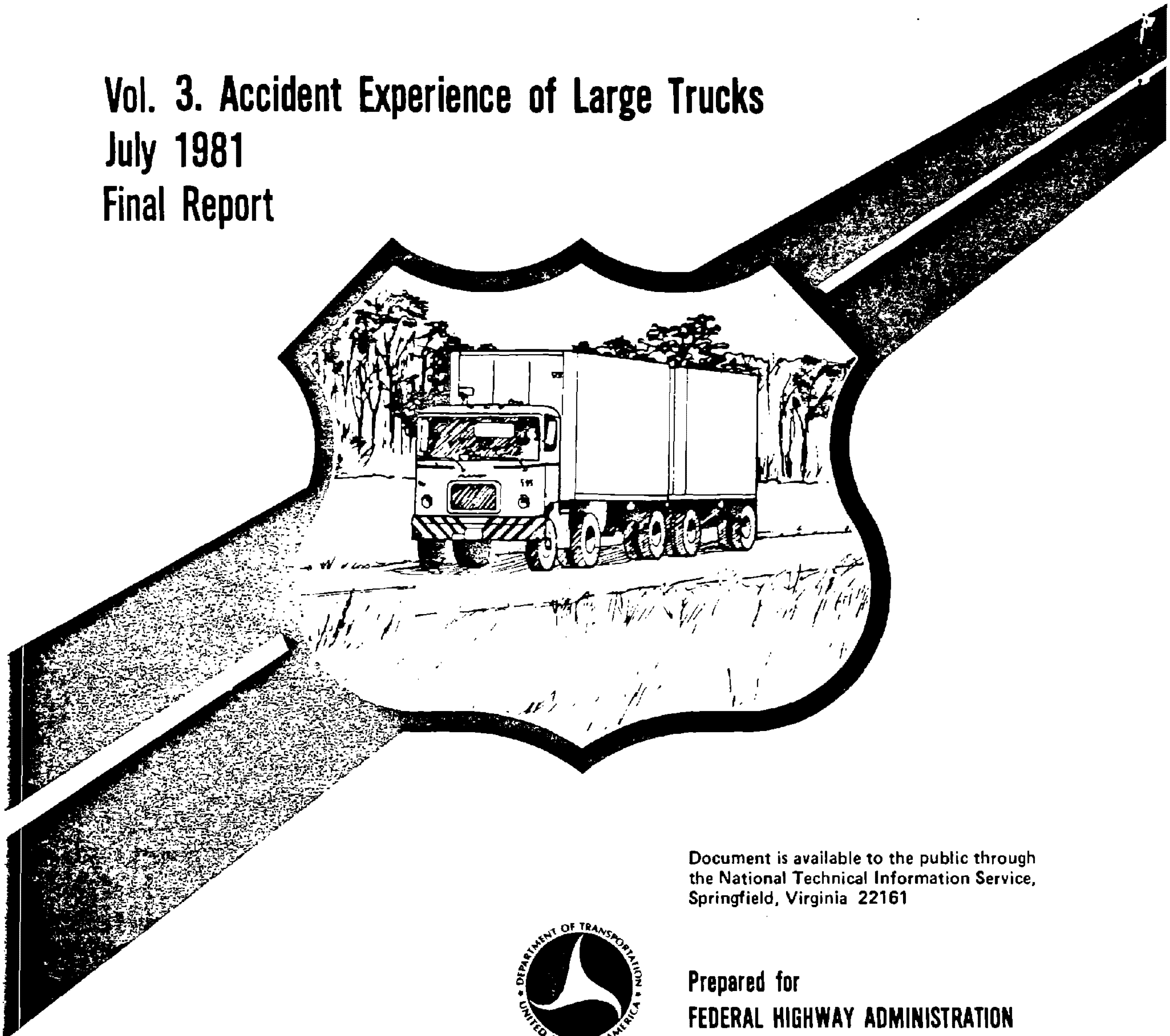
Report No. FHWA/RD-80/137

THE EFFECT OF TRUCK SIZE AND WEIGHT ON ACCIDENT EXPERIENCE AND TRAFFIC OPERATIONS

Vol. 3. Accident Experience of Large Trucks

July 1981

Final Report



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NOTICE

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16. Abstract

The objective of this study was to determine the effect the size and weight of large trucks has on accidents and traffic operations. The effect on accidents was determined by comparing the accident rates for a variety of truck types defined in terms of configuration, size, and weight. The accident rate is obtained by dividing the number of accidents of a specific truck type, size, and weight by the exposure mileage (opportunity to have an accident) for that same truck type, size, and weight.

This volume documents the methodology used to obtain the accident and VMT exposure data. Tables of accident distributions and accident rate calculations are presented. Data were collected for all large truck accidents occurring on 78 roadway segments in six states. In total 2,112 accident involvements were investigated in-depth over a 1½-year period in 1976-1977.

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BIBLIOGRAPHICAL NOTE

This report is part of a multivolume final report with the general title *The Effect of Truck Size and Weight on Accident Experience and Traffic Operations*. Below is detailed the complete list of books comprising the full report.

FHWA/RD-No.	Volume	Title
80/135	I	Executive Summary
80/136	II	Effects on Traffic Operations
80/137	III	Accident Experience of Large Trucks
80/138	IV	Truck Exposure Classification by Size and Weight
80/139	V	Volume II: Appendices
80/140	VI	Volume III: Appendices

FOREWORD

This report, which provides accident and matching exposure information for large trucks of various sizes and weights, was extensively reviewed within and outside the Department of Transportation before its publication. The groups listed below had expressed interest in the study and were thus afforded the opportunity to review the report and provide comments. Not all of the groups agreed with the findings and the contents of the report do not reflect an endorsement by any of these groups.

American Automobile Association
American Trucking Associations, Inc.
DeWitt, Sundby, Huggett and Shumacher, S.C. (Attorneys for Consolidated Freightways)
International Brotherhood of Teamsters
Iowa Department of Justice
Motor Vehicle Manufacturers Association of the United States, Inc.
University of North Carolina
Western Highway Institute

It is important to note that this study was undertaken with the specific and limited objective of collecting and analyzing truck accident and exposure data by various weight classes and truck configuration. The information obtained herein clarifies some issues and provides direction to other research. The report is based on data from six States with a large portion of the data coming from California. Although three of the six States studied permit the operation of twin trailers, 95 percent of the doubles sample was from California. Caution must be exercised in extrapolating these rates to other States or the Nation as a whole.

As a result of the review, several comments and questions were raised relative to the results of the analyses presented. In general, the comments addressed the quality of the data, the types of analyses that were conducted, and the general applicability of the results of this study to other states. Several of these comments led to additonal analyses of the data by the Federal Highway Administration (FHWA). To provide the reader with a proper perspective, the FHWA followup analyses are presented at various sections in the report. Comparisons with three earlier studies that compare single and twin-trailer combinations are also included.

Research in accident involvement of heavy trucks is being conducted under Project 1U, Safety Aspects of Increased Size and Weight of Heavy Vehicles. The project is in the FHWA's federally coordinated program of research and development in highway transportation.

Copies of this report are being distributed to each regional office, each division office, and each State highway agency. Direct distribution is being made to the division offices.

D. Solomon
for Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

FHWA Summary of Findings

The following is a summary of the major findings of this study:

- There is no significant difference in the accident rates of trucks, non-trucks and the total traffic stream.
- Twin trailer combinations have a significantly higher accident rate than single tractor-trailer combinations.[1]
- Empty and near-empty combination trucks have substantially greater accident involvement rates than loaded vehicles.[1]
- Doubles have a significant higher ton-mile accident involvement rate than singles on urban freeways and rural non-freeways. There is no significant difference on other roadway types.[1]
- There is no significant difference in the accident rate of tractor-trailer combinations with conventional tractors and those with cab-over-engine tractors.
- There is no difference in the accident rates of tractor-trailer combinations with 40-foot long trailers and those with 45-foot long trailers.
- Truck drivers under age 20 have the highest accident rate followed by drivers 20-29 and 60 years and older.
- There is no significant difference between drivers of singles and drivers of doubles in terms of age, professional experience, or experience in their type of rig.
- In general, combination trucks with dump or tank type trailers have the highest accident rates.
- At freeway interchanges, trucks have more accidents at off-ramps than at on-ramps.

[1]Note: 95 percent of the doubles sample was from California.

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I. INTRODUCTION

Over the past 20-25 years, the trucking industry has more than tripled in size. Several reasons have contributed to this growth: a growing economy, a deteriorating railroad system, and construction of the Interstate highway system. While numerous statistics can be quoted to provide evidence of this growth, one only has to travel the nation's highways to realize its truth.

