Form R-396 (1/1/87)

Standard Title Page -- Report on State Project

Report No.	Report Date	No. Pages	Type Report: Interim	Project No. :
VTRC 90-R2	July 1989	87	Period Covered:	Contract No.:

Title and Subtitle

Interim Report: Traffic and Geometric Characteristics Affecting the Involvement of Large Trucks in Accidents

Key Words

Large Trucks

Accident Rates

Accident Involvement Causes

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Supplementary Notes Project funded by:
Virginia Department of Motor Vehicles
Transportation Safety Administration

Abstract Recent trends indicate that vehicle miles traveled for large trucks is increasing at a higher rate than for other vehicles. The resulting competition between large trucks and other vehicles for highway space can be expected to result in more multivehicle collisions involving large trucks. The likelihood of these collisions causing severe injuries to vehicle occupants will also increase with the trend towards the use of smaller automobiles and heavier and larger trucks. In order to develop countermeasures that will alleviate this problem, it is first necessary to identify the characteristics of large-truck accidents and the role of traffic and geometric variables in such accidents.

The major factors associated with large-truck accidents including the effect of highway facility type and highway geometry are investigated. Changes in large-truck accidents for periods before and after 1982 are evaluated by a comparison of pre- and post-1982 accident involvement rates. Factors that might have affected large-truck travel and accident rates include the Surface Transportation Assistance Act of 1982 (STAA), the improvement of the nation's economy, and deregulation of the trucking industry.

The results indicate that fatal crashes involving large trucks have been increasing in contrast to all other vehicles, for which the fatality rates are constant for the same period. Driver-related factors are associated with 75 percent of all accidents involving trucks, and driver error is associated with 50 percent of all fatal truck accidents. A significant correlation is also observed between driver error and highway alignment in accidents involving trucks. The risk of a fatality in a multivehicle accident involving a truck and another vehicle is found to be highest on two-way undivided facilities. On divided, limited access facilities, this risk is reduced by 50 percent. An unexpected increase in tractor trailer accident involvement rates for non-STAA primary routes is observed and is attributed to incompatibilities between large-truck characteristics and the non-STAA highway environment.

This interim report presents the results of the first part of a study, which also involves the development of models relating accident occurrence with goemetric and traffic characteristics. The development of these models is now in progress. These models and the information given in this interim report will facilitate the formulation of countermeasures that will reduce accidents involving large trucks in Virginia.

INTERIM REPORT

TRAFFIC AND GEOMETRIC CHARACTERISTICS AFFECTING THE INVOLVEMENT OF LARGE TRUCKS IN ACCIDENTS

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

Charlottesville, Virginia

July 1989
VTRC 90-R2

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ACKNOWLEDGMENTS

The authors are grateful to the Virginia Department of Motor Vehicles for sponsoring this project and to the personnel of the Traffic Engineering Division of the Virginia Department of Transportation, especially to Fred F. Small, Garland C. Campbell, and James B. Robinson who provided the data base on accidents and who assisted with the collection of traffic data on interstates and other highways.

The authors are especially grateful to Lewis Woodson of the Research Council. Without his assistance all the data required for the study could not have been collected.

The research is being performed under the general guidance and advice of the Research Task Force on Traffic and Geometric Characteristics Affecting The Involvement of Large Trucks In Accidents consisting of:

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ABSTRACT

Recent trends indicate that vehicle miles traveled for large trucks is increasing at a higher rate than for other vehicles. The resulting competition between large trucks and other vehicles for highway space can be expected to result in more multivehicle collisions involving large trucks. The likelihood of these collisions causing severe injuries to vehicle occupants will also increase with the trend towards the use of smaller automobiles and heavier and larger trucks. In order to develop countermeasures that will alleviate this problem, it is first necessary to identify the characteristics of large-truck accidents and the role of traffic and geometric variables in such accidents.

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INTRODUCTION

Large trucks, which are defined here as trucks having six or more wheels in contact with the road and having a gross vehicle weight greater than 10,000 lb, have now become a significant proportion of the vehicle fleet on the nation's highways. In Virginia, for example, the proportion of large trucks on some highways is as high as 50 percent. The vehicle miles of travel (VMT) of these large trucks on Virginia highways has continued to increase over the years, and in 1983, for the first time, the rate of increase of large truck VMT surpassed that for passenger cars. Between 1979 and 1982, for example, the average annual rate of increase in the VMT of large trucks was less than 1 percent per annum, whereas that for passenger cars, vans, and pickups was about 2.6 percent. Between 1983 and 1985, however, the VMT of large trucks in Virginia increased at an average rate of 8.4 percent per annum, whereas that for passenger cars, vans, and pickups was about 6.3 percent per annum.

In addition to the increase in VMT of large trucks, both the maximum allowable size and axle weights have been increasing over the years. The Surface Transportation Assistance Act (STAA) of 1982 requires states to allow trucks of 80,000-lb gross weights and 102-in widths and prevents states from establishing limits on overall tractor trailer lengths (Appendix, Table 1). These provisions apply to all interstate highways and other roads in the federal and primary systems that are so designated by the secretary of transportation. These roads are now commonly referred to as "STAA designated and access system of highways."

Fatal accidents per 100 million VMT for all large trucks in Virginia increased from 3.81 to 5.88 between 1982 and 1984 (an increase of about 54 percent); that for tractor trailers increased from 2.81 to 5.36 (an increase of about 90 percent); whereas that for other vehicles (passenger cars, vans, and pickups) remained approximately constant at less than a 0.30 percent increase.

In order to arrest this trend of increasing fatal accident rates for large trucks, it is necessary to identify the crash characteristics and the factors that are associated with these crashes so that appropriate countermeasures can be implemented. A study is now being conducted in which one of the objectives is to identify appropriate countermeasures for highway geometrics to reduce large-truck crashes. The first part of this effort is to carry out a detailed analysis of the historical data on large-truck accidents in order to determine specific characteristics of these accidents. This interim report documents the results of this effort.

PURPOSE AND OBJECTIVES

The purpose of this portion of the study was to identify the characteristics of large-truck accidents in Virginia.

The specific objectives were

- to determine the distribution of large-truck accidents by weekday
- to identify the major causes of large-truck accidents
- to determine whether large-truck accidents are overrepresented in multivehicle accidents
- to determine the effect of the type of highway on large-truck accidents
- to determine the effect of road geometry on large-truck accidents
- to identify significant changes with time in large truck accident characteristics in Virginia.

METHODOLOGY AND RESEARCH APPROACH

The methodology for carrying out this portion of the study involved the following tasks:

- o a review of the literature
- o a compilation of historical accident data
- o an analysis of the compiled accident data.

Literature Review

A review of the literature was carried out to identify results obtained from recent studies similar to this project. Facilities of the University of Virginia, the Virginia Transportation Research Council, and the Transportation Research Information Service were used to identify and select appropriate publications for review. Information was sought on the characteristics of large-truck accidents, particularly in relation to associated causal factors and the types and severity of accidents.

Compilation of Historical Accident Data

The basic data on accidents in Virginia were obtained from the police accident report forms, which are completed by the police officer investigating every accident involving a fatality, injury, and/or property damage of $500 or more. The recorded information for each year is coded and stored in a computer file; these are referred to as "crash files." The Virginia Department of Transportation also collects and records in a computer file travel characteristics of different categories of vehicles. Unfortunately, however, for the period 1980 through 1982, the vehicle type codes permitted only the extraction of tractor trailer data, since twin trailers were then not permitted on Virginia highways. It was therefore not possible to obtain accident data for twin trailers as distinct from that for tractor trailers for these years. This distinction was, however, available from 1983 onward. As a result, in some parts of the analysis, all tractor trailers were considered one vehicle category. Data on VMT were available for single-unit trucks and tractor trailers. The single-unit trucks were categorized as 2-axle 4 tires, 2-axle 6 tires, and 3-axle 6 to 10 tires.

All of the data used in this analysis were extracted from the crash files, Average Daily Traffic (ADT) reports, and accident summary reports for 1980 through 1986.

The term twin trailer is used in this report to describe a combination of a tractor truck and two trailers or a tractor truck, semi-trailer, and a trailer coupled together.

Analysis of the Compiled Accident Data

The cross-correlation technique was used to develop matrices relating accident characteristics and associated factors, and the results obtained were used to prepare some of the charts presented herein. Student's t test and the binomial theory were also used when it was necessary to test for significant differences or overrepresentation. In order to facilitate comparison, some analysis was also carried out on crashes of passenger cars, vans, and pickups.

The analysis was carried out in two parts. In the first, the trends in large-truck travel and the accident rates of large trucks on all interstate and state primary routes were examined. This analysis yielded a macroview of the performance of the entire primary and interstate highway system in the state of Virginia in terms of the impact of the increasing usage of this system by large trucks. Accident rates were determined for the interstate and primary routes both together and separately. These rates are given in terms of accidents per 100 million VMT and are different from the accident involvement rates used in the latter half of the analysis.

Changes in traffic characteristics between the pre- and post-1982 periods are evaluated in the latter half of the analysis, which therefore focused on a microview of different highway and traffic environments represented by three different categories of highways. Data were compiled on selected interstate, designated primary, and undesignated primary routes. The selected routes represented the bulk of the large-truck mileage within each highway category. For example, the selected interstate routes accounted for 90 percent of the total interstate mileage in Virginia and carried 96 percent of the total truck VMT on all interstate routes. The selected STAA primary routes accounted for 75 percent of the total STAA primary mileage in Virginia and carried 66 percent of total truck VMT on all STAA primary routes. The selected non-STAA primary routes accounted for 17 percent of total non-STAA primary mileages and carried 30 percent of the total truck VMT on non-STAA primary routes. The selected routes were:

- interstates: I-64, I-66, I-77, I-81, I-85, I-95, and I-495
- designated primaries: 19, 23, 29, 58, 220, 360, and 460
- undesignated primaries: 1, 10, 11, 15, 17, 50, and 60

In this part of the analysis, accident involvement rates for tractor trailers and other vehicles were compared. Assuming equal responsibility for an accident in the case of two-vehicle accidents, both vehicles were counted in the process of obtaining the involvement rates for each vehicle type. These rates are given in terms of involvements per 100 million VMT. Only injury and fatal accidents were considered in obtaining these involvement rates. The reason for the exclusion of property damage accidents was to avoid the possible introduction of a bias into the reported accidents because of changing repair costs and the role of subjectivity in these estimated costs.

Fatal-accident involvement between the two vehicle categories was also compared in terms of involvement ratios. These involvement ratios are defined as the number of fatal involvements per 100 fatal and injury involvements. These ratios serve as an indicator of accident severity.

Analysis of variance was used to determine significant changes by investigating the following null hypotheses:

- There is no difference between injury and fatal-accident involvement rates for pre- and post-1982 periods.

- There is no difference between fatal-accident involvement rates for pre- and post-1982 periods.

A comparison was also carried out between the involvement rates of tractor trailers and other vehicles over the period under investigation. The relative involvement of tractor trailers compared to all other vehicles is defined in this study as the ratio of their respective involvement rates.

ANALYSIS AND RESULTS

The following sections summarize the results of the analysis conducted for this portion of the study.

Literature Review

The following factors have been identified in previous studies as contributing to truck accidents.

- driver-related factors:

  --age, experience, training   --drug use

--medical condition
--fatigue
--alcohol use
--driver qualifications
--driver safety
--motivation programs

- vehicle-related factors:
  - --vehicle design and weight
  - --crash-worthiness
  - --large-truck dynamics and crash avoidance
- highway/environment related factors:
  - --roadway type
  - --interchanges/intersections
  - --grades
  - --curves
  - --stopping sight distance
  - --roadside hazards
  - --speed differentials
  - --lighting and weather.

