (63.6% vs. 48.7%) for the 1990-1991 models compared to the pre-1990 models.
- The driver fatality rate is 40% higher (12.6 vs. 9%) in the pre-1990 models.

The higher belt use rate and lower fatality rate for post-1989 models should continue to yield a positive trend in reducing occupant fatalities and injuries as the older fleet of vehicles continues to be replaced.

<u>1.4 Accident Data Summary</u> - As evidenced by the information presented in **1.0**, high quality crash data are available for heavy truck fatal crashes. Similar quality data on non-fatal truck crashes, however, do not exist. As stated in a 1990 Transportation Research Board (TRB) Report (11), "there is currently no consensus among existing programs on the annual number of non-fatal truck crashes." The TRB report emphasized the need to develop "a National Monitoring System to assemble nationwide truck accident and travel data on an ongoing basis, with sufficient detail on the vehicle, carrier, roadway, region, driver, and accident circumstances for use in measuring important truck safety trends, identifying emerging truck safety problems, and targeting major truck safety initiatives."

2.0 AN EFFECTIVE "COOPERATIVE PROCESS" INVOLVING PUBLIC & PRIVATE SECTOR ORGANIZATIONS

The government and the trucking industry have made substantial progress in working together since the early '80s to address key truck safety issues. This section provides a chronological overview of some of the key events and joint activities that have effectively contributed to the cooperative accomplishments. The following overview demonstrates the necessity for a long-term, continuous commitment of this nature to effectively resolve and implement fundamental safety advancements. A summary of key cooperative activities follows.

<u>2.1 1972 Williamsburg Conference On-Highway Safety Research (12)</u> - This SAE-sponsored forum, which was convened as a technical conference to develop a plan of needed highway safety research, included a special session on truck safety. Although the eventual expectation of creating the SAE Vehicle Research Institute did not materialize, the 1972 conference was highly successful in identifying a comprehensive list of priority research needs. Shown in Appendix B is a listing of the top priority research recommendations developed for heavy trucks. It is pertinent to note that responsive research initiatives have subsequently been launched by government and industry to address the entire list of issues. Included on the list are three pertinent truck research programs still in progress; namely, (1) truck crashworthiness, and (2) driver fatigue, and (3) tire research. The current status of these programs and others referenced below are reviewed in **3.0**.

<u>2.2 NHTSA S216/217 1987 Study (13)</u> - This comprehensive safety study was conducted by NHTSA under congressional authorization of the Motor Carrier Safety Act of 1984. The S216 study addressed the subject of brakes, handling, stability and truck aggressivity in crashes while S217 addressed the subject of truck occupant protection.

Conduct of the S216/217 study led by Leasure and Clarke of NHTSA was truly a landmark effort. Input for preparing the initial draft report was solicited from a broad array of contacts including truck manufacturers, suppliers, users, and academia. Prior to NHTSA's issuance of the final report to Congress, a productive peer review conference was held in Annapolis, Maryland. On the basis of NHTSA's thorough investigation, analysis, and peer review effort, the following recommendations were set forth:

<u>S216</u>

- Three-phase research plan for improving truck brake system performance.
- Plan to address the following aspects of truck handling and stability performance:
  - Rollover
  - Rearward amplification
  - Low speed off-tracking
  - High speed off-tracking
- Recommend research plan for reducing truck aggressivity aspects of frontal impact attenuation and override prevention.

<u>S217</u>

- Restraint systems
- Steering wheel and interior surface contacts
- Cab structural integrity
- Post crash fires, i.e., fuel system integrity

2.3 U.S. Office of Technology Assessment (OTA) Study (14) - In 1988, the OTA (Edith B. Page, Project Director) published a report on truck safety entitled, *Gearing Up for Safety*. This in-depth study, which was conducted under the auspices of an advisory panel, recommended the following three key action areas:

"• increased attention to human performance factors, including training guidelines for drivers and maintenance personnel, driver hours of service and fatigue, and management practices, such as hiring, scheduling, and drug and alcohol testing;
• stepped-up requirements for technologies to improve safety in over-the-road vehicle operations. These must address vehicle design and equipment requirements, such as tractor-trailer brake compatibility, antilock brakes, and vehicle visibility enhancements, as well as highway structure and design; and
• concentrated efforts to integrate government activities across all jurisdictional levels, to increase national uniformity for regulations and enforcement, and to improve regulatory compliance for all motor carriers."

A broad representation of over 150 people contributed to the OTA study and analysis effort. These included advisory panel members, workshop participants, reviewers, and contributors. This was truly a broad-based collective effort representing a diverse constituency.

2.4 FHWA Symposium on Truck Driver Fatigue - 1988 - The OTA report (ref. **2.3**) contained the following observation: "OTA concludes that aggressive federal research programs to address fatigue and sleep issues and to determine their role in truck accidents are top priorities." As an initial step in a major research effort, the Federal Highway Administration (FHWA) sponsored a two-day symposium in November 1988 (15) to explore the subject of driver fatigue. The specific goal of this symposium was "to review current knowledge concerning truck and bus driver fatigue and plan new fatigue related research needed to improve safety." This symposium brought together scientists and medical experts from the United States and Europe to discuss causal effects of truck driver fatigue and to lay the ground work for a long-range research agenda. A summary of driver fatigue research subsequently sponsored by government and the truck industry is reviewed in **3.0**.