As the industry has grown, it has sought ways to increase its productivity. Certainly the most popular method has been to increase the trucks' load-carrying capacities. With greater expanding manufacturing knowledge, progressively larger and heavier vehicles have been seen on the highways. This phenomenon is most apparent in the western United States where double trailer units are widely used, and triple trailer units are operating in several states. However, this process is not limited to the west. Gross vehicle weight (GVW) limits have been slowly but steadily rising throughout the nation. *Average* GVW *limits* have risen from 69,615 lbs (31.6 Mg) in 1960, to 74,041 lbs (33.4 Mg) in 1967, to 75,049 lbs (34.0 Mg) in 1971 (American Trucking Trends, 1974). Further payload increases, however, are constrained by existing Federal and state limitations.

Limitations in vehicular size and weight were first established by the individual states in the early 1900s. All states currently regulate such dimensions as length, height, width, axle weight, and gross vehicle weight. Initial national policies were developed by the American Association of State Highway Officials (now AASHTO) during the 1940s. The Federal government, through the Federal Highway Act of 1956, promulgated maximum width, axle weight and spacing, and GVW limits for the Interstate highway system. Succeeding that act were several proposed changes. Table 1 shows existing restrictions and example recommendations since 1956. Proposals are afoot today to increase the current limits to even higher values.

Truck size and weight restrictions are established for two primary reasons: protection of the highway itself; and for the safety of the user. Axle weight limits are enacted primarily to prolong the life of the roadway pavement; gross vehicle weight and axle spacing restrictions are designed to protect structures (bridges) from serious overloads (i.e., concentrated weight loads). Most present restrictions can be justified by the stresses that a heavier vehicle would put on a facility. But although the limits were originally meant to protect the highway environment, it has always been assumed that there were associated safety benefits as well. Unfortunately, insufficient knowledge existed concerning the safety implications of weight and dimensional increases. This is not to say that nothing was known, but rather that specific issues had not been resolved.

One of the first major studies addressing the truck size and weight issue was conducted by the Federal Highway Administration (Winfrey, 1968). The study made an analysis of the possible effects of increased truck dimensions and weights. The focus of the study was on the economic benefits of such increases. For example, truck height is limited by the underclearances of existing highway structures. Significant vehicular height increases would come at great expense along the line of "raising the bridges." On the other hand, width increases (from 96 to 102 inches

Table 1. Maximum Vehicle Limitations on Designated Highways

	Federal Aid Highway Act 1956	1964 BPR Recommendation	1968 Proposed Senate Bill S2658	1969 Proposed House Bill HR 11870	1972 Uniform Vehicle Code Suggestions	Maximum State Standards 1974	Typical State Standards 1974	1975 Federal Regulations
Width (Inches)	**96**	102	102	96	96	**108[1]**	**96**	**96**
Weight, Single Axle (Pounds)	**18,000**	20,000	20,000	20,000	20,000	**20,000[1]**	**18,000**	**20,000**
Weight, Tandem Axle (Pounds)	**32,000**	36,000	34,000	34,000	32,000	**44,000[2]**	**32,000**	**34,000**
Overall Gross Weight (Pounds)	**76,280**	105,500*	105,500*	111,500*	106,500*	**136,000**	**73,280**	**80,000**
Length (Feet)	—	—	—	70	65	**105[3]**	**65**	
Height (Ft-In)	—	—	—		13-6	**14**	**13-6**	

Note: Shaded columns indicate actual limitations. Unshaded columns were proposed limitations.

*Based on formula using length and number of axles.

1- Hawaii, 2- Florida, 3- Nevada, Oregon.

Metric Conversions: 10,000 pounds – 454 kgs
12 inches (1 foot) – .3m

[2.4 to 2.6 m]) could be realized without affecting the highway environment, especially on the Interstate system where lane width is 12 feet (3.6 m) or more. However, both of these alternatives would increase the cargo-carrying capacity of the truck only modestly, although certainly the latter would allow for wider modular loads.

The Winfrey report concluded that truck length was the dimension that could most practically be increased and provide the greatest benefit to the economy with a corresponding least damage to the highway. For example, an increase in allowable length from 55 to 65 feet (17 to 20 m) would allow the operation of twin 27-foot (8-m) trailers. Such combinations increase the payload capacity by 30 percent and provide for much greater operational flexibility. Operational data stated that twin trailers maneuvered and tracked as well as single trailer units during normal highway operations.

The major concentration of the Winfrey report was an economic evaluation of axle and gross vehicle weight limits. Pavements are designed to withstand weights equal to or less than the legal limit for the design life of the pavement. Higher axle weights rapidly accelerate pavement deterioration, thereby reducing the pavement's life span and increasing construction and maintenance costs. However, higher weights allow trucks a greater payload which increases their operational efficiency—a direct cost savings. Conversely, a small increase in pavement thickness results in a substantially greater load-carrying ability (Van Trill, et al.).

Winfrey calculated the savings associated with various incremental increases in axle weight limits as well as the costs associated with such savings on several highway types. The resultant benefit/cost ratios were *all* positive. The additional annual costs for construction and maintenance of the highway would be more than offset by the annual reduction in truck operating costs. Subsequent sensitivity analyses and reassessment of these data substantiated the validity of the results obtained (Solomon, 1972).

Although the emphasis of the Winfrey report was on the economic feasibility of increased size and weight restrictions, only a limited analysis was made of the one factor of most concern to the general public—safety. Conclusions indicated that higher limits would have no significant effect on highway safety. However, this was not as carefully addressed as were the economic issues. The safety issue came to the forefront during the post-energy crisis Congressional hearings in 1974.

Following the 1973-74 oil embargo, the U.S. Congress considered a bill to permit the states, if they so desired, to increase the size and weight limits on the Interstate system. Two primary consequences of the embargo spurred these considerations—the lowered maximum speed limit to 55 mph (90 kph), and rapidly rising fuel prices. As a result, the trucking industry was vigorously proposing upgrading vehicle payload capacities through increases in size and weight allowances. Such increases would help offset the slower speeds, therefore longer trip times which, in conjunction with maximum work hour limits, meant less efficient operations. Congress' biggest concern was the implications on safety of such increases. Opinions expressed at the time were that major deleterious effects were not likely (U.S. Senate, 1974). Unfortunately, these were based on very limited information.

Specific data were not available to quantitatively evaluate the likely effects of the proposed increases. Certainly gross and *estimated* accident data were available from several sources: most notably the National Safety Council, Bureau of Motor Carrier Safety, and the National Highway Traffic Safety Administration's National Accident Summary and State Accident File Extract files. However, each of these has its own inherent biases, limitations, and reliability problems. Example problems include underreporting, selective reporting, very general data in the file, and definitional discrepancies. The result of all this was that definitive relationships between, for example, truck weight and accident severity could not be determined. To add to the confusion, reports establishing such a relationship and reports refuting such a relationship both existed (Herzog, 1975; Hedlund, 1977). The result of all this made it obvious that research in this area was desperately needed.

Accordingly, the Federal Highway Administration embarked on a comprehensive research program to determine the impact of increases in truck size and weight limits on highway safety and traffic operations. In addition, cost-effective solutions to any safety problems identified were to be developed. This final report is the result of the first and most comprehensive research study of Project I-U of FHWA's Federally Coordinated Program of Highway Research and Development. The study was specifically concerned with the accident experience and traffic operational effects of various sized trucks.

Objectives and Scope

The objectives of this study were straightforward but quite far-reaching—to determine the impact of increases in truck size and weight on highway safety. Two key areas were included within this objective: (1) the development of accident rates for various types of heavy trucks under various highway and traffic conditions; and (2) an analysis of traffic operations as affected by heavy trucks. This volume presents the methodology and results of the accident investigation portion of the study.

The specific objective of the study was to analyze accident data to determine whether truck size has an adverse influence on accident incidence and/or severity. More precisely, the study attempted to determine whether or not significant differences exist between:

- the accident rates for
  - various weight categories of trucks
  - various dimensional categories of trucks
  - different truck configurations (straight truck, single-, double-, and triple-trailer combinations)
  - different tractor cab configurations (cab over engine, cab behind engine)
- the severity of accidents for the same groups

- the major types of collisions (for example, head-on, sideswipe, single vehicle, or rear-end collisions)
- the major types of involvements (for example, truck-automobile, truck-truck, truck-pedestrian).

II. METHODOLOGY

The purpose of this chapter is to document the procedures followed in developing the truck accident data collection and investigation operations. Basically, the issues involved were determining:

- what data would be collected
- where the data should be collected
- how the data could be obtained.