Driver-Related Factors

Driver error has been recognized as a major link in the causal chain in accidents involving large trucks. Shinar analyzed 161 in-depth accident investigations that involved large trucks and found that 8 of 10 causes cited most frequently were related to driver error [1]. In a separate study in Washington on data based on police reports, inattention and negligence were identified as the most frequent causes involved in large-truck accidents with another vehicle [2]. The truck driver was the causal factor in 62 percent of the accidents compared to 31 percent for the other driver. Defective truck equipment was cited in 6 percent of the accidents.

The following paragraphs briefly summarize the results from numerous studies carried out to investigate the influence of driver-related factors on truck crashes.

o Age, experience, and training: A number of studies have yielded data and statistics on the distribution of large-truck accidents by age of the driver. The results of all the analyses in this area show a clear trend of high accident rates for the younger age group, low for the middle age group, and somewhat high again for older age group [3, 4]. A survey by Wyckoff indicates that drivers under the age of 25 appeared to take greater risks and a greater number of them than other drivers [5]. There is little information available on the influence of formal driver training on large-truck crashes. However, available data have revealed that many drivers involved in accidents have not had any formal driver education [6]. This situation has also been worsened by the influx of many inexperienced drivers into the trucking industry as a result of deregulation.

o Medical condition: Accident researchers and concerned organizations have identified medical conditions that impair a driver's ability to respond to a complex driving situation as a significant contributing factor in motor vehicle accidents. Waller estimated that 15 percent of all accidents could be attributed to medical conditions [7]. There is a lack of data relating truck crashes and relevant driver medical conditions.

o Fatigue: According to a study conducted by the American Automobile Association "fatigue is the probable primary cause of 41 percent" of large-truck crashes [8]. Smist and Ranney concluded that drivers of articulated vehicles were more often reported as fatigued or sleepy [9].

o Alcohol use: The scope and nature of the drinking and driving problem among truck drivers is not well understood. Conclusions from studies thus far must also consider expected under-reporting of alcohol involvement. Among accidents in which the driver was fatally injured, alcohol involvement ranged from 36 percent [10] to 24 percent [11]. Also, drivers of straight trucks were slightly more likely to have been cited as drinking prior to an accident than drivers of articulated vehicles [8].

o Drug use: There have been very few studies focused on the involvement of drug use in large-truck accidents. One study by Terhune and Fall indicated that about 1 percent of truck drivers are drug users [12]. Wyckoff stated that based on his interview data, the use of marijuana appears to be at levels similar to those in overall population [5].

o Driver qualification: The Federal Government, the states, and the motor carrier industry jointly administer the qualification of drivers to operate large trucks. From the point of view of accident causation, what is more relevant is the process of identification and disqualification of problem commercial drivers as a preventive measure. This is complicated by the fact that a significant number of problem drivers hold multiple driver's licenses from different states [13]. This problem may be resolved to a large extent by the new licensing program to be implemented on January 1, 1989, under which every commercial vehicle driver will have only a single license.

o Driver-safety motivation programs: These programs aim at the prevention of large-truck crashes. There is a direct relationship between fuel-economical driving techniques and safe-driving techniques. Galligan describes a program in which carriers gained an increase of 29 percent in fuel efficiency and a 50 percent reduction in accident rates [14].

Vehicle-Related Factors

Vehicle design and maintenance are recognized as direct or indirect causes of accidents. The extent to which these factors interrelate with driver factors and highway or environmental factors to cause an accident is often difficult to establish.

The vehicle-related factors identified thus far in studies on the subject of large-truck crashes and other related topics are summarized in the following:

o Vehicle design and weight: By vehicle design characteristics, reference is made to truck length, width, number of towed units, cargo body type, and gross vehicle weight. Many studies have investigated their influence on off-tracking, splash and spray, aerodynamics, backing, speed on grades, braking and stability. One particular study by the Western Highway Institute claimed that braking and stability can deteriorate as truck length, weight, and the number of towed trailers increases [15]. Some studies have found that the accident involvement rates of double trailers are greater than those for single trailers [3]. Fatal accident rates have also been found to be greater for doubles [16]. There have not been many studies that have examined the relationship between vehicle weight and accident occurrence. Perhaps this is due to the particular difficulty in obtaining accurate weight data. A study by Winfrey found that the heaviest weight group had the highest fatality rate but the lowest accident rate [17].

o Crashworthiness: The crashworthiness of a large truck is defined here in relation to the types of protection provided for the occupants of both the truck and the occupants of other vehicles. The objective of studies done on this have mainly been to reduce the fatalities and injuries resulting from such crashes. Some of the results noted in the literature are summarized here.

--Truck occupants: The most frequent type of accident leading to a truck occupant fatality is truck rollover. Rollover accounts for 50 percent of all single-unit truck fatalities as compared to 26 percent for passenger cars [6]. The relative levels of protection afforded by the different types of tractor cabs also have been studied. Truck driver fatalities for cab-over-engine tractors was found to be more than double that for cab-behind-engine trucks [16].

--Occupants of other vehicles: In all fatal accidents involving a truck and another vehicle, the probability of the fatality being an occupant of the other vehicle has been found to be 69 percent according to the Fatal Accident Reporting System data for 1979 through 1980 [18]. Most (90 percent) of the fatal car-into-truck rear end collisions involved underride [19].

o Vehicular dynamics and crash avoidance: Some accidents occur when a driver exceeds the safe dynamic performance bounds of his vehicle. As the task of driving the vehicle becomes more complex (as in the case of combination trucks), special skills are required to handle the vehicle to avoid a collision. Some of the relevant factors that have been studied in this area are summarized in the following:

--Brake system: One of the common factors contributing to large-truck crashes in which passenger cars were involved was the disparity in the braking capabilities of the two types of vehicles [20].

--Brake system maintenance: The importance of brake system maintenance has been clearly emphasized by the results of many studies of truck accidents. The Bureau of Motor Carrier Safety (BMCS) found brake systems to be the vehicle defect cited most often. Brakes contribute to 31 percent of all accidents resulting from mechanical defects [21].

--Handling and stability: Dynamic instability in a vehicle can be caused by either simple braking or by steering maneuvers that cause unstable lateral motion or rollover. Ervin et al., analyzing 1976 through 1978 BMCS data, found a close relationship between the rollover threshold and the number of accidents involving rollover [22].

--Aerodynamic disturbances and splash/spray effects: Results of truck experiments by Weir et al. [23] indicated that a passenger car passing a truck was displaced laterally by the truck's wake from 0.5 to 3.3 ft depending upon lane widths, relative and absolute speeds, initial vehicle clearance, and crosswind conditions. Large trucks operating on most roads during wet weather create splash and spray. Spray-fouled rear view mirrors on trucks can increase the possibility of lane change accidents. There has been no study that investigated the contribution of this factor to truck accidents.

--Truck-generated stress: The combined effect of long-term simultaneous exposure to heat, noise, and vibration has been suggested to lead to possible negative physiological or psychological effects that in turn lead to stress-induced fatigue. A study by Mackie et al. indicated that truck-cab heat decreased alertness and increased fatigue [24].

--Vehicle conspicuity: Minahan and O'Day have cited this factor as the main cause of accidents involving an impact into the sides or rear of a large truck [19]. Green et al. reported the benefits of retroreflective treatments applied on trucks [25]. Lum found that flashers on trucks during both daylight and night hours are effective in reducing the risk of accidents [26].

Highway, Traffic, and Environmental Factors

Accident experience in Virginia for the years 1980 through 1985 has shown that tractor trailer accident involvement rates are lowest on interstates [27]. The same is true for all other vehicles. This clearly indicates the effect of superior highway and traffic conditions on reducing accidents, all else being equal.

This literature review has indicated that there has been little research investigating the effect of highway and geometric factors on truck accidents. The following paragraphs summarize some of the relevant findings on the role of each factor.

o Roadway type: Classifying roadways into freeways or nonfreeways and urban or rural, an accident rate comparison by Vallette et al. found that the rates for large trucks were highest on urban nonfreeways and lowest on rural freeways [3]. A study by Cirillo et al. found that access control and other freeway design features had a positive impact on truck accident rates [28].

o Interchanges: The study by Vallete et al. found that 16 percent of the truck accidents on freeways occurred in the vicinity of an interchange [3]. A similar finding has been reported by Cirillo, who also found that the accident rates at off-ramps in most cases were higher than the rate at on-ramps [28].

o Intersections: The study by Vallette et al. found that of the large-truck accidents at intersections, 65 percent occurred on urban freeways and 23 percent on rural freeways. Other studies have also indicated that all types of trucks are more involved in accidents at junctions than other vehicles [3].

o Grades: Large trucks encounter special risks on grades. On the upgrades, they are subject to being struck in the rear by faster vehicles, and on downgrades, they are susceptible to runaway accidents or striking slower vehicles. Scott and O'Day endorsed this as the most likely order of accident occurrences on grades [4].

o Curves and superelevation: Accidents involving large trucks on curves have been found to range from a low of 7 percent on urban freeways to a high of 34 percent on rural freeways [3]. An analysis of the fatal accident reporting system (FARS) data for combination trucks in which the driver was killed showed that 45 percent of single-vehicle accidents occurred on curved sections of roadway compared to 16 percent for multiple vehicle accidents.

Despite the critical role of superelevation in maintaining vehicle stability, few studies have addressed this issue. Using data from single-vehicle crash sites and comparison sites, an investigation by Zador et al. has shown that inadequate banking on curves presents a significant risk to trucks [29].

o Stopping sight distance: Stopping sight distance is the distance traveled by a vehicle from the instant its driver sights an object that requires a stop to the instant when the vehicle has been brought to a stop by the application of brakes. It has generally been assumed that the longer sight distance afforded by higher eye height compensated for the longer stopping distances required by trucks. An investigation of this assumption concluded that although there is some compensating effect because of the higher eye height of the truck driver, the length of passing zones standardized for passenger cars are inadequate for trucks [30].

o Roadside hazards: According to FARS data from 1980 through 1985, approximately a third of fatal accidents were reported as collisions with fixed objects. Considerable effort has gone into the development of breakaway roadside features and protection devices to reduce this toll, particularly for passenger cars since they represent the majority of vehicles. Many of these protection devices, such as impact attenuators, guardrails, bridge rails, and median barriers that have been designed for automobiles have been found to be inadequate to contain heavier vehicles [31,32,33].

o Speed differentials: The greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chances of being involved in an accident [34]. A beneficial effect of the national speed limit of 55 mph at the time it was imposed was a reduction in the speed differential that existed between cars and trucks [35, 36].

o Lighting and weather: Although data are available on accidents, there has been a lack of relevant exposure data needed for an investigation into the role played by lighting and weather. A study by Jovanis and Chang included the hours of snow exposure as an independent variable in an accident causation model [37].

Characteristics of Large-Truck Accidents

The results obtained from the different analyses carried out during this portion of the study are summarized in the following subsections. The details of the specific analytical methodology used are also described when this is necessary to clarify the computation carried out.

Effect of Day of the Week

The t test at a 5 percent significance level was performed on each set of data to determine whether accident frequency during weekdays (Monday through Friday) is significantly different from that for weekends (Saturday and Sunday). This was done by proposing the null hypothesis that the average percentage of crashes during the week equals the average percentage during the weekend. The analysis shows that although it can be concluded that there is a significant difference between the frequencies of large-truck crashes during weekdays and weekends, this conclusion cannot be made for other vehicle crashes (Appendix, Table 2). In fact, it can be seen that although Friday accounts for the highest percentage of crashes for both large-trucks and other vehicles, the number of large truck crashes declines significantly during the weekend. The total percentage of large-truck crashes occurring during the weekend is less than that for any other day of the week. This may be due to the reduced truck VMT on these two days. These results suggest that countermeasures such as increased police enforcement for reducing crashes due mainly to driver causes (e.g., speeding) may be effective during any day of the week for other vehicles but will be much more effective for large trucks if implemented during the week rather than on weekends.