2.5 NHTSA Vehicle Safety Research Advisory Committee - In late 1987, the National Highway Traffic Safety Administration established a 13-member Motor Vehicle Safety Research Advisory Committee (MVSRAC). The advisory committee was created to provide a forum for the development and consideration of motor vehicle safety research. And more specifically, to pursue planning and implementation of coordinated research by NHTSA and private sector organizations.

One of the first initiatives of MVSRAC was to establish a subcommittee to deal with exclusive heavy truck research needs. The Heavy Truck Subcommittee (HTS), after much deliberation, established the following top two priorities for research: (1) vehicle braking performance, and (2) tire performance. The HTS in turn established two working panels to formulate specific research programs for brakes and tires. To oversee the technical development and monitoring of the identified research programs, the following subcommittees were then established within the Society of Automotive Engineers (SAE):

- SAE Truck & Bus Vehicle Deceleration & Stability Subcommittee
- SAE Truck Tire Characterization Subcommittee

Program effort accomplished to date by the above subcommittees is summarized in **3.0**.

2.6 Highway/Commercial Vehicle Interface - This initiative was launched in 1992 by the Highway/Commercial Vehicle Interface Coordinating Task Force to promote a more cooperative approach to highway and vehicle (truck) design. The following organizations participated on the coordinating task force:

- American Association of State Highway and Transportation (AASHTO)
- American Bus Association (ABA)
- American Trucking Associations (ATA)
- Federal Highway Administration (FHWA)
- Highway Users Federation for Safety and Mobility (HUFSAM)
- Motor Vehicle Manufacturers Association (MVMA) (member of task force until December 1992)*
- National Highway Traffic Safety Administration (NHTSA)
- National Private Truck Council (NPTC)
- Society of Automotive Engineers (SAE)
- Transportation Research Board (TRB)
- Truck Trailer Manufacturers Association (TTMA)
- University of Texas at Austin

The task force was created as a steering group to find ways of increasing dialogue between road and vehicle designers. The task force convened two orientation programs, one in Fort Wayne, Indiana, in October 1992, and the other in San Antonio, Texas, in December 1992 (16).

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* MVMA reorganized shortly thereafter as the American Automobile Manufacturers Association and no longer represents heavy truck manufacturers.

The Fort Wayne session was organized by MVMA and gave members of the truck community an opportunity to apprise the highway community about factors affecting the design and manufacture of commercial vehicles. Customer requirements, state and federal regulations, and the highway infrastructure itself were among the topics addressed.

Participants reconvened in San Antonio in early December 1992. This session, organized by AASHTO, gave members of the highway engineering community an opportunity to apprise the truck community about factors affecting the design of pavement, bridges, and structures.

Attendees at both sessions (16) included representatives of truck manufacturers, state departments of transportation, other transportation industry groups, academicians, and federal officials from FHWA and NHTSA. Appendix C identifies various points of interest raised at the Fort Wayne and San Antonio sessions.

2.7 1993 International Symposium on Motor Carrier Transportation (17) - This symposium was held in Williamsburg May 31-June 4, 1993, with the objective of debating and disseminating contemporary research findings, identifying research needs and policy questions, and fostering effective cross-disciplinary interaction in the following areas:

- Trends in goods production and markets
- Logistics and goods distribution
- Transborder and other institutional issues
- Truck designs for efficiency, safety, driver and public acceptability, and environmental compatibility
- Efficient and safe motor carrier and intermodal operations
- Design and financing highways for efficient safe goods movement

The symposium was sponsored by the following four organizations in conjunction with 13 other cooperating organizations:

- Transportation Research Board
- Federal Highway Administration
- National Highway Traffic Safety Administration
- American Automobile Manufacturers Association

Conference proceedings for the symposium will be published by the Transportation Research Board in early 1994. The proceedings will include a summary of presentations and workshop discussions along with conclusions and recommendations for future research needs. The proceedings will also include policy options for implementing identified action programs to promote future safety and motor carrier productivity improvements in North America.

2.8 Annual MVMA/DOT Truck Research Symposium - An annual symposium sponsored by the Motor Vehicle Manufacturers Association (MVMA) and the U.S. Department of Transportation (DOT) has been held for 15 consecutive years to deliberate key heavy truck transportation issues. This event initially began as an informal discussion session between truck manufacturers and DOT (NHTSA and FHWA) to review ongoing and future truck related research programs. The symposium eventually evolved to encompass a much broader agenda drawing participants from every facet of the trucking community as well as academia and government.

The last symposium held on July 15, 1992, examined the theme "Trucking in the Year 2000 - The Millennial Perspective" from the following viewpoints:

- North American Strategic Transportation Needs
- Advanced Truck Technology and Productivity
- Truck Transportation and Alternative Fuels
- Beyond CDL - Professionalizing the Truck Driver
- The Truck Safety Agenda
- Motor Truck Research and Development Opportunities
- IVHS and Commercial Vehicles
- The Motor Carriers' Perspective

The annual symposia, which were well attended, represented an effective forum for participants to focus on key current and future issues. Proposals have been advanced to reinstitute sponsorship of this annual event in 1994.

2.9 Summary Comment - The above activities are certainly not all inclusive but are set forth as examples to illustrate how the "cooperative process" has evolved during the last decade. In the author's judgment, the overall trucking industry, government, and society have benefited greatly from this joint cooperative process and related program endeavors. The Motor Truck Manufacturers' Division (MTMD) of the former Motor Vehicle Manufacturers' Association (MVMA) has certainly been a key catalyst in planning, promoting, and fostering the cooperative environment described above.