As mentioned above, one of this study's objectives was to ascertain the overall safety implications of truck size and weight increases. One of the steps in that direction is the calculation of accident involvement *rates* for the various truck types and parameters of interest. One of the unique facets of this study was the effort made to develop rates based on *related* accident and exposure data. Two types of data are required to make such a quantitative analysis. The first characterizes the accident experience of large trucks. The second deals with the relative exposure of large trucks in the traffic environment identified by general vehicle descriptions (truck type, weight, dimensions, etc.).

Combining these two types of data allows one to calculate involvement rates. These rates provide the opportunity to make rational safety comparisons between various classes of vehicles, specific vehicle parameters, and different types of roadways. Rate calculations can determine whether a particular variable of interest is over- or under-represented in the accident data relative to its opportunity to have an accident (i.e., exposure) on the highway system. Mathematically, rate is expressed as follows:

$$\text{Rate} = \frac{\text{No. of accident involvements}}{\text{No. of (100 million) miles of travel}}$$

The remainder of this chapter describes the procedures used to obtain the accident and exposure data. Specific topics addressed are:

- state selection
- roadway segment site selection
- identification of the required data items
- identification of data item availability
- development of the supplemental data collection forms/procedures
- data collection operations.

Site Selection Process

A sampling technique was developed for selecting roadway segments at which large truck accident *and* exposure data were collected. In total, 78 sites in six states were chosen. The final sites comprised approximately 1,058 miles (1,702 km) of highway throughout the participating states. The decision to select 78 sites*was made at the start of the project. It was reasoned that

*Actually, 80 sites in seven states were initially selected. When the seventh state dropped from the study, the two sites lost were not recovered in any of the six participating states.

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this number of locations would provide adequate quantitative data for statistical analysis of the variables of interest. The target was 1,500 truck accidents; in fact, 2,112 large truck accident investigations were made during the 1½-year data collection period.

For this study, the term "large truck" refers to a straight (not articulated) truck greater than 10,000 pounds (4.5 Mg), any tractor-trailer combination, and straight truck-trailer combinations. Pickup and panel trucks, including those pulling a trailer, were totally excluded from the data base.

Selection of Participating States

Early during this study a literature review of existing truck-related research and accident data was conducted. This is reported in the project Interim Report (Forsythe *et al.*, 1975). Based on that information, several candidate states were selected. The bases for this selection were annual truck exposure (miles [km] of truck travel within the state), historical accident frequency, and state laws permitting extremes in truck size and/or weight. The six states selected, and truck characteristics and limits in those states are shown in Table 2.

Table 2. Vehicle Characteristics in States Participating in Study

State	Rank		Comments	Maximum Truck Dimensions			
	Exposure*	Accidents**		Length (feet)	Height (ft.-in.)	Width (inches)	Weight (pounds)
California	1	7	Doubles	65	13-6 14-0(load)	96	80,000
Maryland	–	–	Pilot Test Procedures	65	13-6	96	73,280
Michigan	5	12	Heaviest Doubles	55	13-6	96	165,000
Nevada	–	–	Triples	105	14-0	96	105,000
Pennsylvania	3	1	–	55	13-6	96	73,280
Texas	2	4	–	65	13-6	96	80,000

*1974 Federal Highway Administration data for all trucks and all roads.
**1973 Bureau of Motor Carrier Safety
1 FT = 0.3048 m
1 IN = 0.0254 m

California, Texas and Pennsylvania were selected because they represented more truck miles (km) of exposure per year than any other states; Michigan ranked fifth. Michigan was chosen also because it permits the heaviest truck payloads in the U.S. (up to 165,000 pounds [78.8 Mg]). Nevada was selected because it permits triple trailer combinations (tractor plus three articulated units) to operate over a wider variety of roads than the other states allowing triples; California and Michigan have a high incidence of double-trailer operations. Maryland was chosen to permit pilot testing of all field data collection techniques and, with Pennsylvania, represented "baseline" states with the lowest gross weight allowances. Pennsylvania also had the highest annual accident frequency.

Selection of Roadway Segments

Once the six study states had been selected, and their interest and cooperation verified, the specific site selection process was initiated. A roadway typology was created to partition roadways in the states into one of six exclusive categories. Two classification variables were used: location (urban or rural), and functional type (freeway, primary, or secondary). Thus, six roadway types* were identified:

- Rural Freeway
- Rural Primary
- Rural Secondary
- Urban Freeway
- Urban Primary
- Urban Secondary

Table 3 describes the general characteristics of these six roadway types. "Primary" and "Secondary" are Federal-aid funding classifications. "Freeway" does not necessarily mean Federal-aid Interstate funding as long as the roadway met the other criteria identified in Table 3. That is, some study freeway sites are designated Federal-aid Primary for funding purposes.

In each state a sample of roadway segments identified by the above classification scheme was drawn. A detailed discussion of the sampling technique is presented in Appendix A. A chart diagramming the site selection process as a whole is shown in Figure 1.

The strategy consisted of stratifying the six participating states into distinct regions (districts/counties) and segmenting the roadways in those regions into sections of equal length—the length being determined by the roadway type. For all rural categories the segments were 10 miles (16 km) long; urban-freeways were 3 miles (4.8 km) long; urban-primary and urban-secondary were 2 miles (3.2 km) long. For each of the designated segments, the historical accident experience, using 1974 state data files, was determined. Then, for each roadway classification within a state, an accident distribution curve was plotted. This distribution identified the number and proportion of segments having no truck accidents, one truck accident, two truck accidents, etc. From the plots, 2,453 potential data collection sites were identified.

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*Local urban streets and county roads were not considered for this study.

Table 3. Roadway Type Functional Breakdown

Type	Setting	Basic Characteristics	General Traffic Volume
Rural — Freeway	Farming, undeveloped, nonurban suburban	Limited access 4+ lanes, divided Relatively long distance between interchanges (several miles)	Light → Moderate
Rural — Primary	Farming, undeveloped, nonurban, suburban	Nonlimited access 2+ lanes Could be divided	Light → Moderate
Rural — Secondary	Farming, undeveloped, nonurban, suburban	2 lanes Few intersections	Light → Moderate
Urban — Freeway	Commercial, industrial, residential "Urban"	Limited access 4+ lanes, divided Relatively several interchanges	Moderate → Heavy
Urban — Primary	Commercial, industrial, residential "Urban"	Nonlimited access 2+ lanes Probably several intersections per mile Could be divided	Moderate → Heavy
Urban — Secondary	Commercial, industrial, residential suburban	2 lanes	Moderate