Effect of Month

The percentage distribution of large-truck and other vehicle crashes was also obtained to determine whether the frequency of truck crashes varies seasonaly (Appendix, Table 3). There is little difference between the distributions for large trucks and that for other vehicles. The minimum frequency occurred in February both for large trucks and other vehicles. However, the maximum frequency for large trucks occurred in August, whereas that for other vehicles occurred in November and December.

Major Factors Associated with Large-Truck Crashes

The major factors associated with large-truck crashes can be categorized as follows:

- o driver related
- o vehicle related
- o highway/environmental related.

Although age, experience, fatigue, alcohol, and drug use have in the past been treated as driver-related factors, in this study, the data available will allow a breakdown of driver-related factors into fatigue (handicapped driver), speeding, error, and alcohol and/or drugs. Examples of driver error are improper passing, driving left of centerline while not overtaking, failing to return to right-of-way, improper turns, and following too closely.

Vehicle defects have traditionally included brake system, tires, aerodynamic disturbances, and truck-generated stress--such as heat, noise, and vibration. The data available in Virginia, however, give nine subcategories, which include defects in lights, brakes, and steering, puncture or blow-out, worn or slick tires, and engine trouble. In this study, however, a detailed breakdown of vehicle defects was not carried out since the main objectives did not include the identification of countermeasures relating to vehicle defects.

Environmental causes usually include lighting, weather, and pavement condition (wet or dry). Highway causes usually relate to the geometric characteristics such as grades and curves. In this study, five subgroups were used for geometric characteristics: (1) straight and level, (2) curve and level, (3) grade and straight, (4) grade and curve, (5) and others (which include crest curve and sag curve).

The major factors are first presented for all large-truck crashes and then separately for straight trucks, tractor trailers, and double trailers in terms of the three major groups--driver, vehicle, and environment--and a fourth group that includes all other factors. In each year, driver-related factors accounted for about 75 percent of the crashes. Vehicle-related factors accounted for 6 to 9 percent of crashes, whereas other factors accounted for 14 to about 19 percent (Appendix, Table 4). It should be noted again that it is likely that the percentage for vehicle-related factors may be higher than indicated in this table because of the way the accident reports are normally completed by the police. It is clear, however, that vehicle-related factors are much lower than driver-related factors. It is interesting to note, however, that although the percentage of crashes for which driver-related factors was identified is very high, it decreased between 1984 and 1985. Further analysis of the data also showed that the actual number of crashes for which a driver-related factor was identified increased by only 17 percent between 1984 and 1986, while the number of crashes for which factors other than driver, vehicle, and environment were identified increased by about 47 percent. This shows that the rate of increase in the number of driver-related crashes is significantly lower than that for all other crashes. The identification of countermeasures that will significantly reduce other crashes will therefore help in the reduction of total crashes.

The distribution of accidents by the major associated factors from 1984 through 1986 is similar for the different categories of trucks. Driver-related factors, for example, are the predominant associated factors in that they account for 75, 75, and 74 percent of crashes for straight trucks, tractor trailers, and twin trailers respectively (Appendix, Table 5).

Since it is essential to develop countermeasures that will not only reduce large-truck crashes but will also significantly reduce fatal large-truck crashes, an analysis of the fatal large-truck crashes was also carried out to determine the predominant associated factors. Driver-related factors have been the major cause of all large-truck fatal accidents from 1984 through 1986 accounting for 86 to 92 percent of such accidents (Appendix, Table 6). Driver-related factors were also recorded as being associated with 84 percent of the fatal crashes for single-unit trucks, 92 percent for tractor trailers, and 100 percent for twin trailers (Appendix, Table 7). It should be noted however that only one fatal accident was reported involving a twin trailer from 1984 through 1986. Of the specific driver factors involved, driver error has the highest frequency, followed by speeding, drinking, and driver handicap (which includes fatigue and sleeping) (Appendix, Tables 8 and 9). A counter-measure that will significantly reduce large-truck driver error will significantly reduce fatal crashes. It is, however, not easy to identify the specific errors made by drivers. However, since highway geometry was not considered as a factor in fatal crashes, it was necessary to investigate the correlation between driver error and road alignment. It is likely that driver error is related to the alignment characteristics of the road in that a driver is more likely to make a maneuvering error on a curvy section than a straight and level section of road. The influence of road alignment on fatal crashes was therefore investigated. It should be noted, however, that for this part of the analysis, data on alignment characteristics were obtained from the police accident report forms. In the development of the models relating geometric and accident characteristics, actual field data were collected, which will be described in the appropriate section.

Thirty-two to forty-eight percent of all fatal truck accidents at different alignments occur on straight and level sections of road (Appendix, Table 10). In 1984, for example, about 60 percent of all fatal truck accidents occurred on sections of roads on which there is either a horizontal curve or a vertical curve and/or a grade (Appendix, Table 10). Although twin trailer data indicate that all fatal accidents occurred on straight and level road sections, this is based on a total of one accident and is therefore not an accurate representation of the effect of geometry. Both straight trucks and tractor trailers experienced 59 to 66 percent of all fatal accidents on road sections with horizontal and/or vertical curves (Appendix, Table 11).

The alignment distribution for the locations of 1984 fatal large-truck crashes for which driver error was identified, and for the different categories of trucks separately shows that nearly all of these crashes occurred at curves, which again suggests that highway alignment may be of importance (Appendix, Tables 12 and 13).

The results therefore indicate that alignment may influence fatal large-truck crashes and that an identification of the alignment characteristics that are predominant in fatal large-truck crashes would be useful in determining engineering countermeasures that would be effective in reducing these crashes.

Number of Vehicles Involved in Crashes

Table 14 gives the distribution of total 1984 crashes by the number of vehicles involved in each crash for both large trucks and other vehicles on all highways. It is important to note that although about 35 percent of other vehicle crashes involve one vehicle, only about 22 percent of large-truck crashes involve one vehicle. The highest percentage (69) of large-truck crashes involve two vehicles, whereas about 59 percent of other vehicle crashes involve two vehicles. Also, 9 percent of large-truck crashes involve three or more vehicles, whereas about 6 percent of other vehicle crashes involve three or more vehicles. The results indicate that it is much more likely for a large-truck crash to involve more than one vehicle than a crash involving other vehicles (Appendix, Table 14).

Further analysis of the data for the interstate and primary highways (Appendix, Table 15) indicates that when a large truck is involved in a two-vehicle crash, there is a 94 percent chance that the other vehicle involved is not a truck. One may be tempted to conclude that this over-representation should be expected because of the large percentage of other vehicles in the vehicle fleet on the highways.

In order to determine whether this phenomenon is due to the over-representation of other vehicles in the vehicle fleet, the binomial theorem was used to compare the actual and expected proportions of other vehicle/other vehicle, large-truck/other vehicle, and large truck/large-truck crashes based on the exposure represented by VMT of each vehicle type. Only two-vehicle crashes were considered since they were the largest percentage of the multivehicle crashes.

Let the proportion of other vehicle exposure = p

and the proportion of large-truck exposure = q

Then the expected proportions of crashes are:

other vehicle/other vehicle crashes = p^2

large-truck/large-truck crashes = q^2

large-truck/other vehicle = $1 - (p^2 + q^2)$

$= 2pq$ (since $p+q = 1$)

1984 Annual VMT on Virginia Interstate and Primary Highways

other vehicle = 21.73×10^9

large trucks = 2.63×10^9

Thus: $p = \frac{21.73}{24.36} = 0.89$

$q = \frac{2.63}{24.36} = 0.11$

The number of two-vehicle crashes in 1984 on the interstate and primary highways for which both vehicles were identified was:

other vehicle/other vehicle	19,951
large-truck/large-truck	333
large-truck/other vehicle	5,015

The results show that while the proportion of other vehicle/other vehicle crashes is slightly lower than expected, those for large-truck/large-truck and large-truck/other vehicle are slightly higher (Appendix, Table 16).

Number of Vehicles Involved in Fatal Crashes

Although the highest percentage of other vehicle fatal crashes involved only one vehicle, the highest percentage (60.1) of large-truck fatal crashes involved two vehicles (Appendix, Table 17). Also, about 15 percent of the fatal large-truck crashes involved three or more vehicles, whereas only about 3 percent of the other vehicle fatal crashes involved three or more vehicles (Appendix, Table 17). The percentage of single-vehicle crashes that are fatal is 1.6 for large trucks and 1.3 for other vehicles, but the percentage of multivehicle fatal crashes involving large trucks is 13.3, while that for other vehicles is only 0.3 (Appendix, Table 18). This clearly indicates that whereas the frequency of fatal crashes when a single vehicle is involved is about the same for large trucks and other vehicles, it is about 40 times more likely that a fatality will occur when a large truck is involved in a multivehicle crash than when only other vehicles are involved.

Under the assumption that all crashes are random events, the binomial theorem was used to compare actual and expected fatal crashes involving two vehicles on the interstate and primary systems. This analysis was based on VMT for large trucks and other vehicles using the following data. The number of two-vehicle fatal crashes in 1984 on the interstate and primary highways for which both vehicles were identified:

other vehicle/other vehicle = 196

large-truck/large-truck = 2

large-truck/other vehicle = 113

Other vehicle/other vehicle and large-truck/large-truck fatal crashes are underrepresented, while large-truck/other vehicle fatal crashes are significantly overrepresented (by as much as 85 percent) (Appendix, Table 19). These results suggest that countermeasures that will reduce the number of multivehicle crashes involving large-trucks will have a significant impact on fatal crashes involving large trucks. Since the data show that most multivehicle crashes involving large trucks also involve other vehicles, the separation of large trucks from other vehicles on the highway may be an effective way of reducing multivehicle crashes involving large trucks. It must be emphasized however, that such a countermeasure should not be implemented until its full impact has been identified.

Effect of the Type of Highway Facility on the Severity of Accidents Involving Large Trucks

For the purpose of this analysis, data for the years 1984 through 1986 were considered. Three types of highway categories were considered; two-way undivided facilities, divided facilities with partial or no control of access, and divided facilities with full control of access. The first and second categories consist entirely of the primary system, and the third category consists of the interstate system and some primary system mileage in Virginia. A comparison of the severity of all accidents involving large trucks on the different types of facilities and by the types of truck gave the following results. Injury accidents accounted for 35 to 38 percent and property damage accidents accounted for 59 to 63 percent of all accidents involving large trucks on all types of facilities (Appendix, Table 20). However, statistics for fatal accidents indicate a clear difference between the types of facilities. For facilities with full control of access fatal accidents account for 1.4 percent, for divided facilities with partial or no control of access, 2.0 percent, and 3.0 percent for two-way undivided facilities (Appendix, Table 20). All accidents involving large trucks were considered to belong to one of three categories: (1) large-truck/other vehicle accidents, (2) single vehicle large-truck accidents, (3) large truck/large truck accidents.

Large Truck/Other Vehicle Accidents

A closer examination of the accidents on each type of facility and the accident type indicate that a majority of fatal and injury accidents involving large trucks consist of accidents involving large trucks and other vehicles on all of the facilities (Appendix, Tables 21-23). The risk of injury or property damage in any accident involving large trucks and other vehicles seems to be approximately the same for all truck types on any facilty (Appendix, Tables 24-26). However, the risk of fatality seems to be worst on the two-way undivided facilities for tractor semitrailers (Appendix, Table 24). When the truck is a straight truck, this risk is almost equal for all divided facilities but is twice as much on undivided facilities. When the truck is a tractor semitrailer, the risk is lowered by about 80 percent as we go from undivided two-way facilities to facilities with full control of access (Appendix, Tables 24-26). No such conclusions regarding the fatality risk can be arrived at for the twin trailers since there was only one fatal accident involving twin trailers during this period.