3.0 KEY TRUCK RESEARCH PROGRAM AREAS

As part of the "cooperative process" outlined in the previous section, there has been a considerable amount of coordinated research work conducted to address key truck safety issues. This section will provide an overview of these pertinent research activities. Proceedings of the Transportation Research Forum (October 1992) (18) are included as a reference for additional information on heavy truck research priorities for the '90s.

3.1 MVMA Sponsored Research - Prior to its discontinuance, the MVMA traditionally sponsored research for the purpose of developing a better understanding of safety related heavy truck societal issues and concerns. MVMA's fiscal sponsorship of research programs exclusive to heavy trucks was nominally $500,000 per year and was conducted under the auspices of the MVMA Motor Truck Research Committee. Other organizations also provided additional financial contributions for joint sponsorship of selected projects. The following list identifies the general type of program areas that were funded by MVMA over the years:

- Accident and exposure data collection and analysis
- Braking, handling and stability
- Crashworthiness/restraint systems
- Driver environment/anthropometrics
- Fuel system integrity
- Size and weights/highway cost allocation
- Splash and spray
- Truck ride quality/driver fatigue
- Tire/wheel systems

A December 1992 bibliography of MVMA Sponsored Motor Truck Research (19) contains a list of MVMA sponsored research reports issued prior to December 1992. Even though the MVMA Motor Truck Manufacturers Division was disbanded as of December 31, 1992, its 1993 fiscal truck research programs were funded through June 30, 1993. As further information, the following MVMA (now AAMA) Motor Truck Programs were included in the 1993 budget (20):

Motor Truck Program	**Source**
Braking and Stability	SAE
Measuring Truck Tire Performance	SAE
Encouraging Safety Belt Use in Large Trucks	CVSA
Center for National Truck Statistics	UMTRI
Computerization of Suspension Data Library	UMTRI
Computerized UMTRI Heavy Truck Factbook	UMTRI
Truck Simulation for the '90s	UMTRI

Reports on the above projects will be published by AAMA upon completion by the research contractor shown.

Trucks involved in Fatal Accidents (TIFA) was implemented by UMTRI in 1980 at the request of and with technical assistance and funding by MVMA. Subsequent funding by MVMA has continued through June 30, 1993. TIFA is, without question, highly regarded as the best source of fatal truck crash data in the U.S. The UMTRI TIFA process augments FARS data and the original police accident reports. UMTRI survey staff interviews drivers, owners, or investigating officers to resolve discrepancies and collect additional information from carriers.

Funding for TIFA has also been subsequently provided by the American Trucking Association (ATA), the Western Highway Institute (WHI), and more recently, the U.S. Department of Transportation (DOT). To date, the accrued funding level for TIFA is in excess of $3,500,000. MVMA has contributed over 75% of that amount with the remainder being furnished by DOT, ATA, and WHI.

3.2 Brakes - In October 1989, the Heavy Truck Subcommittee of the NHTSA's MVSRAC established an Anti-lock Test Procedures Task Force. This task force was assigned the research objective of developing a consensus test procedure for evaluating the braking and stability and control performance of air-braked tractors.

On the basis of an extensive amount of vehicle testing, including three round-robin series at ten different sites, a reproducible test procedure (SAE J1626 *Braking, Stability, and Control Performance Test Procedures for Air-Braked-Equipped Truck Tractors*) was developed. All U.S. heavy truck manufacturers, four anti-lock suppliers, NHTSA representatives, and the SAE Vehicle Deceleration and Stability Subcommittee participated in what was truly a highly successful venture.

A specific task of the above effort was to compare surface friction characteristics of dry high Mu and wet low Mu test surfaces at the different proving grounds. Similar stopping distance results were obtained on the vehicles on the high Mu surfaces at the various proving grounds, but this was not the case on the low Mu surfaces. For two low Mu surfaces with identical friction values (over the speed range tested) vehicle stopping distances varied by as much as 33%. Accordingly, consensus was reached in the codification of SAE J1626 that a low Mu surface should only be used for evaluating vehicle stability and control, and not for stopping distance performance.

SAE J1626, which documents the end product of the above closely coordinated activity, forms the basis for NHTSA's recent rulemaking notices proposing to reinstate MVSS 121 requirements for stopping distances (58 FR 11009 - February 23, 1993) and anti-lock brake systems (58FR 50138 - September 28, 1993). SAE Report (922484), *MVMA/NHTSA/SAE Heavy Truck Round-Robin Brake Test* (November 1992), describes the final series of round-robin testing.

3.3 Tires - In June 1989, the Heavy Truck Subcommittee of NHTSA's MVSRAC established a Truck Tire Task Force (TTTF) to investigate the availability of existing tire performance data and, if necessary, develop a research project to generate appropriate data.

Braking, tracking, control stability, and rollover were identified as key vehicle performance characteristics which are directly affected by various physical properties of tires. Pertinent tire properties identified were peak/slide friction in straight ahead and cornering maneuvers, cornering stiffness, combined lateral/longitudinal friction, and braking stiffness. The TTTF determined that since there is only a limited amount of data available to address the above vehicle/tire attributes and because tire industry test procedures are not consistent, there was need to develop a standardized test protocol.

Subsequently, a tire research project has been initiated under the auspices of the SAE Cooperative Research Program. The objective of this testing program currently underway at UMTRI (with mobile dynamometer) and Calspan (with flat belt laboratory machine) is to develop standardized test procedures for evaluating tire characteristics affecting the key vehicle performance factors mentioned above. The initial study effort is targeted to be completed by mid-year 1994. Most of the technical consultation for this study is being provided by truck and tire manufacturers.