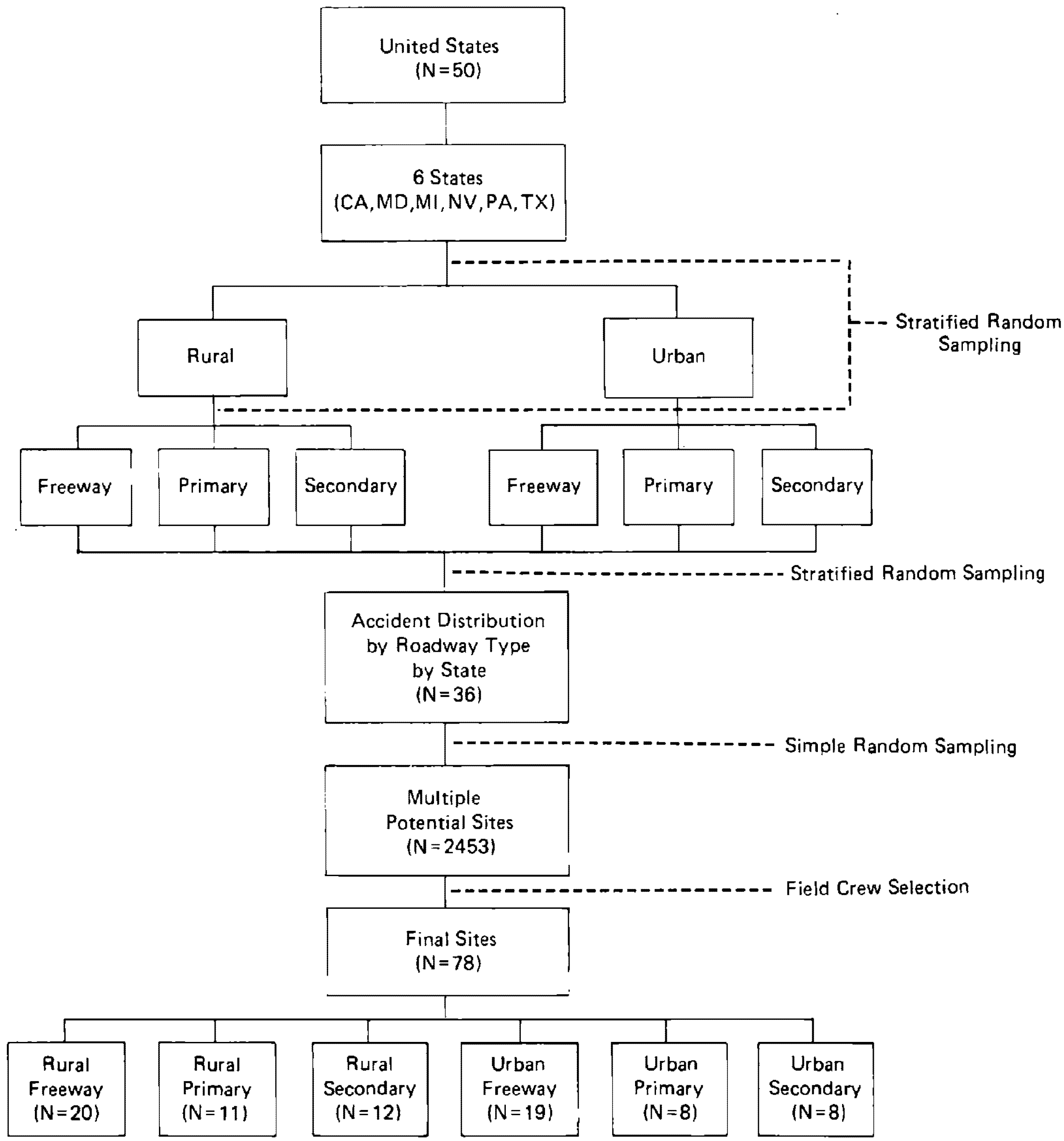

Figure 1. Site selection process.

Final Site Selection. All of these calculations did little more than identify potential site segments. The final selection of the sites used during the study was made by a trained two-man field crew after an on-scene drive-through evaluation of potential sites. The crew was equipped with information which identified the accident category of each segment of each roadway by county in each state. Since the number of each site type in each state to be selected was known, the crew's task was to choose one site from each accident category (see Appendix A).

Six primary criteria were used in making the 78 selections. These were:

- Well defined points of entrance and egress: to gain some assurance that vehicles (trucks and cars) entering one end of the site would be exiting the other end.
- Truck volume: selecting a site where there were no trucks would defeat the purpose of the study. State ADT data were usually available and used.
- Maximize site length: to increase total vehicle miles traveled (VMT) for the analysis and the potential accident data base without increasing the accident rate. For example, if two adjacent segments were in the same accident category and there were no major entry/egress points between the beginning of one and the end of the second, the two segments became one final selected site.
- High potential to collect exposure (film) data: some point within the site at which night photogtaphic data could be obtained (i.e., some light source); and an unobstructed view of the road from the camera position.
- High potential to collect size and weight data: sites with weigh stations, truck stops, rest areas, etc. were preferred.
- Cooperation of local police and highway jurisdiction, and of any building owners, etc. on whose property equipment was to be installed.

The rather elaborate sampling procedure employed made possible an analysis of large truck accidents that are representative of the experience of each of the six states that participated in the study. The final distribution of the 78 sites by state and roadway type is shown in Table 4. The allocation across roadway types within a state very approximately reflect the percentage of miles of each of those roadway types. The specific sites and short descriptors of them individually are presented in Appendix B to this volume.

Accident Investigation Procedures

It is unfortunate, but facts were that state police accident report forms did not contain the data necessary to address the issues of concern during this study. To overcome this deficiency, a followup accident investigation procedure was employed. In-depth investigations were made by trained field investigators using a supplemental data collection form. The form contained all the data items necessary for this project.

Table 4. Distribution of Sites by State and Roadway Type

	Rural (43 sites)			Urban (35 sites)				
	Freeway	Primary	Secondary	Freeway	Primary	Secondary	Total	Approximate Mileage
California	5	3	3	5	2	2	20	213.0
Maryland	1	0	1	1	1	2	6	52.0
Michigan	5	2	2	4	2	2	17	235.4
Nevada	3	3	2	2	1	0	11	215.5
Pennsylvania	3	2	2	3	1	1	12	189.2
Texas	3	1	2	4	1	1	12	152.8
TOTAL	20	11	12	19	8	8	78	
MILEAGE	501.0	171.4	165.4	125.9	57.2	36.8		1057.7

1 mile = 1.609 km

Field Investigator (FI) Recruitment

As soon as the study sites were selected, FI recruiting efforts in those areas were initiated. These efforts typically consisted of contacting the placement office of the colleges and universities in the vicinity of the sites. Schools which assisted the recruiting effort posted a colored flyer describing the job opportunity. Approximately 250 of the short application forms were returned by interested applicants. In addition, field investigators who had worked with BioTechnology on a previous rural pedestrian accident study were contacted. Several of them were also interested. The applications were reviewed and the most qualified individuals contacted for a telephone interview. Some of these were invited to a recruiting session in their local area conducted by a BTI staff member. The most qualified individuals who attended these sessions were selected to fill the available positions.

After selection, each FI was indoctrinated and trained in the accident and/or exposure data collection procedures (depending on what his/her tasks would be). The indoctrination consisted of five major steps:

- Issuing a Data Collection Case containing the necessary equipment and coding manuals, and instruction on all of the equipment to be used.
- Taking a Polaroid picture of each FI for an identification badge to properly identify himself/herself while conducting the study.
- Instruction in the use of the Daily Logs and Two-Week Summaries used to record day-to-day hours worked, sites visited, interviews conducted, etc.
- Signing a consulting agreement detailing the relationship between BTI and the FI.
- Completing a personnel data form, including personal references.

Accident Data Collection Form Development

Determination of what specific data items were relevant to the issues addressed in this study covered a wide range of topics. Variables investigated had to include sufficient information to develop clear-cut conceptual models of truck accidents. Three "sources" of data concerns were considered. Foremost, of course, were the primary concerns of the project as outlined in the original RFP. These were the involvement of dimensional and weight categories in accident frequency and severity. The second group of issues were identified during the "state-of-the-art" literature review (Interim Report). These were primarily issues relating to truck safety in general. Finally, appropriate Government personnel were consulted to identify any additional elements of concern.

Accident Data Items. The result of these consultations was a supplemental data collection form which contained all the information relevant to determining what happened during the collision sequence. As such, it was designed to stand alone, totally independent of the associated police report. The following variables of interest were recorded on the supplemental form (a copy is shown in Appendix C along with the Coding Manual):

- Identification items: site number (state, roadway type), date, day of week, time of day, mileage marker.

- Truck factors: truck type (based on the number of units and axle configuration), length, width, height, tractor cab configuration, engine size, anti-locking brake system, tractor hitch (fifth wheel) location, vehicle defects, type of tires, trailer(s) type and configuration, cargo type, and point of impact.
- Truck driver factors: age, sex, condition, injury severity, experience as a truck driver, experience with the specific truck type, typical trip length, percent driving done at night, percent driving with a partner, and distance since last 6+ hours rest.
- Accident sequence factors: accident dynamics, vehicle movements preceding collision, evasive actions, speeds prior to collision, and special collision descriptors (e.g., underride, override, cargo spillage, unit separation).
- Environmental factors: weather, lighting, roadway pavement condition, temporary roadside features, and truck driver vision obstruction.
- Site characteristics (baseline): median, shoulder, and roadway characteristics, and roadside features (including detailed data on any roadside fixture struck [guardrails, bridge railings]), vertical placement, slope, and horizontal curvature. In addition, speeds of the traffic population going through that location at that time of day were recorded for cars, single unit trucks, and truck combinations.

Sources of Data. Information for the variables of interest were available from several sources. Table 5 lists these sources and their applicability to the accident data groups.

Table 5. Information Sources for Data Item Groups

Data Item Group	Source of Information					
	Police Report	Truck Owner/ Driver	Investigating Officer	Other Driver/ Witness	FI Observations/ Measurements	FI Opinion
Identification Items	X					
Truck Factors	X	X	X	X	X	
Driver Factors	X	X				
Accident Sequence Factors	X	X		X		X
Environmental Factors	X				X	
Site Characteristics					X	

Data Collection Procedures

The in-depth accident investigations were made by the field investigators using the supplemental data form. Data collection ran for a 1½-year period from 01 July 1976 through 31 December 1977. Each large truck accident occurring within the study sites and time frame was investigated. In general, there were two aspects to the accident data collection process—obtaining the police reports, and the followup investigation itself.