Single Vehicle/Large-Truck Accidents

A comparison of the percentages of fatal single-vehicle truck accidents on different types of highways indicate that tractor semitrailers have the worst record on all facilities (Appendix, Tables 27-29). A somewhat surprising result is that the highest percentage of such involvements occurred on divided facilities with partial or no control of access (Appendix, Table 28). This may be attributed to the fact that a significant amount of large-truck mileage in Virginia takes place on such facilities and at higher operating speeds than on the two-way undivided facilities. Also, these roads are not as safe as interstate facilities and are more susceptible to run-off-the-road accidents.

Large-Truck/Large-Truck Accidents

An examination of all large-truck/large-truck accidents indicate that accidents involving two tractor-trailers tend to be more severe than accidents involving other combinations of large trucks on all types of highways (Appendix, Tables 30-32). It should be noted, however, that only a small number of accidents involving a double-trailer and a tractor trailer were recorded, and no accident involving two double trailers was recorded.

Types of Collision in Accidents Involving Large-Trucks

The distribution of various combinations of two-vehicle accidents involving large-trucks by the type of collision shown in Table 33 in the Appendix indicates that in all accidents involving two large trucks, the leading type of collision is rear-end followed by same-direction-sideswipe. For accidents involving a large-truck and any other vehicle, the leading type of collision is same-direction-sideswipe except in the case of straight trucks, for which it is rear-end collisions.

The high incidence of rear-end collisions between large trucks may be attributed to an inadequacy in the braking capability of large trucks. However, when both vehicles involved are trucks, the braking distances could be expected to be similar, resulting in lower numbers of rear-end accidents between large trucks. The fact that crash data indicate otherwise may be because of large disparities in braking capabilities or braking demand among trucks. Such disparities could arise because of differences in truck configuration and gross vehicle weight.

In collisions between large trucks and other vehicles, the high incidence of same-direction-sideswipe collisions indicate that a large percentage of such accidents take place in vehicle maneuvers that involve lane changing, passing, or lane straddling.

The Effect of Road Geometry on Accidents Involving Large-Trucks

It is common knowledge that the demands on any vehicle or driver are greater on roadway sections that have curves or grades. This demand on the driving task is known to be greater in the case of large trucks, because of their weight and size. In order to investigate the effect of road geometry on accidents, we compared the incidence of accidents on two types of roadway sections: (1) curves and grades and (2) all other geometries.

Single-Vehicle Large-Truck Accidents

Tractor trailers seem to have the highest probability of involvement in single-vehicle large-truck accidents (Appendix, Table 34). Although twin trailers show a 1 percent involvement in such accidents, this is based on a small number of accidents involving twin trailers, hence this may not indicate the true risk for twin trailers.

All types of trucks experience more single-vehicle accidents on curves and grades than at all other locations (Appendix, Table 34). Twin trailers seem to experience the highest risk on such roadway sections followed by tractor trailers and straight trucks. However, the proportion of fatal accidents is lowest for twin trailers and highest for tractor trailers.

Large Truck/Other Vehicle Accidents

The results for large truck/other vehicle accidents indicate that straight trucks are involved in most of these accidents (53.2 percent) followed by tractor trailers (46.5 percent) and twin trailers (0.3 percent) (Appendix, Table 35). Twin trailers seem to have the highest proportion (51.0 percent) of accidents with other vehicles on roadway sections with curves or grades. All of the fatal accidents involving twin trailers occurred on straight roadway sections. However, this is based on a single accident. Tractor trailer accidents have the next highest risk with 42 percent of all such accidents occurring on curves and grades. The proportion of fatal accidents on curves is 1.5 times that on all other road alignments. Straight trucks are least involved on curve/grade road sections with 36.0 percent of all accidents. However, their proportion of fatal accidents on such road sections is twice what it is on all other road alignments.

Pre- and Post-1982 Large-Truck Travel and Accidents

This section describes the results of an investigation carried out to assess changes in pre- and post-1982 large-truck travel and accident involvement in Virginia. These periods are 1980 through 1982 and 1983 through 1985. This division was selected because the larger and longer vehicles allowed by the Surface Transportation Assistance Act (STAA) of 1982 first appeared on Virginia Highways in 1983. First, a macroview of the performance of the interstate and primary highway system in Virginia was obtained by comparing travel miles and accident rates for the period 1980 through 1985. The performance of three different highway and traffic environments using the selected routes listed earlier was obtained through a comparison of their respective accident rates before and after 1982. The three highway environments--interstates, STAA designated primaries, and undesignated primaries--were represented by the routes that carry the highest truck mileage within each category.

STAA of 1982

STAA of 1982 provided for the expansion of the federal role in the regulation of the size and weight of large trucks. STAA required states to raise any limits that were more restrictive than federal ones, and federal limits were extended to roads other than interstates.

Table 1 (in the Appendix) shows the size and weight provisions of the STAA compared with those stipulated in the Federal-Aid Highway Act of 1956. The maximum allowable axle load is 20,000 lb for tractor trailers and 34,000 lb for tandem trailers. The overall gross weight of trucks with five or more axles is 80,000 lb. All states are prohibited from imposing lower weight limits than those shown in Table 1. In addition to the increase in axle loads, no state can limit the length of the semitrailer in a tractor trailer combination to below 48 ft, nor the length of each trailer in a twin-trailer combination to less than 28 ft. The act also prohibits all states from limiting overall lengths of tractor semitrailers or combinations with two trailers, and requires all states to raise the limit on truck width to 102 in. These provisions apply to all interstate highways and other roads in the federal and primary systems that are so designated by the Secretary of Transportation. These roads are now commonly referred to as "designated and access highways."

Large Trucks VMT

An increase in the number of tractor trailers and twin trailers has been observed on the nation's highways since 1983. A similar increase has also been observed on Virginia highways, where the annual daily VMT for tractor trailers on interstate, arterial, and primary routes increased by about 27 percent between 1983 and 1986, while the increase for passenger cars during the same period was only about 23 percent. During the same period, the annual VMT for all large trucks increased by about 26 percent on similar roads (Appendix, Table 36). One reason commonly given for the support of some aspects of the STAA is that the increased use of twin trailer trucks will not have a significant impact on overall highway safety since increased capacity of twins may cause the overall truck travel to decline. Analysis of the data in Virginia showed, however, that annual miles of total truck travel has continued to increase at a very high rate, despite increasing twin trailer travel. Tractor trailer VMT significantly increased in 1983 and continued to increase through 1986 (Appendix, Table 36). Overall, large-truck travel also significantly increased in 1983 and has continued to increase since. Two- and three-axle trucks also showed similar results. These results do not indicate that large-truck travel decreased as anticipated. In fact, the results indicate that not only is the travel of tractor trailers increasing in the state, the travel of other large trucks is also increasing significantly. It should be noted, however, that other factors such as the growth in the nation's economy and deregulation of the trucking industry might have contributed to the significant increase in large truck VMT.

Large-Truck Accident Rates

An analysis of the accident rates for different types of vehicles will indicate the extent to which STAA vehicles are involved in accidents, and thereby the effect of the STAA on highway safety in Virginia. However, because of the way accident data have been recorded in Virginia, data on lengths and widths of large trucks involved in accidents are unavailable for the period before 1987. Also, it is not possible to determine the VMT of twin trailers as distinct from that for tractor semitrailers, since up to recently the data for both types of vehicles were recorded as "tractor trailers." Some sections of the analysis presented here, therefore, cover both types of vehicle under the category tractor trailer. Also, because of the lack of adequate data, the direct effect of STAA vehicles on overall large-truck accident rates cannot be evaluated at this time.

o Total Accident Rates on Interstate and Primary Routes: A comparison of the accident rates on interstate and state primary highways for different categories of vehicles was carried out to determine whether a significant increase in these rates occurred for tractor trailers after 1982. These accident rates are based on the total number of accidents per 100 million VMT. A comparison between the average accident rates for the pre- and post-1982 periods indicate that the tractor trailer total accident rates have decreased by 0.17 percent, whereas those for all vehicles have decreased by 2.80 percent (Appendix, Table 37).

o Fatal Accidents: The average fatal accident rates for the pre- and post-1982 periods indicate that there has been a decrease of 10.75 percent for all vehicles, whereas for tractor trailers there has been an increase of 26.75 percent (Appendix, Table 38).

On the interstates, tractor trailer fatal accident rates have increased by almost 34 percent, whereas the rate for all vehicles has only increased by 5.06 percent (Appendix, Table 39). In the case of state primary highways, tractor trailer fatal accident rates have increased by 27.3 percent, while those for all vehicles have decreased by 13.33 percent (Appendix, Table 40).

o Comparison of Pre- and Post-1982 Accident Involvement Rates: In the following analysis, the hypothesis that the accident involvement rates for the pre- and post-1982 periods are the same was tested. These accident involvement rates are based only on injury and fatal accidents. The reason for omitting property damage accidents is the possible bias introduced into the data when such accidents are included without making adjustment for the effect of increasing property damage estimates and changes in property damages reporting thresholds.

The involvement rates used in this analysis are the annual (injury + fatal) involvement total per 100 million VMT. Therefore, for the pre- and post-1982 periods, equal samples of 21 observations from the selected seven routes were obtained. Each observation consisted of an accident involvement rate for tractor trailers and one for all other vehicles. These involvement rates are shown in Tables 41, 42, 43 in the Appendix.

The results of ANOVA for the pre- and post-1982 periods carried out for three categories of highways and two categories of accidents, are shown in Table 44 in the Appendix. In the usual testing procedure, the null hypothesis is tested at a suitable level of significance in order to reject or accept it. Following this procedure, for the 5 percent significance level, the null hypothesis cannot be rejected for all the highway and vehicle combinations since the F values are all less than the critical value of 4.08. However, in order to investigate the dissimilarity between involvement rates, Type I error probabilities for rejecting the null hypothesis were obtained from the corresponding F values and are shown in Table 45 in the Appendix. For example, if a Type I error probability for rejecting the null hypothesis is very high, there is hardly any difference between the pre- and post-1982 involvement rates. However, if this probability is low, that indicates some difference between the pre- and post-1982 involvement rates, although this difference may not be large enough to be significant at the 5 percent confidence level. Therefore, these error probabilities serve as an indicator of the dissimilarity between the pre- and post-1982 involvement rates compared in the hypothesis. They can also be interpreted as the probability of obtaining the observed accident rates if the hypothesis is true. Although these probability values are indicative of the significance of the dissimilarity between the pre- and post-1982 accident involvement rates, they do not directly indicate whether the difference is an increase or a decrease (Appendix, Table 45). These indications are, however, given in Table 46.

In the case of tractor trailers, the involvement rates have increased mostly on undesignated primaries, followed by designated primaries and interstates (Appendix, Table 46). The probability value of 0.256 for non-STAA primaries in Table 45 indicates the lowest probability of error for rejecting the null hypothesis that pre- and post-1982 truck involvement rates are the same. Similarly, the highest probability of 0.824 is indicated for interstates, implying the least change in involvement rates. In the case of accident involvement rates of other vehicles, interstates have experienced a decrease, the STAA primary routes and non-STAA routes a slight increase. The involvement rates of other vehicles for non-STAA primary routes show the least change, which is reflected by a probability value of 0.843.

o Involvement in Fatal Accidents: In order to determine whether there had been any significant change in accident severity, the involvement of tractor trailers and all other vehicles in fatal accidents were analyzed. The fatal involvement ratio is defined as the percentage of fatal involvements in all injury and fatal involvements.

Tables 47, 48, and 49 in the Appendix show the fatal involvement ratios for the selected routes. The fatal involvement ratio is considered to be a measure of the involvement in severe crashes. The analysis was carried out by comparing the pre- and post-1982 ratios for tractor trailers and other vehicles. The results of ANOVA on these ratios are presented in Table 50 in the Appendix, with the corresponding probability values in Table 51. The mean involvement ratios are given in Table 52.

These results indicate that the interstate routes have experienced the least change in fatality involvement ratios, which is also a decrease for tractor trailers and a slight increase for other vehicles. On both STAA and non-STAA primary routes, there has been a significant drop in fatal involvement ratios for other vehicles which is indicated by the low probability values supporting the null hypothesis. However, on these same routes, tractor trailers have experienced an increase in fatal involvement ratios with the highest such rates occurring on non-STAA routes.