A major portion of the funding is being furnished by government, i.e., NHTSA, TACOM, and FHWA. The remainder of the funding is being provided by U.S. truck manufacturers via MVMA, Rubber Manufacturers Association, International Brotherhood of Teamsters, and National Research Council - Canada.

A second tire testing project, *Heavy Truck Brake Tire Test,* is being conducted under MVMA sponsorship by the Transportation Research Center, Inc., East Liberty, Ohio. The objective of this project is to evaluate several brands of tires to determine effect of tire performance variability on results of braking tests performed per SAE J1626.

3.4 Driver Comfort/Fatigue/Health Considerations - Truck manufacturers, suppliers, users and government have had a long-standing interest in truck ride quality as it relates to driver comfort, fatigue and safe operation of commercial vehicles. Some vehicle design attributes that came into question over a decade ago included issues such as cab design, front axle loading, fifth wheel offset, suspension types, wheel base length, etc. In an effort to address these issues, the Motor Vehicle Manufacturers Association conducted a comprehensive ride demonstration (21). It involved 16 tractor-trailer combination vehicles evaluated over a 600-mile course, from Detroit to Mackinaw City and return. The objective of the demonstration was to simulate some of the vehicle parameters under questions (i.e., fifth wheel offset and front axle loading) and to compare traditional versus latest vehicle technology. Observers who drove and rode the vehicles included professional truck drivers, government officials, and industry representatives. An analysis of the results of the demonstration, compiled by an independent firm, yielded the following conclusions (22):

- Ride quality of all the vehicles tested was rated "easily tolerable for long periods" by both professional drivers and guests.
- None of the demonstration participants, including professional drivers, could tell the difference between loads of 10,000 and 12,000 pounds on the front axle (the load variation was achieved by moving the fifth wheel).
- Trailer suspension, trailer load or different tractor wheel bases made little difference in the ride ratings.
- Evaluation of different tractor configurations varied widely. For example, a cabover got the highest overall rating of the entire 16 tractors. But in one case a short-nose conventional was favored over a COE, and in another case a long-nose conventional was favored over a different short-nose conventional. All of which supports the long-accepted view in the industry that the human element is the biggest uncertainty in the development of good ride.
- The rubber block suspension, which has been widely criticized by government officials and some drivers, received a lower "score" than a newer tractor with air suspension. But it rates surprisingly well in the categories of vibration and being tolerable for long periods of time.
- In comparing newer cab designs with older ones, professional truck drivers ranked the newer tractors as the best ride they had ever had.
- There are no data to support the claim by some that truck ride adversely affects driver health and safety.

3.4.1 - A more recent study, *The SAE Truck Driver Work Space and Anthropometric Study* (23), was conducted to better define driver accommodation criteria. This study represented a cooperative effort of labor, trucking industry, truck manufacturers and government. It consisted of two parts: the first being the clinical anthropometrics and demographics, with the second part being the work space needs development. The study was conducted at sites across the U.S.A. to get a statistically valid cross-section of the U.S. heavy duty truck driving population, male and female. Output of the study resulted in a series of SAE technical papers detailing the "how and why" of the study in addition to the development of four new and three revised SAE Recommended Practices, as shown in Appendix D. The information generated by this study provides useful design tools and guidelines for truck manufacturers to utilize in cab design.

3.4.2 - In response to a directive from Congress, the U.S. DOT Federal Highway Administration issued *A Report to the Congress on Truck Ride Quality*, June 1983 (24). This report was based on a three-pronged study effort by the University of Michigan's Highway Safety Research Institute (HSRI), including experimental measurements of truck vibrations, a state-of-the-knowledge review of vibration/safety relationship, and a conference to explore the consensus among experts on the topic. Key conclusions and recommendations of the report are displayed in Appendix E. The first four recommendation are listed below:

- By far, the most critical and difficult issue of ride quality to understand is the vibration component.
- No definitive research findings have scientifically quantified the significance of the relationship between vibration experienced in trucks and safety.
- At this time, clear-cut answers to the relationship between truck ride quality and

highway safety cannot be provided by the scientific community.

- Research findings on the effects of vibration on man are often inconclusive, conflicting, and difficult to apply to the real world.

Two additional current driver fatigue studies are summarized below:

3.4.3 - A *Pilot Study of the Relationship Between Truck Cab Vibration Levels and Driver Alertness* (November 1992) (25) was conducted by the Institute for Circadian Physiology under the sponsorship of MVMA. This study was conducted utilizing an interactive driving simulator coupled to a vehicle ride simulator while subjects were driving for a 10-hour period at night. One driving session reproduced "smooth" road conditions normally encountered on a well-paved interstate highway whereas the other session represented a "bumpy" road condition such as an average two-lane state highway. The analysis did not reveal any strong difference between road conditions. However, the EEG analysis suggested that subjects showed slightly more bursts of drowsiness under the smooth condition. And, almost all subjects (four out of five investigated) had more "accidents" on the smooth road. While the findings of this study reveal the need for running additional subjects, the results indicate that the methodology adopted in this study is appropriate for distinguishing subtle differences in driver alertness.

Recommendation and incentive for conducting the above pilot study resulted from the study *Relationship Between Truck Ride Quality and Safety Operations: Methodology Development*, June 1980 (26), completed for NHTSA by Systems Technology Incorporated. This report concluded that "although the consensus is that shock and vibration are a major source of driver discomfort and fatigue, there is little objective data to show how this affects driving performance.... The recommended solution presented in this report is to combine a fixed base driving simulator with a high-frequency motion base 'ride quality' facility. The result is an interactive 'ride simulator' that allows line drivers to perform real-world tasks while under very tightly controlled traffic and vibration scenarios. This approach has never been attempted before."