Obtaining Police Accident Reports. Arrangements were made with the appropriate state police personnel to receive a copy of their reports for all large truck accidents occurring in the study sites. The FI closest to the state capital picked up the reports on a weekly basis. He/she verified that each accident involved a large truck as defined for the study. Inappropriate reports were forwarded to BTI; the rest of the reports were sent to the other FIs in the state for the sites they were delegated to handle. Of course, as accident frequencies varied, as indeed they did, the FIs assisted each other as necessary. Police reports were generally received two to four weeks after the accident's occurrence.

Accident Investigation. After receiving the police reports, the FIs verified the site in which the accident occurred. Data available from the report were transferred to the supplemental form. Of course, because of differences between police forms, different data items were available in each of the six states. For example, the California report specifically identified the truck type; other states gave more general descriptors.

The followup investigation involved contacting the truck owner/driver for the specific truck and driver data desired, and visiting the accident site. Contacts with the owner or operator were done to obtain the data that were the key to the entire study—dimensional and weight information. Police reports generally did not record these data. If possible the FI visited the truck terminal to observe the accident-involved vehicle or one identical to it. Driver-specific data were also obtained if available. All contacts made with individuals were open-ended free-form discussions.

Field investigators visited the accident scene to make observations and take measurements to complete the investigation. Site visits were scheduled for the same day of the week and time of dat as the accident occurred. This was particularly crucial for the vehicular speed data collected for baserate information—especially at urban sites where rush hour speeds may be much different than free-flow condition speeds. Of course, accident scene pictures had to be taken during daylight hours.

During their indoctrination, field investigators were furnished with the equipment necessary to complete the accident investigation. Equipment issued included:

- Accident investigation coding manual (Appendix C of this volume)
- Supplemental data forms
- Safety vest
- Polaroid camera and film

- Rolatape mm45 measuring wheel
- Stop watch
- Traffic accident symbols template
- Traffic investigation template
- Clipboard

Exposure/ADT Data Collection

One of the primary objectives of this study was to establish the relationships between accident frequency/severity and various types of trucks, and size and weight categories. To establish these relationships, many of the analyses involve the use of accident rate calculations for trucks and various truck parameters. Accident and involvement rates are much more meaningful than the simple frequency statistics so often quoted. They provide the opportunity to make rational safety comparisons between classes of vehicles and types of roadways. They can determine whether a particular item of interest is over- or under-represented in the accident data relative to its exposure (i.e., opportunity to have an accident).

Simply stated, rate is:

$$\text{Rate} = \frac{\text{No. of Truck Accident Involvements (by type)}}{\text{No. of truck (100 million) miles of travel (by type)}}$$

However, because specific variables and roadway types were of interest, the following mathematical equation is used:

$$[R_{ij}] = \frac{\sum_k (A_{ij})_k}{\sum_k (E_{ij})_k}$$

where:

R	=	accident involvement or severity rate
i	=	roadway class of interest (N = 6)
j	=	variable of interest (whatever)
k	=	specific site (N = 78)
$[A_{ij}]_k$	=	truck accident involvement frequency, or truck accident involvement severity per year of the "k"th site for the "i"th roadway class and the "j"th variable
$[E_{ij}]_k$	=	truck miles of travel per year of the "k"th site for the "i"th roadway class and the "j"th variable.

In deriving a rate for each parameter of interest for a given site, it is essential to have a good estimate of the volume (frequency) of that parameter; hence the need for reliable exposure data. Two types of exposure data were required and obtained. The first identifies the miles traveled of the various truck types and variables of interest through each of the study sites. These are VMT (vehicle miles traveled) data and were collected once each quarter during the study. The use of VMT is based on the assumption that the number of vehicle-miles is representative of a vehicle's presence on the highway and, therefore, its opportunity (exposure) to have an accident. The vehicle-miles method is not a very accurate approximation of exposure to "specific" accident situations, but rather an exposure to accidents in general.

The vehicle miles (kilometers) of travel through a specific site is a function of the percent of the vehicle type or variable of interest, multiplied by the average daily traffic for the quarter, multiplied by the length of the site. *Total* exposure is obtained by adding the quarterly exposures for the time duration of interest.

The second type of exposure data identifies the percentage distribution of truck parameters within the total population. Most of these data were obtained at weigh stations and truck stops. Volume IV of this final report discusses the collection, reduction, and analysis of that size and weight data gathering effort. The exposure collection effort discussed below addresses the VMT and truck type distribution data acquisition.

It was realized at the onset of the project that there was an insufficient data base on truck exposure either at the state or Federal level for nearly all of the study sites. In most cases, what was available was limited in its level of classification. Therefore, an exposure data collection plan was developed that provided the needed data. In summary, it consisted of:

- obtaining the most recent ADT information (with or without vehicle classification) in each site from the appropriate state agency
- collecting data on the distribution of vehicle and truck types for each site.

Average Daily Traffic (ADT) Data

The ADT data are the numbers which, when multiplied by the percent distribution of vehicle type or variable, will yield the number of vehicles of that type or parameter of interest. Therefore, the accuracy of the ADT value is as important as the accuracy of the classification distributions.

The highway departments in each of the six states were contacted to obtain the most recent and detailed ADT for each site. Where data were not collected within a specific site segment, the nearest ADT data on the same roadway were obtained.

Vehicle Distribution Data

Most of the ADT data received gave only a total traffic count for the roadway. There was little or no categorizing of the data into vehicle types. Because one of the focuses of this study is on the relative safety of different truck types, a determination of their individual exposures was necessary. As noted above, the percent distribution, when multiplied by the ADT and the site length, yields the denominator (vehicle miles traveled) for the rate calculations.

The primary method for collecting these distributions was an automated time-lapse photography sampling technique. This was supplemented where necessary by a manual tally data collection effort. This sampling plan called for exposure data (ADT/distribution *and* size and weight) to be collected once during each of the six quarters of the accident investigation study at each of the 78 sites. This "simultaneous" data collection process is illustrated in Figure 2.

Given the concern that there is variation in percents across the day, week, and quarter, a cost-effective film data collection procedure was developed. The photographic technique consisted of a modified time-lapse Super-8mm camera which was automatically triggered by a road switch sensor. The remotely-controlled camera was located at a convenient distance from the highway in order to provide a suitable field of view and to afford some protection from vandalism. Pictorial data supplied by Super-8mm film were used to visually identify selected vehicles which activated the road switch. The sensing apparatus sampled axles passing over the road switch and triggered the camera to expose a single frame when a specified axle count was reached. The number of axles detected between exposures was dependent upon site-specific traffic volumes and vehicle mixes. This number was set so that one roll of Super-8mm film (3600 frames) provided a full week of coverage. Final vehicle distributions were then based on the observed distributions of vehicles of varying axle configuration. The system, as it was deployed in the field, is illustrated in Figure 3. A summary discussion of specific components of the system follows. Appendix D of this volume is the Equipment Deployment Manual used by the field investigators.

Road-switch Sensor. A stainless steel shielded coaxial cable, 1/8" in diameter, was attached to the pavement surface using a rubber-based asphaltic compound. The cable had the characteristic of generating a single noise pulse in response to traumatic deformation. A single road switch was capable of withstanding high traffic volumes for the week-long period.

Roadside Signal Transmitter. The road switch sensor was connected to a sealed metalic box, unobtrusively located near the roadway shoulder. This device transmitted a signal to the camera's receiver when it was time for another exposure. Road switch pulses were received and decoded within a noise filter. The desired axle count required between camera exposures was manually set on a counter. When the selected pulse count was reached, a 72 MHZ signal was transmitted to the receiver at the camera location. A 1000-cycle tone was utilized so as to prevent interference from other radio stations.

Camera Housing. The dual problem of camera obtrusiveness and potential vandalism was solved by building fake "birdhouses" in which to enclose the time-lapse camera and signal receiver. These units were mounted in trees, on telephone poles, etc. in proximity to the highway. The time-lapse camera was focused at infinity and the zoom lens was adjusted to the appropriate field of view prior to mounting the camera in the birdhouse. Once in the birdhouse, the camera was positioned by sighting along one edge of the house. To protect the equipment from real birds, the entrance of the house was covered with glass. Another design feature was that no perch was used at the entrance in order to ensure an unobstructed camera view of the highway.