Comparison of Tractor Trailer and Other Vehicle Involvement Rates for Injury and Fatal Accidents

Trends in the involvement rates (number of involvements per 100 million VMT) for the two categories of vehicles considered were examined. Since these rates are based on the annual VMT, which is a measure of exposure, a comparison of rates between the vehicle categories will yield an indication of the relative accident risk.

The selected routes for each category of highway type represent the bulk of the highway miles bearing large-truck traffic. Therefore, by this comparison, an effort is made to identify any significant differences between tractor trailers and other vehicles particular to a highway environment with a relatively high presence of truck traffic.

The involvement rates for tractor trailers on interstates were relatively unchanged from 1981 through 1983, with an increase in 1984 (Appendix, Table 53). Rates for tractor trailers on all highway categories indicate a decrease in 1985. The involvement rates for tractor trailers on primary routes indicate a decreasing trend from 1980 through 1982, which is a low year for each of the highway systems analyzed (Appendix, Table 53). The involvement rates for other vehicles also indicate a similar decrease from 1980 through 1982 and an increase from 1983 through 1985 (Appendix, Table 53). In light of this, it is difficult to attribute the increase in tractor trailer involvement rates since 1982 to STAA per se.

The relative accident involvement of tractor trailers in comparison to other vehicles was estimated by the ratio of tractor trailer involvement rates to other vehicle involvement rates. Considering the change in relative involvement between pre- and post-1982 periods, an increase across all categories of highways was observed (Appendix, Table 54). STAA primary routes have experienced the lowest increase (4.38 percent); non-STAA primary routes have experienced the highest (11.43 percent); and Interstate routes have experienced an increase of 10.24 percent (Appendix, Table 54).

From these results, it seems that the relative accident involvement risk for tractor trailers has increased the least on STAA-primary routes and the most on non-STAA primary routes.

SUMMARY OF FINDINGS

The major findings from this portion of the study are summarized below.

Factors Associated with Large-Truck Accidents

Since 1983, annual VMT for large trucks in Virginia has been increasing at a rate higher than that for all other vehicles. Fatal crashes for all large trucks increased from 3.81 to 5.88 per 100 million VMT and for tractor trailers from 2.81 to 5.36 per 100 million VMT between 1982 and 1984, whereas that for other vehicles remains practically constant below 0.30 per 100 million VMT.

Although the frequency of crashes of vehicles other than large trucks is not significantly different on any day of the week, the frequency of large-truck crashes is affected by the lower truck VMT on weekends. Countermeasures that are designed to reduce large-truck crashes primarily due to driver-related causes (e.g., police enforcement to reduce speeding) will therefore be more effective when implemented during the week than on weekends.

No significant difference was observed in the monthly percentage distribution of large-truck crashes. Large-truck crashes tend to involve more than a single vehicle, and when a large truck is involved in a two-vehicle crash, there is a 94 percent chance that the second vehicle is not a large truck.

Based on the VMT of each type of vehicle, large truck/other vehicle crashes are overrepresented when compared with the expected frequency for two-vehicle crashes. Large-truck/other vehicle fatal crashes are also overrepresented by as much as 85 percent when compared with the expected frequency for two-vehicle fatal crashes.

Driver-related factors seem to be the primary associated factors for truck crashes: they are associated with an average of about 90 percent of all fatal crashes involving large trucks. Driver error is associated with over 50 percent of fatal accidents involving large trucks; whereas, speeding is associated with 21 percent, and alcohol with 15 percent. Also, crashes involving large trucks, particularly fatal crashes for which driver error is listed as a factor, occur predominantly on stretches of highways with vertical or horizontal curves and/or grades. This strongly suggests that drivers are more likely to make maneuvering errors on a curvy section than on a straight level section of the road.

The risk of either injury or property damage in any large-truck/other vehicle accident is approximately the same for all types of trucks on any single type of highway facility.

The risk of a fatality in any large-truck/other vehicle accident is highest for such accidents involving a tractor trailer. This risk is highest when the type of facility on which the accident occurs is a two-way undivided highway, and the risk is reduced by 50 percent on divided highways with partial or no control of access. It is further reduced to 25 percent of the maximum (that on undivided facilities) if the facility is divided with full control of access.

In single-vehicle large-truck accidents, tractor trailers have the highest proportion of fatal accidents, on all types of highway facilities. The highest percentage of single-vehicle fatal accidents involving tractor trailers take place on two-way divided facilities with partial or no control of access.

Most truck/other vehicle accidents are same-direction sideswipe collisions except when a straight truck is involved: whereas, most large-truck/large-truck accidents and straight truck/other vehicle accidents are rear-end collisions.

Most single-vehicle large-truck accidents take place on roadway sections with curves and/or grades, with the worst such record for twin trailers. However, the proportion of fatal accidents is highest for tractor trailers.

Twin trailers have the highest percentage of accidents with other vehicles on roadway sections with curves and/or grades, followed by tractor trailers and straight trucks. However, the proportion of fatal accidents is again highest for tractor trailers.

Pre- and Post-1982 Changes

Although tractor trailer travel has increased significantly since the enactment of STAA, as reflected by annual VMT, the total truck VMT has also continued to increase, contrary to projections made during hearings in

Congress before the enactment. This however may be due to the significant growth in the nation's economy and/or deregulation of the trucking industry.

From 1980 through 1985, tractor trailer accident rates on all interstate and primary routes increased by about 1 percent in comparison to a 0.03 percent increase for other vehicles. Although there is no clear evidence of any impact on accident rates by the passage of STAA, the rates of fatal accidents involving tractor trailers increased immediately after the enactment of STAA.

The injury/fatal-accident mean involvement rates for tractor-trailers and other vehicles prior to and after 1982 indicate that:

o Tractor trailer involvement in accidents has increased across all types of highways since 1982, with the highest increase on non-STAA primary routes. The next highest increase was on STAA primary routes and the smallest increase was on interstate routes.

o For all vehicles other than tractor trailers, the mean involvement rate has decreased on the interstates and increased on the STAA primary routes and on non-STAA primary routes.

o On the interstate routes, tractor trailers have experienced higher accident involvements than all other vehicles since 1982. On all primary routes, on the other hand, all other vehicles exhibit higher involvement rates than tractor trailers.

The mean fatal accident ratios for tractor trailers and other vehicles prior to and after 1982 indicate:

o A decrease in the proportion of fatal accidents since 1982 for vehicles other than tractor trailers on all primary routes.

o An increase in the proportion of fatal accidents for tractor trailers on STAA and non-STAA primary routes with the non-STAA primary routes showing the largest increase.

Between the pre- and post-1982 periods, the relative accident involvement of tractor trailers (when compared with all other vehicles) has increased across all highway categories. The highest such increase has taken place on non-STAA primary routes (11.43 percent) followed by interstate routes (10.24 percent) and STAA primary routes (4.38 percent). These trends in relative involvement indicate significant increases on interstate and undesignated primary routes.

CONCLUSIONS

1. The identification of highway alignment as a predominant factor influencing the occurrence of crashes resulting from driver error suggests the need for a study that will identify those geometric characteristics that contribute to these crashes. The results of such a study could be used to develop engineering countermeasures that will be effective in reducing this type of crash.

2. The increase in tractor trailer involvement in accidents may be due to a multitude of factors including deregulation of the trucking industry and the passage of the STAA. However, the role of STAA in increased tractor trailer involvement rates is likely to be secondary to other factors such as the type of highway environment and its conduciveness to accommodating large trucks.

3. Although non-STAA routes experienced the highest increase in accident rates after the passage of the STAA, the fact that these routes were not affected by this legislation indicates this increase may be due to reasons other than the STAA.

4. The significant increases in tractor trailer accident involvement rates and relative involvement on non-STAA primary routes may be the result of an incompatibility between the geometric characteristics of these highways and tractor trailer dynamic characteristics coupled with the general trend of increasing truck travel across all types of highways.

5. Safety on Virginia highways may be significantly improved if large- truck traffic is separated from all other truck traffic. This may however create other traffic problems if implemented on existing facilities. A detailed study should be carried out to determine the feasibility of implementing such a plan.

WORK IN PROGRESS

Having gained a thorough understanding of the nature of the problem of truck accident occurrence through the analysis of accident data as reported in this interim report, work is now proceeding with the final phase of this project. During this phase, relationships between the traffic and geometric characteristics of the roadways and large-truck accidents will be established. This requires the collection of data on traffic and geometric variables at large-truck accident sites. In order to simplify and expedite the collection of geometric measures such as grades and radius of curvature, a new technique using an electronic ball bank indicator was developed. In addition to the geometric data, speed samples of large trucks and other vehicles have been obtained at these sites. On the primary routes with ADT fewer than 10,000, data have been collected at a total of 20 sites. On the interstate routes and primaries with high ADT, data have been collected at 40 sites.

The analysis of all the data collected is now in progress. Models will be developed relating accident occurrence with traffic and geometric characteristics. It is envisaged that these models and the background information gathered thus far, will enable the formulation of recommendations for the control and reduction of large-truck accidents in Virginia.

REFERENCES

1. Shinar, D. "Truck Drivers: Licensing and Monitoring. An Analysis with Recommendations. Appendix Volume D-1: An Analysis of the Causes of Large Truck Accidents, and Volume D-2: An Evaluation of Heavy Vehicle Driver Visual Requirements," Final Report, Highway Safety Research Center, Chapell Hill, North Carolina, December 1979.

2. Washington State Utilities and Transportation Commission. "Summary and Analysis: Heavy Truck-Hazardous Material Accidents," Olympia, Washington, 1980.

3. Vallete, G.R., McGee, H.W., Sanders, J.H., and Enger, D.J. "The Effects of Truck Size and Weight on Accident Experience and Traffic Operations, Volume III: Accident Experience of Large Trucks", FHWA /RD-80/137 FHWA, Washington D.C., July 1981.

4. Scott, R.E., and O'Day, J., "Statistical Analysis of Truck Accident Involvements," DOT-HS-800-627 NHTSA, Washington D.C., December 1971.

5. Wyckoff, D.D., Truck Drivers in America, Lexington Books, Lexington, Massachusetts, 1979.

6. Partyka, S.C., "Heavy Truck Report to Congress Working Group Papers, Number 1 through 8" National Center for Statistics and Analysis, NHTSA, Washington, D.C., June 1979.

7. Waller J.A., "Medical Impairments to Driving," Thomas, Springfield, Illinois, 1973.

8. American Automobile Association, Foundation for Traffic Safety, "A Report on the Determination and Evaluation of the Role of Fatigue in Heavy Truck Accidents," Falls Church, VA, 1985.

9. Smist, T.E. and Ranney, T.A., "Heavy Truck Accident Causation," Calspan Field Services, Inc., August 1981.

10. Baker S.P., "Alcohol in Fatal Tractor Trailer Crashes," Proceedings, 19th Conference of the American Association of Automotive Medicine, 1975.

11. Simpson, H.M., Warren, R.A., and Page-Valin, L., "Medical Conditions and Risk of Collision; A Feasibility Study," Traffic Injury Research Foundation of Canada, Ottawa, Canada, June 1977.

12. Terhune, K.W. and Fell, J.C., The Role of Alcohol, Marijuana, and Other Drugs in the Accidents of Injured Drivers," NHTSA, October 1981.

13. National Transportation Safety Board (NTSB). "Safety Effectiveness Evaluation of Detection and Control of Unsafe Interstate Commercial Drivers," Washington, D.C., February 1980.

14. Galligan, J., "The Hunt for Better MPG," Commercial Car Journal, Volume 138, Number 9, September 1981.

15. Western Highway Institute. "Motor Vehicle Size and Weight Standards, Western Objectives," A Study for the TRED Foundation, San Bruno, California, July 1980.