The 1992 MVMA pilot study has seemingly demonstrated the scientific feasibility and methodology for conducting this type of research investigation.

3.4.4 - A significant ongoing congressionally mandated *Driver Fatigue and Alertness Study* is being co-funded by the Federal Highway Administration, the ATA Foundation's Trucking Research Institute, and Transport Canada. The part of the study which will measure fatigue and alertness of truck drivers in two U.S. and one Canadian fleet began in June 1993. Its objective is to conduct a comprehensive study of the causes of truck driver loss of alertness at the wheel and identify and evaluate potential countermeasures. The test vehicles will be equipped to measure the subjective, objective, and physiological dimensions of fatigue. Ten-hour and 13-hour driving cycles will be evaluated. The study will also focus on local pick-up and delivery operations assessing the impact of loading, unloading, and waiting time as fatigue causal factors. A final phase of the project will examine the feasibility of using a driving simulator or other research tool to evaluate promising fatigue countermeasures. The 60-month study is projected to be completed by mid-year 1994.

3.5 Crashworthiness - An assessment of heavy truck occupant crash protection, by Clarke and Mergel 1982 (27), presented research findings and recommended action plans for much of the progress that has been subsequently accomplished.

One of the key crash protection issues addressed in this study dealt with the need to establish a crash severity upper threshold level for "survivable truck crashes." Based on NHTSA's crash testing and accident data analysis, the authors concluded that it appears reasonable "to assume that impacts generating deceleration environments above nine g's represent a point above which practical occupant protection design improvements may not be possible." This premise seems to have withstood the "test of time" with regard to subsequent peer-review published work by other knowledgeable people in the truck safety field.

The Clarke/Mergel paper further identified the following three vehicle injury mechanism factors as having highest priority:

1. Restraint System (driver perception, usage, and seat belt design, i.e., comfort and convenience).
2. Steering Wheel (frequency and severity of contact injuries and entrapment).
3. Cab Structural Integrity (energy management vs. survival space).

A second point of reference for crashworthiness research is NHTSA's S217 Truck Occupant Protection Study (13) mentioned earlier in **2.2**.

The S217 report also identified restraints, steering wheel contacts and cab structural integrity as the top three priority areas. It additionally identified fuel-system integrity (i.e., post-crash fires) as a fourth priority injury-causal mechanism to be investigated.

Subsequent to NHTSA's publication of the S217 report, the SAE Truck Crashworthiness Subcommittee of the Cab Occupant and Environment Committee has initiated further study and action programs to address the top four crash protection issues. A summary of accomplishments on these top priority topics follows:

1. Restraint Systems - The single largest contributor to the significant reduction in truck occupant fatalities reported in **1.0** is increased usage of improved restraint systems (i.e., from 6% in the early 1980's to 57% in 1991). Truck manufacturers have played a key role in this

improvement by facilitating the implementation of three-point shoulder belts as standard equipment in all medium/heavy truck models. The SAE Truck Crashworthiness Subcommittee has also developed and approved SAE Recommended Practice SAE J1834 (June 1992) Seat Belt Comfort, Fit and Convenience. This Recommended Practice provides design, test, and performance guidelines on the comfort, fit and convenience for active restraint systems for heavy trucks and multi-purpose passenger vehicle applications over 10,000 GVWR.

As noted earlier, one of the FY 1993 MVMA funded truck research projects includes a program being carried out by the Commercial Vehicle Safety Alliance (CVSA) to encourage seat belt use by truck drivers. This program entails development of a training program for approximately 5000 inspectors in the U.S. and Canada, development and dissemination of driver education materials, and development of an incentive program to motivate use by hard-core non-user drivers. The FHWA and NHTSA are also contributing to the financial support and promotion of this driver-focused initiative.

2. Steering Wheel Injuries - As noted in **1.3.1**, a study by UMTRI of 1982/83 truck crashes found the vast majority of steering wheel induced fatal occupant injuries occurring to upper body regions as opposed to lower body abdominal injuries. Lack of abdominal injury was particularly significant since only about 6% of the drivers were belted at that time. Increasing use of shoulder belts should prove to be an effective countermeasure in reducing steering wheel injuries. It may be desirable to conduct a similar accident analysis of non-fatal driver injuries resulting from steering system contact.

3. Cab Structural Integrity - A research study to define fundamental aspects of structural integrity performance is in progress under the jurisdiction of the SAE Crashworthiness Subcommittee. The first two tasks of this study have been performed by Failure Analysis Associates, Inc. (FaAA) but not yet published as a final report. The goal of Task 1 is to develop sets of accident sequences that characterize heavy truck accidents resulting in occupant fatalities. The goal of Task 2 is to develop crash pulses for the prominent accident scenarios determined in Task 1. The Task 3 effort currently underway is to conduct additional rollover analysis, and parametric cab structure studies. Additional follow-on work is undefined at this time.

4. Fuel System Integrity - Studies conducted to date have identified dual fuel tank cross-over lines as the top priority area of interest. Work is currently in progress to develop an SAE test procedure for evaluating structural integrity performance of cross-over lines.

4.0 CONCLUSIONS

4.1 Crash Involvement Rates

4.1.1 - Since overall crash involvement rates for heavy trucks first became available in 1989 (via NHTSA's General Estimates System), the heavy truck involvement rate is declining an average of 7% per year (21.8% from 1989 to 1991).