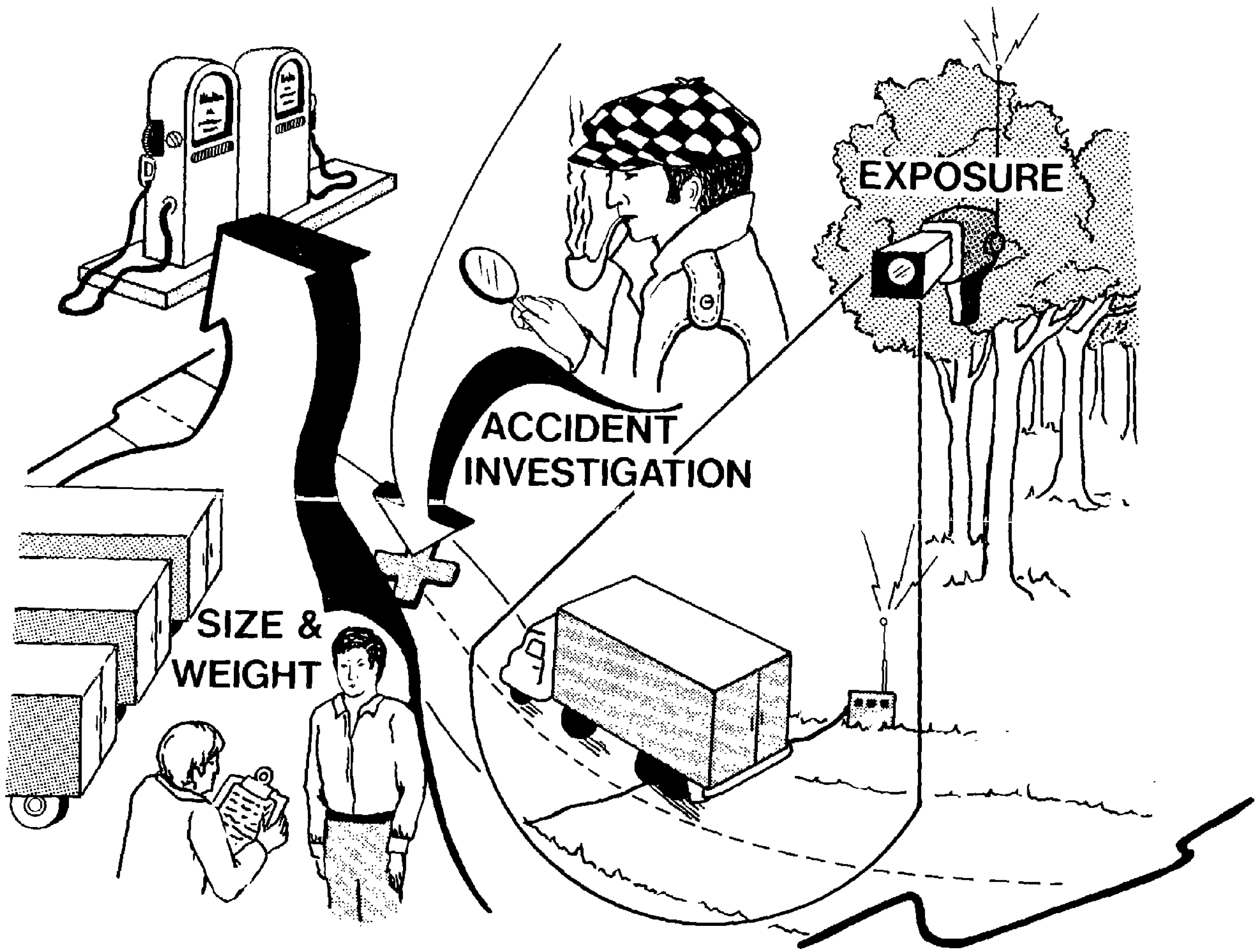

Figure 2. Illustration of simultaneous data collection procedures.

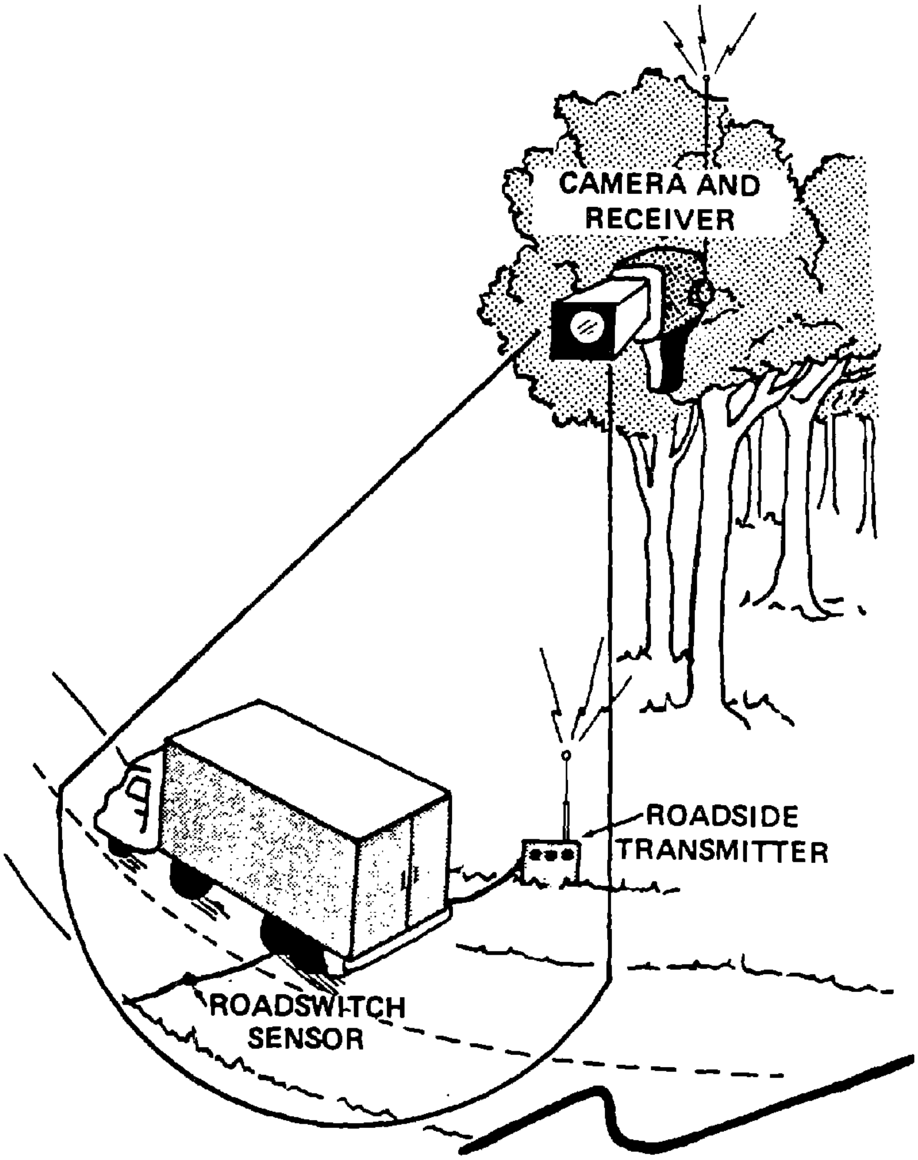

Figure 3. Illustration of Timelapse Camera System components and camera's field of view.

Camera. Requirements of the utilized camera were: (a) an electronic shutter release (due to excessive power needed for a mechanical release), (2) automatic exposure compensation capability, and (3) sufficient wide-angle lens system to view up to 200 feet of roadway from a relatively close distance. A modified Minolta XL-400 Super-8 camera met these requirements. The zoom lens ranges from 8.5mm to 35mm. The automatic metering system can close the lens to less than F44 or open it to a maximum of F1.2. The electronic shutter may be set for single frame operation. Modification of the camera was required so that a 1200 ASA film was properly exposed using the camera's metering system. An extremely high ASA was required to permit nighttime sampling. The film used was Kodak 4X black and white movie film rated and processed to yield an ASA of 1200.

Manual Count Sampling

While the photographic system was successfully deployed at several locations, many problems of various types resulted in less data than anticipated. The problems were multi-faceted and involved the hardware, winter weather, personnel (field investigators) and, in some instances, delays by the states. In Michigan and for most of the Texas sites, no data using this system were collected. At other sites, only partial data (i.e., not a full week) due to malfunctioning equipment were obtained.

To supplement the film data and avoid the possibility of having little or no classification data for several sites, a manual data collection procedure was initiated. The manpower requirements needed for a seven-day 24-hour/day manual counting effort (to obtain the type of data being obtained from the film) were deemed too prohibitive to be feasible. Therefore, a shorter time frame was considered. After reviewing the literature, which investigated the feasibility of less than 24-hour counts reflecting the entire day (Pfalzer & Hopkins, 1977; Cunagin, n.d.), it was decided that an 8-hour operation would be used.