16. Campbell, K.L., and Carsten, O., "Fleet Accident Evaluation of FMVSS 121," Highway Safety Research Institute, Ann Arbor, Michigan, March 1981.

17. Winfrey, R. et al., "Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights, Volumes 1 and 2," FHWA, Washington, D.C., September 1968.

18. Eicher, J.P.; Robertson, H.D.; and Toth, G.R., "Large Truck Accident Causation," NHTSA Technical Report, NHTSA, July 1982.

19. Minahan, D.J. and O'Day, J., "Car-Truck Fatal Accidents in Michigan and Texas," Highway Safety Research Institute, Ann Arbor, Michigan, October 1977.

20. Radlinski, R.W., "NHTSA Air Brake Research Program, 1979-1981," NHTSA, Washington, D.C., March 1982.

21. Bureau of Motor Carrier Safety. "1976 - 1978 Analysis of Motor Carrier Accidents Involving Vehicle Defects or Mechanical Failure," FHWA, Washington, D.C., November 1979.

22. Ervin, R.D., "Unintended Responses of Heavy Trucks to Braking or Steering Inputs," The HSRI Research Review, Vol10, No.5, March - April 1980.

23. Weir D.H.; Ringland, R.F.; Heffley, R.K.; and Ashkenas, I.L., "An Experimental and Analytical Investigation of the Effect of Truck-Induced Aerodynamic Disturbances on Passenger Car Control and Performance, Executive Summary Report and Technical Report," FHWA, Washington, D.C., October 1971.

24. Mackie, R.R.; O'Hanlon, J.F.; and McCauley, M., "A Study of Heat, Noise, and Vibration in Relation to Driver Performance and Physiological Status," NHTSA, Washington, D.C., December 1974.

25. Green, P.; Kubacki, M.; Olson, P.L.; and Sivak, M., "Accidents and the Nighttime Conspicuity of Trucks," Highway Safety Research Institute, Ann Arbor, Michigan, January 1980 .

26. Lum H.S., "Evaluation of Techniques for Warning of Slow-Moving Vehicles Ahead: Executive Summary," FHWA, Washington, D.C., July 1979.

27. Joshua S.C., and Garber, N.J., "Large Truck Accident Involvement in Virginia," Unpublished Report, Virginia Transportation Research Council, Charlottesville, Virginia, May 1988.

28. Cirillo J.A. et al., "Interstate System Accident Research Study - 1," FHWA, Washington, D.C., October 1970.

29. Zador, Paul L., Stein, Howard, Hall, Jerome, and Wright, Paul. "Relationship Between Vertical and Horizontal Roadway Alignments and the Incidence of Fatal Rollover Crashes in New Mexico and Georgia", Washington, D.C., Insurance Institute for Highway Safety, 1985.

30. Gordon D.A., "Highway Sight Distance Requirements: Truck Applications," Final Report, Office of Research, FHWA, Washington, D.C., February 1979.

31. VanZweden, J. and Bryden, J.E., "In-Service Performance of Highway Barriers," New York State Department of Transportation, Research Report 51, July 1979.

32. Post, E.R.; Hirsch, T.J.; and Nixon, J.F., "Truck Tests on Texas Concrete Median Barrier," Highway Research Record #460, 1973.

33. Texas Transportation Institute (TTI). "Test and Evaluation of High Performance Median Barriers," College Station, Texas, February 1982.

34. Soloman, D., "Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle," Bureau of Public Roads, Department of Commerce, Washington, D.C., July 1964.

35. Zaremba, L.A. and Ginsburg, M.J., "The 55 MPH Limits and Front-to-Rear Collisions Involving Autos and Large Trucks," Accident Analysis and Prevention, Volume 9, 1977.

36. Radwan, A.E.S. and Sinha, K.C., "Effect of the National Speed Limit on the Severity of Heavy Truck Accidents," Traffic Quarterly,Vol.32, No.2, April 1978.

37. Jovanis, P.P., and Chang, H.L., "Modeling the Relationship of Accidents to Miles Traveled," Transportation Research Record 1068 TRB, Washington, D.C., 1986.

Appendix

Table 1

Maximum Size and Axle Weights of Large Trucks

Static Characteristics	Federal-Aid Highway Act 1956	Surface Transportation Assistance Act of 1982
Loaded Weight (lb.)		
Single axle	18,000	20,000
Tandem axle	32,000	34,000
Loaded	76,280	80,000
Width (in.)	96	102
Length* (ft.)		
Semitrailers and trailers	--	48
Each Twin Trailer	--	28
Overall length	55	*

*No state is allowed to establish limits on overall truck lengths.

Table 2

Percentage Distribution of 1984 Crashes
by Day of Week

Day of Week	Large-Truck	Other Vehicle (passenger cars, vans, and pickups)
	Percent*	Percent**
Monday	17.3	13.8
Tuesday	16.6	12.5
Wednesday	16.9	13.3
Thursday	17.4	13.4
Friday	19.1	17.7
Saturday	8.2	16.8
Sunday	4.5	12.5
Week day mean	17.5	14.1
Weekend mean	6.4	14.7

* Based on 11,399 truck crashes
** Based on 123,355 other vehicle crashes

Table 3

Percentage Distribution of 1984 Crashes by Month

Month	Large-Truck	Other Vehicles (Passenger cars, vans, and pickups)
	Percent*	Percent**
January	7.9	8.0
February	6.6	6.9
March	7.8	7.1
April	7.2	7.6
May	9.0	8.9
June	8.6	8.4
July	8.4	8.8
August	9.5	8.8
September	8.6	8.6
October	8.8	8.7
November	9.2	9.1
December	8.4	9.1

* Based on 11,399 Crashes
** Based on 123,355 Crashes

TABLE 4

Accidents Involving Large Trucks
By Percentage of Associated Factors

Year	Number	Driver	Environmental	Vehicle	Others
		Percentage			
1984	5431	75.6	0.7	8.8	14.9
1985	5587	72.8	2.3	6.2	18.7
1986	6347	75.8	1.1	5.7	17.4

TABLE 5

Accidents Involving Large Trucks (1984-1986)
By Percentage of Associated Factors for Different Truck Types

Truck Type	Number	Driver	Environmental	Vehicle	Others
		Percentage			
Straight Truck	8459	74.9	4.3	8.0	12.8
Tractor Trailer	8685	74.5	5.2	5.8	14.5
Twin Trailer	72	73.9	15.1	4.1	6.9

TABLE 6

Large-Truck Fatal Accidents
By Percentage of Associated Factors

		Percentage			
		Driver	Environmental	Vehicle	Others
Year	Number				
1984	115	92.3	0.0	6.0	1.7
1985	96	91.5	2.1	2.1	4.3
1986	110	86.0	0.9	5.6	7.5

TABLE 7

Fatal Accidents Involving Large Trucks (1984-1986)
By Type of Truck and Percentage of Associated Factors

		Percentage			
		Driver	Environmental	Vehicle	Others
Truck Type	Number				
Straight Truck	81	83.7	2.4	7.6	6.3
Tractor Trailer	224	91.8	1.8	1.7	4.7
Twin Trailer	1	100.0	0.0	0.0	0.0

TABLE 8

Large-Truck Fatal Accidents
By Percentage of Major Factors Associated with Drivers

		Percentage			
Year	Number	Error	Alcohol	Speeding	Handicap
1984	106	49.1	15.1	29.2	6.6
1985	88	65.9	10.5	11.8	11.8
1986	95	71.8	5.4	8.7	14.1

TABLE 9

Large-Truck Fatal Crashes By Percentage
of Major Driver Factors for Different Truck Types

		Percentage			
Truck Type	Number	Error	Alcohol	Speeding	Handicap
Straight Truck	68	59.8	19.4	11.9	8.9
Tractor Trailer	206	61.8	7.9	19.2	11.1
Twin Trailer	1	100.0	0.0	0.0	0.0

TABLE 10

Large-Truck Fatal Crashes
By Percentage of Location Alignment

		Percentage				
		Straight/ Level	Curve/ Level	Grade/ Straight	Grade/ Curve	Others
Year	Number					
1984	115	39.1	7.8	28.7	19.1	5.3
1985	96	48.4	10.8	17.2	19.4	4.2
1986	110	31.8	10.3	39.3	14.0	4.6

TABLE 11

Large-Truck Fatal Crashes (1984-1986) By Percentage
of Location Alignment for Different Truck Types

		Percentage					
		Straight/ Level	Curve/ Level	Grade/ Straight	Grade/ Curve	Hillcrest Str/Curve	Dip/Str/ Curve
Truck Type	Number						
Straight Truck	86	33.7	16.2	25.0	16.3	6.3	2.5
Tractor Trailer	234	41.0	7.3	30.3	17.9	2.2	1.3
Twin Trailer	1	100.0	0.0	0.0	0.0	0.0	0.0

TABLE 12

Distribution of 1984 Large-Truck Fatal Crashes
Associated with Driver Error By the Location Alignment

Location Alignment	Number	Percentage
Hillcrest/Curve	96	90.4
Dip/Curve	8	7.7
Not Stated	2	1.9

TABLE 13

Large-Truck Fatal Crashes (1984 - 1986) Associated with Driver Error
By Percentage of Alignment and Type of Truck

		Percentage					
Truck Type	Number	Straight/ Level	Curve/ Level	Grade/ Straight	Grade/ Curve	Hillcrest/ Str/Curve	Dip/Str/ Curve
Straight Truck	24	27.5	12.5	30.0	22.5	7.5	0.0
Tractor Trailer	80	42.1	8.3	34.6	12.0	2.3	0.7
Twin Trailer	--	0.0	0.0	0.0	0.0	0.0	0.0

Table 14

Distribution of 1984 Crashes by Number of Vehicles Involved*

Number of Vehicles Involved in Crash	Large Truck		Non-Large-Truck	
	Number	Percent	Number	Percent
1	2,529	22.1	39,661	35.4
2	7,855	68.9	65,731	58.7
3	830	7.3	5,591	5.0
4	157	1.4	784	0.7
5	18	0.2	140	0.1
6 or more	10	00.1	49	00.1
TOTAL	11,399	100.0	111,956	100.0

*Crashes on all highways for which all vehicles involved are identified.

Table 15

Percentage Distribution of Vehicle Mix in Two-Vehicle Crashes Involving Large Truck

Vehicle Mix	Number of Crashes*	Percentage
Large-Truck/Large-Truck	333	6.2
Large-Truck/Other Vehicle	5,105	93.8

* These are for two-vehicle crashes involving large trucks on the interstate and primary highways where the other vehicle was identified.

Table 16

Comparison of Actual to Expected Proportions of Vehicle Mix in Two-Vehicle Crashes

Collision Type (1)	Actual Proportion (2)	Expected Proportion (3)	Actual/Expected (4)
Other Vehicle/ Other Vehicle	0.7886	0.7921	0.9956
Large-Truck/ Large-Truck	0.0132	0.0121	1.0909
Large-Truck/ Other Vehicle	0.1982	0.1958	1.0122

Table 17

Distribution of 1984 Fatal Crashes by Number of Vehicles Involved*

Number of Vehicles Involved in Crash	Large Trucks		Other Vehicles (Passenger Cars, Vans and Pickups)	
	Number	Percent	Number	Percent
1	40	25.3	520	68.0
2	95	60.1	219	28.6
3	18	11.4	21	2.8
4	4	2.6	4	0.5
5	1	0.6	0	0.0
6 or more	0	0.0	1	0.1
TOTAL	158	100.0	765	100.0

* Fatal crashes on all highways for which all vehicles involved were identified.