4.1.2 - Although crash involvement rates for passenger vehicles have also declined from 1989 to 1991, the decline in crash involvement of heavy trucks is over 300% greater than that experienced by passenger vehicles.

4.2 Heavy Truck Fatal Crashes

4.2.1 - From the peak year of 1979 to 1992, frequency of heavy truck occupant fatalities has declined 57% while vehicle miles traveled have increased over 40%. The occupant fatality rate for heavy trucks has declined 60% from 1980 to 1991.

4.2.2 - While the occupant fatality rate has also declined for passenger vehicles, it is considerably higher than for heavy trucks. From 1980 to 1991, the average occupant fatality rate for passenger vehicles was 225% higher than for heavy trucks. For 1991, the rate differential increased to 325%.

4.2.3 - About 75% of truck occupant fatalities occur in combination tractor-trailer units and the remaining 25% in straight trucks. Head-on crashes with in-cab fatalities occur slightly more often for straight trucks than tractor-trailer units; however, for similar rear-end crashes, tractor-trailer units are 250% more likely to be the striking vehicle than straight trucks.

4.3 Single Vehicle Crashes - Single vehicle crashes account for 13% of all heavy truck fatal crash involvements (excluding pedestrians and pedal cyclists) and two-thirds of all in-cab fatalities. Even though tractors and straight trucks have a similar involvement rate in single vehicle crashes, the probability of a tractor driver being fatally injured if involved in a single vehicle crash is over 50% higher than for a straight truck driver.

4.4 Rollover and Ejection

4.4.1 - Rollover crashes account for 15% of heavy truck fatal crashes and 57% of driver fatalities. Rollovers in which the cab roof is the principal impact point (i.e., 180° rollover) account for 9.6% of all rollovers and 11.5% of rollover fatalities. The probability of a belted driver being killed in a rollover is 29.5% and if unbelted, 61%. Of drivers killed in rollover crashes from 1980 to 1990, 94% were unbelted. Tractors and straight trucks experience similar frequency of involvement in fatal rollover crashes.

4.4.2 - Ejection in rollover crashes fatal to the driver is over 50% higher for straight trucks than tractors. Conversely, seat belt use is 50% higher in tractors than straight trucks.

Given involvement of a heavy truck in a fatal crash, belted drivers experience a 0.43% ejection rate vs. 9.0% for unbelted drivers. For rollover crashes fatal to the driver, belted drivers experience a 5.6% ejection rate vs. 41.5% for unbelted drivers.

4.5 Restraint System Effectiveness - Increased use of seat belts by truck occupants is the single largest contributor to the dramatic decline in heavy truck fatalities. Belt use has steadily increased from about 6% in the early '80s to over 55% in 1991. Given involvement in a fatal crash, probability of survival for belted truck occupants is 96% compared to 80% for unbelted occupants. This would represent about a 75% reduction in truck fatalities accrued from 1980 to 1990 if all occupants would have been belted.

4.5.1 - In comparing 1990 and 1991 model trucks (which have three-point belts as standard equipment) with pre-1990 models, belt use in the newer models is over 30% higher. The driver fatality rate in the pre-1990 models is 40% higher than for the 1990/91 models. Thus, the synergistic effect of the older fleet being replaced with newer vehicles should lead to a continuing decline in truck injuries and fatalities.

4.6 Driver Intoxication - NHTSA's statistics for 1992 show frequency of driver intoxication in fatal crashes as 1.4% for medium/heavy trucks, 21.7% for passenger cars, 25.5% for light trucks and 35.6% for motorcycles. The low incidence of alcohol use by truck drivers is no doubt being influenced by the requirement for random drug testing of motor carrier fleets which began in November 1991, drug testing required as part of the hiring procedure, and testing during the biennial physical evaluation, and for "reasonable cause."

4.7 Quality of Truck Accident Statistics - Even though high quality data, as reviewed in this paper, are available for fatal truck crashes, similar data for non-fatal crash injuries are grossly lacking. To rectify this situation, a 1990 Transportation Research Board Report (10) recommended the development of a National Monitoring System to assemble nationwide truck accident and travel data on an on-going basis.

4.8 Government/Industry Cooperation - As described in sections **2.0 and 3.0**, during the past decade, government and the trucking industry have developed an effective cooperative working relationship. This participative process has been successful in carrying out jointly coordinated research programs leading to the identification, resolution, and implementation of effective countermeasures.

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SUMMARY OF FATAL TRUCK* COLLISIONS

	Truck Involvements	Truck Collision Fatalities	Truck Occupant Fatalities Driver	Passenger	Total	Non-Truck Fatalities
1980	5,052	5,637	929	212	**1,141	4,496
1981	5,165	5,761	881	195	1,076	4,685
1982	4,655	5,228	743	168	911	4,317
1983	4,868	5,498	768	177	945	4,553
1984	5,241	5,773	876	179	1,055	4,718
1985	5,303	5,901	802	171	973	4,989
1986	5,185	5,674	750	152	902	4,772
1987	5,167	5,803	687	127	814	4,989
1988	5,288	5,905	761	142	903	5,002
1989	5,115	5,741	720	141	861	4,880
1990	4,774 (55,813)	5,383	564 (8,481)	116	680 (10,261)	4,703
1991	4,168	4,714	527	96	623	4,091
1992	4,275	4,638	551	23	574	4,064
	64,256	71,656	9,559	1,899	11,458	60,198