A trained two-man field crew visited sites in Michigan and Texas to manually collect vehicle distribution data. Counts were made for eight hours, normally between 0800 and 1700, with one hour for lunch. In all cases, traffic in all lanes was counted for at least one direction.

Data Reduction

Although they were certainly the crux of the whole study, completion of the field data collection efforts initiated an even larger effort—the reduction and analysis of the massive amounts of data. For each of the three types of data (accident, size and weight, and truck type), review, data reduction, and editing procedures were carried out.

Accident Data Reduction

Upon completion of their followup accident investigation, the field investigators forwarded the Supplemental Data Form and the state police report to BTI. Every accident returned went through review by one of two accident reviewers. Items checked during this review were:

- ensure that it was a large truck
- ensure it was in site
- proper coding
  - reflect any changes in coding as more knowledge of trucks was gained
  - reflect new/additional codes
  - make sure all boxes on the form were filled in.

Reports that were totally wrong were returned to the FIs to be recompleted. This rarely happened.

The reviewers completed the Summary Data Page (page 0 of the form). This was particularly important for the culpability variable where a lot of interpretation was possible. High intercoder reliability was realized with all accidents being checked by just two staff members.

After the reports were reviewed, the data were keypunched. Final editing was done after univariate distributions were obtained. Out of range and unlikely codes were checked and corrections made as appropriate. From this 153-variable corrected file, a 67-variable subfile was made which was used in the analyses which follow.

Size and Weight Data Reduction

Volume IV of this final report discusses the reduction and editing of the size and weight data. In brief, the size and weight data could not be reviewed as thoroughly as the accident data. Two reasons precluded this: the size of the data base (32,105 trucks vs. 2,112), and no supplemental data source (such as the police reports) to verify the data. Out of range and unlikely codes were corrected after the univariate distributions were run after keypunching.

Film/VMT Data Reduction

After undeployment, the field investigators returned the exposed film cartridge to BTI for processing. The films were reviewed and a tally made of all vehicles seen passing over the cable. Data reduction was accomplished by two reviewers; high intercoder reliabilities were obtained. From this, the distribution of vehicles through the sites was determined.

The objective of the film data collection effort was to obtain exact information on the type and number of vehicles passing through the study sites. To get this, a frame of film was exposed for every Nth axle passing over the sensing cable; N being based on traffic volume and mix at the site. State ADT data were used to set the counter to the appropriate value. For several varying reasons, seven full days of film data were not always obtained. Because of the inconsistency across quarters and sites of this problem, only the distribution data were actually used from the film. The ADT data from the states, on which the counter settings were based, were used for the total ADT. The vehicle type distributions were applied to these data to get vehicle miles traveled (VMT) for each truck. The VMTs are the denominator of the rate calculations.

III. PRESENTATION OF FINDINGS: KEY STUDY ISSUES

This and the next chapter present the results of the accident analysis. The results are divided into two distinct sections. Chapter III addresses the key issues that are the focus of the study—the safety implications of truck size, weight, and configuration. Chapter IV discusses data of concern to the safety community, but which were supplemental to the key issues.

The format of the presentation is a series of tables and discussions. For each topic, on the left-side page is a primary table addressing the issue. For the most part, these tables consist of bivariate distributions (cross tabulations) of the accident involvements for the variables of interest. The facing right-side page consists of three sections. The first is an "Issue" phrased as a question. This identifies the topic being addressed. The "Analysis" is a discussion of the highlights of the primary table. As necessary, to clarify portions of the main table and/or provide insights into the specific issue, an additional table(s) is incorporated into the analysis. The third part is the "Findings." These are concise statements summarizing the results.

In the tables, unknowns have been suppressed from the analysis and percent calculations. The variables in each table are usually self-explanatory or are described in the analysis text. The reader is advised to review the Accident Investigation Coding Manual (Appendix C to this volume) for complete descriptions of the codes for each variable.

About the Data

The data base created in this study is unique to this effort. As such, there are several aspects of the data that should be understood before proceeding. First, as a whole the data base contains 2,112 records of trucks involved in 1,816 accidents. When an accident involved more than one large truck, a record was created for each truck. Consequently, even though the term "accidents" is used frequently, these are really truck accident involvements.

Second, the Supplemental Accident Data Collection Form (Appendix C) had a total of 153 possible items of descriptive information to be gathered for each accident. For a multitude of reasons, not all of these data could be collected for every involvement. Thus, although there are 2,112 involvement records, for any one variable there may be somewhat less than that.

Third, not all variables for which data were collected are discussed in this report. Appendix E to this volume shows the univariate distributions of all responses for each of the 153 variables on the accident report. Two levels of analysis are made with this data base. The basic analysis presents bivariate distributions of variables relevant to the primary and supple-mental topics of interest. The second level analysis combines the accident distributions with the corresponding exposure data and vehicle miles traveled (VMT) data to obtain accident involvement rates. This is done for some of the primary issues. The accident rates are stated in 100 millions of vehicle miles.

Fourth, the data base reflects the experience of six states (California, Maryland, Michigan, Nevada, Pennsylvania and Texas) from 01 July 1976 through 31 December 1977. It should *not* be construed as being representative of the United States. The sampling plan was biased toward states with specific truck types, accident frequency and/or exposure. Consequently, many of the results cannot be extrapolated to the nation as a whole. However, it is believed that certain variables, particularly those related to accident dynamics and causation, are not likely to vary significantly between the states. Therefore, they probably do represent all large truck accidents.

Finally, the caveats associated with the data base and state biases should especially be recalled when considering the rate analyses. The involvement rates quoted reflect only this data base. Because of the nature of the data, the site selection process, or other reasons, individual rates may be high or low depending on the variable. However, *within* the analyses, the *relative* rates between variables (e.g., truck types) are real; the same biases apply to all the data. There are few internal discrepancies. Indeed, it is the relative rates that are important to the issues in this study anyway.

About the Analyses

For each of the topics and tables presented, statistical tests were made on the data to identify significant findings. Depending on the nature of the data, one of several standard tests was used: multiple linear regression, analysis of variance (ANOVA), paired t-test, chi-square (χ^2), and z-test of proportions. To designate significance, a 95 percent level of confidence was used. Only results having a statistic $<$ .05 are identified as significant.

Multiple linear regression analyses were used to determine the relationships between the independent variables and each dependent variable. After calculating the correlation coefficients, step-wise multiple linear regression was employed to identify the independent variables which contributed to explaining the variance in each dependent variable. It should be noted that the results of this analysis were used only as a guideline for conducting subsequent data analyses; the results of the regression models should only be considered as a preliminary screening procedure for selecting and arraying the variables for further analysis.

Analysis of variance is a method used to divide observed variation in experimental data into parts with each part assigned to a known source or variable. Its purpose is to determine whether a particular part of the variation is greater than would be expected by chance. The null hypothesis generally assumed for the ANOVA is that the means of the sample data are not statistically different; that is, the independent variables have no effect on the dependent variable.

Results of the analyses of variance can be used to determine whether significant differences exist for multiple treatments. However, the analysis does not indicate which specific characteristic was significantly different from other similar characteristics. To determine which means were different, the paired t-test was used.

The chi-square test is used to measure the discrepancy between observed and expected frequencies of data. For this analysis, the chi-square test was appropriate for comparing the observed frequency of accidents in a particular severity category versus the expected frequency.

The z-statistic is used to determine if the proportion of events in one group is statistically different from the proportion of events in another group. Assumptions underlying the z-test are that the observations for the two sample groups are independent and that the sample size for each group is greater than 30. For this study, proportions from exposure and accident data were available and used for the following categorical variables: size and weight of truck, age of the driver, professional experience, and rig experience.

The exposure data (that is, the proportion [of drivers] in each category actually in the traffic stream), and the proportion of accidents that occurred in each category formed the two groups for the z-test analysis.

Synthesis and Discussion

The remainder of this chapter is devoted to presentation of the individual tables for the key study issues. Because the overall results are based on the findings of several topics, a short discussion summarizing the significant findings precedes the tabular presentations. Each topic contains a short discussion of the issue, followed by a summarization of the results of the accident study. When appropriate, considerations that may have affected the results are also acknowledged. The areas addressed are:

- truck type and weight
- truck dimensions: length, width, height
- cab type
- cargo area configuration
- driver characteristics
- roadway type and geometrics.