Table 18

Single and Multivehicle Fatal Crashes

	Large Trucks			Other Vehicles		
Type of Crash	Total No. of Crashes	Fatal Crashes	Percentage of Fatal Crashes	Total No. of Crashes	Fatal Crashes	Percentage of Fatal Crashes
Single-Vehicle	2,529	40	1.6	39,661	520	1.3
Multivehicle	8,870	118	13.3	72,295	245	0.3

Table 19

Comparison of Actual to Expected Proportions of Vehicle Mix in Two-Vehicle Fatal Crashes

Collision Type (1)	Actual Proportion (2)	Expected Proportion (3)	Actual/Expected (4)
Large-Truck/ Other Vehicle	0.6302	0.7921	0.7956
Large-Truck/ Large-Truck	0.0064	0.0121	0.5284
Large-Truck/ Other Vehicle	0.3633	0.1958	1.8554

Table 20

The Effect of Type of Facility on Severity of
All Accidents Involving Large Trucks for the Period 1984 through 1986

Type of Facility	Fatal	Injury	Prop. Dmg.
Two-Way Undivided	146 3.0%	1835 37.9%	2864 59.1%
Divided No/Partial Access Control	84 2.0%	1547 37.0%	2550 61.0%
Divided Full Access Control	83 1.4%	2111 35.5%	3753 63.1%

Table 21

The Effect of Vehicle Type on Severity of
All Accidents Involving Large Trucks on Two-Way Undivided Facilities*

		Percentage	
Severity	Number	Truck/ Other Vehicle	All Others
Fatal	146	82.2%	17.8%
Injury	1835	70.7%	29.3%
Prop. Dmg.	2864	68.2%	31.8%
All	4865	69.7%	30.3%

*Based on 1984 - 1986 data

Table 22

All Accidents Involving Large Trucks
on Divided Facilities with No or Partial Control of Access

The Effect of Vehicle Type on Severity*

		Percentage	
Severity	Number	Large Truck/ Other Vehicle	All Others
Fatal	84	70.2%	29.8%
Injury	1547	77.3%	22.7%
Prop. Dmg.	2550	76.8%	23.2%
All	4181	77.0%	23.0%

*Based on 1984 - 1986 data

Table 23

All Accidents Involving Large Trucks
on Divided Facilities with Full Control of Access

The Effect of Vehicle Type on Severity*

		Percentage	
Severity	Number	Large-Truck/ Other Vehicles	All Others
Fatal	84	63.9%	36.1%
Injury	2111	66.2%	33.8%
Prop. Dmg.	3753	70.9%	29.1%
All	5947	69.1%	30.9%

*Based on 1984 - 1986 data

Table 24

The Effect of Vehicle Type on Severity of
All Large-Truck/Other Vehicle Accidents
on Two-Way Undivided Facilities*

Vehicle Type	Number	Percentage Fatal	Injury	Prop. Dmg.
ST/Other Vehicle	2214	1.7%	38.7%	59.6%
TT/Other Vehicle	1156	7.2%	38.0%	54.8%
TW/Other Vehicle	7	0%	28.6%	71.4%

*Based on 1984 - 1986 data
ST - Straight Truck
TT - Tractor-Trailer
TW - Twin Trailer

Table 25

All Large-Truck/Other Vehicle Accidents
on Divided Facilities with No or Partial Control of Access

The Effect of Truck Type on Severity*

Vehicle Type	Number-	Percentage Fatal	Injury	Prop. Dmg.
ST/Other Vehicle	1982	0.9%	35.9%	63.2%
TT/Other Vehicle	1231	3.3%	39.3%	57.4%
TW/Other Vehicle	8	0%	37.5%	62.5%

*Based on 1984 - 1986 data
ST - Straight Truck
TT - Tractor Trailer
TW - Twin Trailer

Table 26

All Large-Truck/Other Vehicle Accidents
on Divided Facilities with Full Control of Access

The Effect of Vehicle Type on Severity*

Vehicle Type	Number	Percentage Fatal	Injury	Prop. Dmg.
ST/Other Vehicle	1295	0.8%	34.1%	65.1%
TT/Other Vehicle	2794	1.5%	33.9%	64.6%
TW/Other Vehicle	20	0%	45.0%	55.0%

*Based on 1984 - 1986 data
ST - Straight Truck
TT - Tractor Trailer
TW - Twin Trailer

Table 27

All Single-Vehicle Large-Truck Accidents on
Two-Way Undivided Facilities

The Effect of Truck Type on Severity*

Truck Type	Number	Percentage Fatal	Injury	Prop. Dmg.
ST	567	0.9%	38.1%	61.0%
TT	553	1.6%	34.2%	64.2%
TW	1	0%	0%	100.0%

*Based on 1984 - 1986 data
ST - Straight Truck
TT - Tractor-Trailer
TW - Twin Trailer

Table 28

All Single-Vehicle Large-Truck Accidents on
Divided Facilities with No or Partial Control of Access

The Effect of Truck Type on Severity*

Truck Type	Number	Percentage Fatal	Injury	Prop. Dmg.
ST	280	0%	39.6%	60.4%
TT	424	4.5%	36.4%	59.1%
TW	7	0%	14.3%	85.7%

*Based on 1984 - 1986 data
ST - Straight Truck
TT - Tractor Trailer
TW - Twin Trailer

Table 29

All Single-Vehicle Large-Truck Accidents on
Divided Facilities with Full Control of Access

The Effect of Truck Type on Severity*

Vehicle Type	Number	Percentage Fatal	Injury	Prop. Dmg.
ST	437	0.9%	39.6%	59.5%
TT	937	1.6%	38.3%	60.1%
TW	15	0%	20.0%	80.0%

*Based on 1984 - 1986 data
ST - Straight Truck
TT - Tractor Trailer
TW - Twin Trailer

TABLE 30

All Large-Truck/Large-Truck Accidents on Two-Way Undivided Facilities

The Effect of Truck Type on Severity

Vehicle* Combination	Number	Percentage: Fatal	Percentage: Injury	Percentage: Property Damage
SU - SU	136	0	27.7	72.3
SU - TT	92	2.2	34.8	63.0
SU - TW	--	0	0	0
TT - TT	68	2.9	41.2	55.9
TT - TW	1	0	0	100.0
TW - TW	--	0	0	0

*SU - Single Unit Truck
TT - Tractor Trailer
TW - Twin Trailer

TABLE 31

All Large-Truck/Large-Truck Accidents on Divided Facilities with No or Partial Control of Access

The Effect of Truck Type on Severity

Vehicle* Combination	Number	Percentage Fatal	Injury	Property Damage
SU - SU	88	0%	33.0%	67.0%
SU - TT	69	1.4%	31.9%	66.7%
SU - TW	0	0%	0%	0%
TT - TT	61	1.6%	34.0%	63.9%
TT - TW	--	0%	0%	0%
TW - TW	--	0%	0%	0%

* SU - Single Unit Truck
TT - Tractor Trailer
TW - Twin Trailer

TABLE 32

All Large-Truck/Large-Truck Accidents
on Divided Facilities with Full Control of Access

The Effect of Truck Type on Severity

		Percentage		
Vehicle* Combination	Number	Fatal	Injury	Property Damage
SU - SU	69	0	46.4	53.6
SU - TT	91	3.3	36.3	60.4
SU - TW	3	0	66.7	33.3
TT - TT	227	1.8	37.4	60.8
TT - TW	3	0	33.3	66.7
TW - TW	--	0	0	0

* SU - Single Unit Truck
TT - Tractor Trailer
DT - Twin Trailer

Table 33

Types of Collision for Two-Vehicle Accidents
Involving Large Trucks

Vehicle Type	Number	Rear	Angle	Head	Side Swipe*	Side Swipe**	Others
		Percentage					
Straight Truck/ Other Vehicle	6042	43.8	25.0	1.9	23.3	3.5	2.5
Tractor Trailer/ Other Vehicle	5591	28.7	14.5	1.4	47.0	3.2	5.2
Twin Trailer/ Other Vehicle	38	35.2	13.5	0	43.2	2.7	5.4
Straight Truck/ Straight Truck	331	58.4	16.1	2.0	13.8	6.2	3.5
Straight Truck/ Tractor Trailer	280	50.2	15.8	1.5	20.4	7.9	4.2
Straight Truck/ Twin Trailer	3	66.7	0	0	33.3	0	0
Tractor Trailer/ Tractor Trailer	390	56.1	8.7	0.6	20.1	4.5	10.0

* Same Direction
** Opposite Direction

TABLE 34

Effect of Road Geometry on Single-Vehicle Large-Truck Accidents from 1984 through 1986

All Single-Vehicle Truck Accidents

	Straight Truck 42.0%		Tractor Trailer 57.0%		Twin Trailer 1.0%	
	Curves & Grades	All Others	Curves & Grades	All Others	Curves & Grades	All Others
	55.01%	45.01%	61.01%	39.01%	65.01%	35.0%
Fatal	1.0%	0.5%	2.5%	1.5%	0.0%	0.0%
Injury	45.0%	32.0%	40.5%	30.6%	18.0%	33.3%
Prop.Dmg.	54.0%	67.0%	57.0%	67.9%	82.0%	67.7%

TABLE 35

Effect of Road Geometry on Large-Truck/Other Vehicle Accidents from 1984 through 1986

	Straight Truck/ Other Vehicle		Tractor Trailer/ Other Vehicle		Twin Trailer/ Other Vehicle	
	53.2%		46.5%		0.3%	
	Curves & Grades	All Others	Curves & Grades	All Others	Curves & Grades	All Others
	36.0%	64.0%	42.0%	58.0%	53.0%	47.0%
Fatal	1.6%	0.8%	3.8%	2.5%	5.0%	0.0%
Injury	41.3%	33.8%	36.9%	35.9%	55.0%	18.0%
Prop.Dmg.	57.1%	65.4%	53.9%	61.6%	40.0%	82.0%

Table 36

Average Daily (24 HR) Vehicle Miles of Travel (VMT) on the Interstate, Arterial, and Primary Routes

Year	2-Axle Six Tires and 3-Axle Six Tires Trucks		Tractor Trailers		All Large Trucks	
	VMT (10^6)	Percentage Increase	VMT (10^6)	Percentage Increase	VMT (10^6)	Percentage Increase
1980	2.26	--	3.99	--	6.25	--
1981	2.20	-2.65	4.06	1.75	6.26	0.16
1982	2.16	-1.82	4.03	-0.74	6.19	-1.12
1983	2.24	3.70	4.35	7.94	6.59	6.46
1984	2.45	9.37	4.76	9.42	7.21	9.41
1985	2.58	5.31	5.08	6.72	7.66	6.24
1986	2.77	7.36	5.51	8.46	8.28	8.09

Table 37

Total Accidents Per 100 Million Vehicle
Miles of Travel on Interstate and Primary Highways

Year	Tractor Trailers			Other Vehicles		
	Rate	B/A	Percent Change	Rate	B/A	Percent Change
1980	143.10			168.07		
1981	140.22	140.69*		169.04	165.46*	
1982	138.75		-0.17	159.28		-2.80
1983	144.55			154.68		
1984	132.09	140.45**		159.66	160.82**	
1985	144.70			168.13		

B/A = before/after 1982
*Average for before period
**Average for after period

Table 38

Fatal Accident Rates Per 100 Million Vehicle
Miles of Travel on Interstate and Primary Highways

Year	Tractor Trailers			Other Vehicles		
	Rate	B/A	Percent Change	Rate	B/A	Percent Change
1980	4.05			2.43		
1981	3.17	3.29*		2.19	2.14*	
1982	2.65		+26.75	1.75		-10.75
1983	3.90			1.83		
1984	5.01	4.17**		2.06	1.91**	
1985	3.61			1.85		

B/A = before/after 1982
*Average for before period
**Average for after period

Table 39

Fatal Accident Rates* on Interstate Highways

Year	Tractor Trailers			Other Vehicles		
	Rate	B/A	Percent Change	Rate	B/A	Percent Change
1980	1.21			0.84		
1981	1.38	1.53		0.79	0.79	
1982	2.00		+33.99	0.74		+5.06
1983	2.16			0.82		
1984	2.25	2.05		0.93	0.83	
1985	1.74			0.74		

* Fatal Accident Rate=Number of Fatal Accidents per 100 Million VMT;
B/A = before/after 1982

Table 40

Fatal Accident Rates* on Primary Highways

Year	Tractor Trailers			Other Vehicles		
	Rate	B/A	Percent Change	Rate	B/A	Percent Change
1980	8.81			3.26		
1981	6.27	6.30		2.95	2.85	
1982	3.82		+27.30	2.34		-13.33
1983	7.03			2.33		
1984	9.92	8.02		2.66	2.47	
1985	7.10			2.43		

*Fatal Accident Rate=Number of Fatal Accidents per 100 Million VMT;
B/A = before/after 1982

Table 41

Injury and Fatal Accident Involvement Rates on Interstate Routes

	1980		1981		1982		1983		1984		1985	
RT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT
64	40.6	41.5	50.3	44.9	35.2	46.3	45.0	49.0	45.2	49.7	53.1	55.6
66	17.7	27.2	32.6	32.1	21.7	34.4	34.2	40.6	32.2	33.8	42.8	40.6
77	78.6	51.5	42.6	42.3	44.9	20.3	43.4	22.4	40.9	21.5	36.2	30.5
81	17.8	35.0	22.8	37.8	20.4	25.7	20.1	24.7	23.4	27.5	23.7	29.2
85	48.6	49.4	29.1	48.1	18.9	39.5	19.0	36.2	26.4	35.0	26.9	41.8
95	52.7	76.3	48.0	75.9	51.2	59.7	52.2	66.8	64.5	67.6	61.7	68.4
495	79.7	49.5	57.6	41.9	120.8	45.1	62.1	46.2	138.3	41.1	79.4	41.7

*RT = route; TT = tractor trailers; Others = all vehicles other than tractor trailers.