*Trucks over 19,500 lbs. GVWR

**This number estimated by UMTRI

APPENDIX B

1972 WILLIAMSBURG CONFERENCE ON HIGHWAY SAFETY RESEARCH

SAE VEHICLE RESEARCH INSTITUTE NOVEMBER 29-30, DECEMBER 1, 1972

SESSION VII

Truck, Bus and Multi-Purpose Vehicle Safety

High Priority Research Recommendations

1. Occupant Injury Severity
   - Establish Energy Management Criteria

2. Driver Performance Factors
   - Driver Fatigue
   - Drugs/Alcohol
   - Regulated Vs. Non-Regulated Drivers
   - Driver Training Programs

3. Ability to Measure Safety Effectiveness

4. Vehicle Accident Reduction Factors
   - Driver Field of View
     - Eyelipse Tool and Visibility Targets
   - Vehicle Handling
   - Tires
   - Truck Splash
     - Test Procedure
     - Vehicle Design Solutions

APPENDIX C

SUMMARY OF FORT WAYNE AND SAN ANTONIO SESSIONS

(Points of interest raised at the Fort Wayne meeting)

- Vehicle factors affecting pavements include axle type (single or tandem); axle weight; tire pressure; single or dual tires and width; suspension system; and axle spacing.
- Static axle load is the most important factor in pavement wear. Low weight per axle is more important than gross combination weight in minimizing pavement damage.
- Trucks are equipped with different suspension systems for different vocational needs: walking beam suspension for off-road vehicles like dump trucks; four-spring suspension for trucks operating on smooth highways; and air suspension, which has virtually replaced the four-spring suspension in new trucks.
- On smooth roads, suspension type doesn't affect pavement damage caused by single axles. Tandem axles on rough roads are a greater concern because of unequal load sharing.
- Long wavelengths of roads cause most damage because they excite the rigid body motions of trucks. The dynamic response of vehicles tends to be the same, leading to pavement wear in the same spots.
- Productivity demands are causing vehicle design changes that affect pavement. Radial tires, for example, have operating benefits but run at higher pressures and leave a smaller "footprint." This concentrates the load on the pavement and can result in more rutting.

(Points of interest raised at the San Antonio meeting)

- Factors determining pavement condition and performance include thickness of pavement layers; quality of construction materials and practices; maintenance history; roadbed soil; environment and weather; number of axle loads; and weight of axle loads.
- Functional performance is determined by the Present Serviceability Index (PSI); International Roughness Index (IRI); skid number; noise; appearance; and down time for maintenance.
- Structural performance is affected by traffic (i.e., truck characteristics); subgrade (strength, thickness, drainage, stability); paving materials (concrete or asphalt, layer thickness); maintenance and rehabilitation efforts; and design uncertainties.
- Truck fleets have relatively short life cycles while highway systems have long life cycles (decades). Many Interstates are 30-40 years old, but the geometrics have not been changed. It is not possible to rebuild the highway system overnight to accommodate changes in truck sizes and weights.

APPENDIX D

U.S. TRUCK DRIVER ANTHROPOMETRIC AND WORKSPACE STUDY (SP 712)

SAE Recommended Practices Developed Or Revised

J941	October RP	"Motor Vehicle Driver's Eye Range
J1052	May 1987 RP	"Motor Vehicle Driver and Passenger Head Position
J1100	June 1984 RP	"Motor Vehicle Dimensions"
J1516	October 1985 RP	"Accommodation Tool Reference Point"
J1517	October 1985 RP	"Driver Selected Seat Position"
J1521	March 1987 RP	"Truck Driver Shin-Knee Position for Clutch and Accelerator
J1522	October 1985 RP	"Truck Driver Stomach Position"

APPENDIX E

A REPORT TO CONGRESS ON TRUCK RIDE QUALITY

Key Conclusions

- By far, the most critical and difficult issue of ride quality to understand is the vibration component.
- No definitive research findings have scientifically quantified the significance of the relationship between vibration experienced in trucks and safety.
- At this time, clear-cut answers to the relationship between truck ride quality and highway safety cannot be provided by the scientific community.
- Research findings on the effects of vibration are often inconclusive, conflicting, and difficult to apply to the real world.
- At the present time, there is no hard evidence that whole body vibration related to truck ride is or is not a factor in causing health problems which might affect the highway safety of trucks.
- It is not possible nor practical to establish any significant link between ride vibrations and accident involvement using accident data files and forms. It may be possible to investigate such a link through a specially designed study at substantial expense.
- The exact behavior of the vehicle and the degree to which vibration modes influence the vibration environment within the vehicle cab are dependent upon the specific design actions adopted by the vehicle manufacturer in order to satisfy simultaneously, the detailed specifications prepared by the purchaser and the road-use laws prevailing in the States in which the vehicle will be used.
- The level of vibration the driver is exposed to can be substantially reduced by vehicle design options that are available at an additional cost.
- It may be predicted that truck ride vibration levels will generally increase in severity if the highway system continues to deteriorate in its surface roughness condition.
- The methodology for relating truck vibration directly to common measures of road roughness does not exist. To establish such relationships, better measures of road roughness, such as profiles, are needed.
- The amount of shock and vibration impinging on a driver is a function of a number of variables, some of which are: road surface roughness, wheel rim and tire balance, vehicle suspension, vehicle load, truck design, fifth wheel placement, seat type, and seat suspension.

APPENDIX E (Cont.)