Injury and Fatal Accident Involvement - Number of Injury and Fatal Involvement Per 100 Million Miles of Travel (VMT)

Table 42

Injury and Fatal Accident Involvement Rates on Primary STAA Routes*

	1980		1981		1982		1983		1984		1985	
RT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT
19	119.4	81.6	50.6	83.6	14.4	74.9	92.1	87.0	134.8	71.2	46.5	85.0
23	133.3	118.2	113.6	102.6	73.1	88.0	127.6	104.4	115.3	105.1	161.2	104.9
29	72.1	152.6	89.3	172.1	74.9	134.9	81.1	137.8	55.9	159.8	65.5	166.8
58	96.2	130.3	104.4	133.0	97.6	122.7	86.4	121.0	109.0	145.4	91.4	138.8
220	128.2	114.5	121.9	146.7	102.6	105.8	95.8	117.7	119.5	125.4	65.5	132.2
360	40.6	99.8	42.3	117.4	44.5	95.4	79.9	122.7	51.6	116.2	55.1	134.4
460	64.2	108.6	74.5	127.8	67.0	126.0	84.9	125.8	93.7	118.2	61.9	126.9

*RT = route; TT = tractor-trailers; Others = all vehicles other than tractor trailers

Injury and Fatal Accident Involvements - Number of Injury and Fatal Involvements Per 100 Vehicle Miles of Travel (VMT)

Table 43

Injury and Fatal Accident Involvement Rates on Primary Non-STAA Routes*

	1980		1981		1982		1983		1984		1985	
RT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT	TT	Non-TT
1	125.0	258.9	198.4	265.2	188.0	250.2	180.4	279.5	186.2	290.7	163.7	278.7
10	92.5	149.2	152.5	165.9	86.9	124.3	213.3	161.5	105.2	158.6	95.2	162.3
11	97.1	133.5	85.2	129.5	75.1	117.6	89.8	117.5	121.3	129.0	106.2	133.0
15	72.0	100.6	63.2	99.4	59.5	83.1	83.3	94.7	100.3	92.6	60.1	100.4
17	73.9	141.6	102.7	137.9	75.8	107.1	143.8	109.8	85.1	113.0	101.8	133.2
50	81.3	196.9	119.0	220.7	73.6	201.3	85.1	204.2	153.0	180.9	91.9	174.1
60	160.9	156.3	123.5	141.6	97.8	130.2	107.8	152.4	125.0	146.7	103.7	169.7

*Rt = route, TT = tractor trailers, Others = all vehicles other than tractor trailers

Injury and Fatal Accident Involvements - Number of Injury and Fatal Involvements Per 100 Million Vehicle Miles of Travel (VMT)

Table 44

ANOVA Results for Hypothesis I

Highway Type/ Accident Type	F(n, d)*		
	Interstate	STAA Primary	Non-STAA Primary
Tractor Trailer	F(1, 40) = 0.05	F(1, 40) = 0.52	F(1, 40) = 1.33
Non-Tractor Trailer	F(1, 40) = 0.35	F(1, 40) = 0.50	F(1, 40) = 0.04

* F(n, d) - F value with numerator = n, denominator =d

Table 45

Probability Values for Hypothesis I

Highway Type/ Accident Type	Type I Error Probability*		
	Interstate	STAA Primary	Non-STAA Primary
Tractor Trailer	0.824	0.475	0.256
Other Vehicle	0.557	0.484	0.843

*Probability = the probability of error in rejecting the null hypothesis

Table 46

Mean Involvement Rates (Injury & Fatal)

		Interstates	STAA Primary	Non-STAA Primary
Tractor Trailer	B	44.42	82.17	105.00
	A	46.28	89.17	119.19
Other Vehicle	B	44.08	116.08	157.72
	A	41.47	121.33	161.12

B - (1980-1982)
A - (1983-1985)

Table 47

Fatal Involvement Ratio on Interstate Routes*

	1980		1981		1982		1983		1984		1985	
RT	TT	Others	TT	Others	TT	Others	TT	Others	TT	Others	TT	Others
64	11.6	4.1	1.8	2.6	7.6	2.0	3.7	1.7	3.5	3.0	4.1	1.1
66	25.0	4.4	0.0	4.1	16.6	0.6	0.0	0.3	16.6	2.7	0.0	1.6
77	4.0	8.2	21.4	11.1	6.6	3.1	0.0	10.8	5.8	5.0	5.5	6.3
81	2.7	2.8	5.2	4.3	3.5	3.1	9.6	6.2	5.8	4.4	5.3	3.3
85	0.0	1.2	0.0	3.7	0.0	2.8	10.0	8.0	28.5	7.8	0.0	2.5
95	1.5	2.0	3.8	2.5	5.7	2.0	3.5	2.0	2.0	1.2	3.0	1.3
495	0.0	1.4	0.0	3.7	5.5	0.7	0.0	0.3	0.0	1.5	0.0	1.4

* the above ratios are fatal involvements per 100 involvements in all fatal and injury accidents
RR = route; TT = tractor trailers; Others = all vehicles other than tractor trailers

Table 48

Fatal Involvement Ratios on Primary STAA Routes*

	1980		1981		1982		1983		1984		1985	
RT	TT	Others	TT	Others	TT	Others	TT	Others	TT	Others	TT	Others
19	12.5	7.4	0.0	3.8	0.0	0.0	14.2	5.0	8.3	2.3	0.0	2.3
23	0.0	2.4	0.0	1.3	0.0	2.2	0.0	1.8	16.6	4.1	0.0	2.9
29	2.9	2.2	6.9	2.6	2.6	1.3	6.5	1.7	5.7	0.9	4.5	1.9
58	13.7	5.6	11.1	4.3	4.0	2.5	6.2	3.5	7.2	2.4	8.0	3.5
220	7.6	5.6	7.5	6.3	2.8	2.5	2.7	1.6	12.2	1.9	3.7	3.0
360	13.3	4.0	0.0	2.3	0.0	1.4	0.0	2.2	0.0	0.6	4.3	2.7
460	20.0	6.5	6.5	3.8	7.5	2.0	11.1	2.7	9.2	2.0	15.2	2.8

* the above ratios are fatal involvements per 100 involvements in all fatal and injury accidents
RT = route; TT = tractor trailers; Others = all vehicles other than tractor trailers

Table 49

Fatal Involvement Ratios on Primary Non-STAA Routes*

	1980		1981		1982		1983		1984		1985	
RT	TT	Others	TT	Others	TT	Others	TT	Others	TT	Others	TT	Others
1	13.3	1.9	0.0	2.0	0.0	0.7	16.6	1.3	7.4	1.3	7.1	1.1
10	20.0	3.7	33.3	5.9	0.0	1.6	6.2	1.5	25.0	2.4	12.5	2.7
11	5.8	2.1	13.3	4.8	0.0	2.5	0.0	1.7	4.0	3.1	5.8	2.2
15	5.8	6.7	0.0	3.4	7.1	4.7	21.7	3.3	25.0	6.7	5.2	2.2
17	15.7	4.0	3.8	3.7	4.7	4.4	7.1	2.3	11.1	3.2	3.5	1.8
50	14.2	1.8	0.0	2.2	0.0	1.2	12.5	1.4	6.6	2.3	37.5	1.2
60	7.1	4.6	0.0	3.0	0.0	1.8	9.0	1.7	15.3	1.5	9.0	0.8

*the above ratios are fatal involvements per 100 involvements in all fatal and injury accidents
RT = route; TT - tractor trailers; Others = all vehicles other than tractor trailers

Table 50

ANOVA Results for Hypothesis II

Highway Type/ Era	F(n, d)*		
	Interstate	STAA Primary	Non-STAA Primary
Pre-STAA	F(1, 40) = 0.12	F(1, 40) = 0.22	F(1, 40) = 3.27
Post-STAA	F(1, 40) = 0.01	F(1, 40) = 3.26	F(1, 40) = 5.23

* F(n, d) - F value with numerator = n, denominator = d

Table 51

Probability Values for Hypothesis II

Highway Type/ Era	Type I Error Probability*		
	Interstate	STAA Primary	Non-STAA Primary
Pre-STAA	0.731	0.642	0.079
Post-STAA	0.921	0.079	0.028

*Probability = the probability of error in rejecting the null hypothesis

Table 52

Mean Fatal Involvement Ratios*

		Interstates	STAA Primary	Non-STAA Primary
Tractor Trailer	B	5.859	5.684	6.892
	A	5.119	6.485	11.853
Other Vehicle	B	3.396	3.393	3.234
	A	3.483	2.514	2.221

* Involvement Ratio in Fatal Accidents =

$$\frac{100 \text{ x total involvement in fatal crashes}}{\text{total involvement in fatal \& injury accidents}}$$

Table 53

Annual Fatal-Injury Accident Involvement Rates

Year	Interstate		STAA Primary		Non-STAA Primary	
	Tractor Trailer	Other Vehicles	Tractor Trailer	Other Vehicles	Tractor Trailer	Other Vehicles
1980	48.00	47.25	93.47	115.13	100.43	162.48
1981	40.49	46.22	85.28	126.26	120.70	165.80
1982	44.77	38.76	67.77	106.85	93.86	144.80
1983	39.48	40.88	92.15	116.70	129.11	160.00
1984	53.05	39.51	97.16	120.24	125.20	158.83
1985	46.31	44.02	78.20	127.04	103.27	164.52

*Number of fatal injury involvements per 100 million vehicles miles of travel (VMT)

Table 54

Relative Involvement of Tractor Trailers in Fatal-Injury Accidents
Before and After 1982

Year	Interstate			STAA Primary			Non-STAA Primary		
	Ratio	B/A	Percentage Increased	Ratio	B/A	Percentage Increased	Ratio	B/A	Percentage Increased
1980	1.016			0.812			0.618		
1981	0.876	1.016		0.675	0.707		0.728	0.665	
1982	1.155			0.634			0.648		
			+10.24			+4.38			+11.43
1983	0.966			0.790			0.807		
1984	1.343	1.120		0.808	0.738		0.788	0.741	
1985	1.052			0.618			0.628		

B/A - Before and After 1982

Relative Involvement - Ratio of tractor trailers involvement rate to other vehicles involvement rates