- The most widely recognized guides for evaluating human exposure to whole-body vibration are the International Standard, ISO-2631 and the American adaptation, ANSI S3.18-1979.
- Although in-cab measurement made by some investigators indicate that the exposure level may often exceed the threshold for impaired performance established in the International Organization for Standardization (ISO), Standard 2631, the validity of those thresholds has not been adequately demonstrated for the driving task.
- The general level of knowledge on the effects of vibration on driver health and highway safety cannot, without further research, support or preclude the need for federal standards relative to vibration.

Report Recommendations

- The federal government should monitor, cooperate and participate in ride quality related efforts undertaken by the industry (manufacturers, owners, and drivers) in the following areas:
    a. Measurement and characterization of the truck ride vibration environment, with emphasis on characterizing the long-term vibration exposure of truck drivers, including occurrences of short duration, high level transients.
    b. Effects of factors specific to the truck driving environment (vibration, noise, schedule, etc.) on driver fatigue, performance, safety, and health.
    c. Effects of road roughness on vehicle vibrations as may adversely affect ride, safety, and roadway deterioration.
    d. Effects of vibration on the long-term health of truck drivers.
- The FHWA should continue to study road surface characteristics affecting truck ride quality. This information should be used to determine which specific types of road surfaces commonly produce poor ride quality, as well as the correlation of vehicle configuration and road surface characteristics with ride quality.
- FHWA should monitor health-related problems of the motor carrier industry through the Voluntary Employee Injury and Illness Reporting System (VEIIRS) which is the process of being developed for complete implementation. Effort should be made to identify those employee injuries and/or illnesses that may be related to ride quality problems.
- The ISO and ANSI writing groups should work on admendments to ISO 2631 and/or ANSI S3.18-1979 for application to the evaluation of truck driver vibration environments with emphasis on the high amplitude, short-duration transient acceleration.
- The society of Automotive Engineers (SAE) should develop Standards and Recommended Practices for the measurement and analysis of truck ride vibration data.

APPENDIX F

ABOUT THE AUTHOR

Farrel L. Krall

The author, with a BSME degree, has been employed by a leading manufacturer of medium/heavy trucks, buses, and engines since April 1960. The first six years included assignments in vehicle design (axles, brakes and transmissions), critical path scheduling of major engineering programs, and engineering test and development. The latter assignment, in 1965 and 1966, included responsibility for developing test procedures and a vehicle evaluation program to establish compliance with GSA 515 Federal Safety Standards, which served as a basis for many of the initial Federal Motor Vehicle Safety Standards (FMVSS). This responsibility covered a product line of vehicles including light trucks, multi-purpose passenger vehicles, medium/heavy trucks, and buses.

With congressional enactment of the 1966 "Safety Act," the author was transferred to the legislative safety group having liaison responsibility with the federal government. In 1972, he assumed responsibility for the legislative safety function, and since 1979 has been responsible for all areas of product-related technical legislation, including liaison with NHTSA, FHWA, and NTSB.

Since 1966, the author has served on numerous committees of the Society of Automotive Engineers (SAE), the Motor Vehicle Manufacturers Association (MVMA), and various government/industry advisory groups. Participation on these various committees has provided the author opportunity to be directly involved in most of the coordinated government/industry activities outlined in Sections 2.0 and 3.0 of the subject SAE paper. See Appendix F, Exhibit 1, for a listing of SAE and MVMA committee memberships.

The author has had considerable involvement since 1967 in the planning, development, and monitoring of various heavy truck accident data programs. In 1979, the MVMA Motor Truck Research Committee (with the author as chairman) worked with the staff at University of Michigan Transportation Research Institute (UMTRI) in developing accident data criteria pertinent to truck manufacturers. This effort led to the 1980 implementation of the UMTRI TIFA Program with funding support from MVMA.

The author has been a member of NHTSA's Motor Vehicle Safety Research Advisory Committee (MVSRAC) since October 1987. He is a member of the MVSRAC's Heavy Truck Subcommittee (HTS), chairman of the HTS Tire Research Task Force, and chairman of the SAE Truck Tire Characterization Subcommittee, which oversees ongoing research work at Calspan and UMTRI.

In June 1992, the author was appointed a member of the National Research Council Transportation Research Board's "Committee on Motor Vehicle Size & Weight."

APPENDIX F
Exhibit 1

COMMITTEE MEMBERSHIPS
FARREL L. KRALL

SAE

Current Affiliations

- Cab Occupant & Environment Committee *(Charter Member - 1978)*
    - Truck Crashworthiness Subcommittee *(Charter Member - 1980)*
    - Truck Crashworthiness Task Force
    - Fuel Systems Task Force *(Charter Member - 1990)*
- Truck Tire Characterization Subcommittee *(Chairman and Charter Member - 1991)*
    - Tire Research Task Force (Ex-Officio Member - 1991)
- Intelligent Vehicle Highway Systems (IVHS) - Commercial Vehicle Operations *(Chairman and Charter Member - November 1992)*

Past SAE Committees

- Automotive Safety Committee (1968-1972)
- Vehicle Research Institute/Safety Research Advisory Committee (1971-1974)

MVMA (1966-1992)

- Motor Truck Manufacturers Policy Committee *(Alternate)*
    - Motor Truck Research Committee *(Chairman 1977-1986)*
- Engineering Policy Committee *(Alternate)*
    - Vehicle Engineering & Safety Standards Committee
    - Engineering Research Subcommittee
    - Vehicle Safety Development Committee (Trucks)
    - Accident Data Collection and Coordination Subcommittee
- Transportation Committee
- International Standards Liaison Committee