Truck Type and Weight

To increase truck payload capacities, the trucking industry has proposed two methods—by allowing longer, or allowing heavier, combinations. As was discussed in Chapter I, the economic benefits of increased length are apparent. However, just increasing the length of a trailer creates, among other things, offtracking problems. Therefore, allowing a second or third trailer with a relatively short wheelbase has been the most popular method of creating longer trucks. With an overall length limit of 65 feet (19.8 m), the most popular such combination is the tractor plus twin 27-foot (8.2 m) trailer combination. These configurations (tractor plus semi- plus full trailer) are referred to as "doubles" in this report. Straight truck plus full trailer configurations are operated as well. Tractor plus semi-trailer configurations are called "singles." At present double trailer combinations are allowed in a majority of the states—primarily in the midwest and west. Most of the southern and eastern states allow only tractor/semi-trailer configurations. Several western states currently also allow triple trailer operations. There are also several states where twin 40-foot trailer combinations are allowed to operate under special permit. These operations are primarily limited to limited access highways.

Weight restrictions are established primarily to help prolong the life of the roadway pavement and to protect structures (bridges) from serious overloads. However, past research has shown that, economically, the savings in transportation costs would offset the higher reconstruction and maintenance costs. (See the discussion in Chapter I.) Weight increases can be allowed in one of three manners:

- higher gross vehicle weight (GVW) by increasing axle weights
- higher GVW with the same axle weight limits but more axles on the configuration
- higher GVW with the same axle weight limits but more axles by adding trailer units.

The third method is essentially a "truck type" issue. The second method is what is done in Michigan. Unfortunately, the data base in this study of the "Michigan singles" and "Michigan doubles" (i.e., the multi-axle singles and doubles combinations) is not large enough to make any conclusive statements regarding the safety implications of these heavier trucks. In general, there do not appear to be any deleterious effects of weight increases through this method for distributing loads.

The issues of how truck configuration and weight affect safety were addressed by analyses of accident frequency, accident involvement rate, and injury-accident rate across several variables: roadway type, grade, accident dynamics, and location (rural or urban). For truck configuration the prime concern is the comparison of singles and doubles combinations; but triple trailer configurations are also of interest. Although the study design included sites where triples were operating, no accidents involving triples occurred on these sites during the data collection period. Discussions with officials in the states in which triples are allowed to operate indicate that, due to limited exposure, accidents involving triples are extremely rare.

In specifically comparing singles and doubles, it was decided to use data from states in which both vehicles were allowed to operate. This was done to avoid any differences due to state reporting requirements or highway and traffic conditions. All six states participating in the study allow singles, while only three (California, Nevada, and Michigan) allow doubles. However, the doubles configuration allowed in Michigan is a unique multi-axled double quite unlike the more common western double. Thus, only California and Nevada data were used in the single-doubles comparison.

Accident rates by truck and roadway type were compared to assess the relative safety of various truck configurations and to account for the relative safety of various roadway types. The results showed that doubles, relative to both straight trucks and singles, had a higher mean accident rate. Further investigation into this phenomenon revealed that the significant difference between singles and doubles was occurring in the empty mode. Loaded singles and doubles had similar accident rates. (See below for a further discussion of this phenomenon.)

An analysis of injury-accident rate by truck type was also made. No statistically significant differences were found between straight trucks, singles, and doubles. To test whether the severity of the injuries incurred varied by truck type, distributions of the most severe injury in an accident were compiled. Three different occupant categories: truck occupants in single vehicle truck accidents; truck occupants in multi-vehicle accidents; and other vehicle occupants in multi-vehicle accidents were used in this analysis. For single vehicle truck accidents, straight trucks had a higher percentage of injury-producing accidents than either singles or doubles; singles were slightly higher than doubles. In multi-vehicle collisions, doubles produced a higher percentage of injury accidents to both the truck occupant(s) and other vehicle occupant(s). However, the most severe injury in this situation was the nonincapacitating (minor) severity level.

The accident rates of singles and doubles on a ton-mile basis were also calculated. These results indicate the frequency of accidents by the weight carried times distance traveled (vs. just by the vehicle distance traveled as is the case above with accident rates). No significant differences were seen in the mean ton-mile accident rates between singles and doubles. The significant difference in the accident rates seen above disappeared in the ton-mile comparison.

In considering collision types and accident dynamics for single vehicle accidents, there was no difference in the distribution of accident dynamics between singles and doubles across all roadway types. Doubles had slightly more jackknife accidents, but this was not significant. For multi-vehicle truck accidents, only rearend accidents show significant differences between truck types. Doubles were rearended by other vehicles more frequently than were singles. Singles and doubles rearended other vehicles with about the same frequency. Straight trucks pulling trailers rearended other vehicles significantly less often than did the other truck types; they were also rearended the most frequently. It is unknown at this time why this result occurred.

In considering the grade of the roadway at the accident scene, doubles appear to have more problems on downgrades than upgrades; singles do not reflect this same discrepancy. Straight truck plus dolly combinations also had a problem on downgrades.

In the gross vehicle weight analyses, accidents involving articulated combinations were generally concentrated at the lower (empty) and upper (full or nearly full) ends of the weight continuum. The upper end concentration reflects the high percentage of trucks operating in a full mode (Volume IV, Table 21), and does not appear to reflect an overinvolvement in accidents. However, the concentration of accidents for the empty mode does show an overinvolvement of low-weight articulated trucks. Both singles and doubles had their highest accident rates at the low-weight end of the scale. In fact, the doubles accident rates were very high at the empty end, and were much higher than the rates for empty singles. In the loaded condition there was no difference in the accident rates of singles and doubles. This result is consistent across all roadway types. Thus, it would appear that problems exist for articulated vehicles when empty, and that this problem could be severe for doubles.

Only the straight trucks showed a consistent pattern of higher accident rate with increased weight. However, this appears to be due to differences in truck configuration rather than weight, since straight trucks of any one configuration do not operate across the entire weight spectrum of straight trucks. The discussion of Cargo Area Configuration below explains this in more detail.

Regarding the injury severity produced by different weight trucks, distributions were made of the most severe injury received by a truck occupant in single vehicle truck accidents, or a truck occupant or other vehicle occupant in multi-vehicle collisions. Within an individual truck type there were no significant differences in the most severe injury received distribution across weight categories for any of the three occupant groups regardless of vehicle weight.

Considerations: The accident rates calculated for these analyses were made by dividing the number of accidents by the number of vehicles in the exposure (size and weight) data for the same category. Most of the size and weight data were collected in California, and the majority of that was at truck weigh stations. Weigh station operators, especially when traffic was heavy, frequently waved through trucks that were empty. Because of this, there is an underreporting of empty trucks in the exposure data. The result is a higher accident rate than actually exists (because all empty truck accidents were obtained). Therefore, within the singles or doubles truck type, the empty rate relative to higher weight categories is somewhat exaggerated. However, while not as extreme as portrayed, real differences do exist between empty and loaded trucks. In addition, because there was no apparent bias in doubles being waved through relative to singles, real differences exist between the two truck types.

Truck Length

Truck length restrictions vary considerably between the states and are related to the type of trucks operating. For singles, the western states typically allow an overall length of 60 feet (18.3 m) or more; eastern states usually limit them to 55 feet (16.7 m). Where allowed, doubles combinations have overall lengths which are typically 65 feet (19.8 m).

The perceived safety impact of longer trucks, ignoring the interrelationship of increased weight, is twofold: the offtracking problem of larger wheelbases, and greater passing distance requirements. Offtracking (the lateral distance between the tracks made by the front and the rear tires of a vehicle during a turn) increases with increasing wheelbase—a consequence of longer trailers. If the offtracking is too extensive, the vehicle (trailer) can encroach into an adjacent traffic lane. Longer wheelbase trucks would thus have more problems on small radius curves, such as off- and on-ramps.* Longer trucks also affect passing distances both from the point of passing other vehicles and being passed. This poses a potential safety problem, particularly on two-lane roadways with opposing traffic where the amount of time available to pass is at a minimum.

When possible, lengths were determined for the straight truck or tractor, all trailers, and the overall length (not necessarily equal to the sum of the parts). In addition, if a truck was determined to have been overlength, it was so noted. The analysis of overall truck length did not lead to any conclusive findings regarding the effect of truck length on accident frequency. For combinations this is not unexpected because there is very little variety in truck length. On the other hand, for straight trucks the accident rate did decrease as length increased. However, this is probably due to "different" straight trucks (i.e., different cargo area configurations). Straight trucks of similar configuration do not vary much in length. The relationship of accident rate to length is, therefore, more a comparison of cargo area configuration than it is of similar truck types of different lengths. A discussion of cargo area differences follows.

While total configuration length is regulated in all states, most states do not place restrictions on trailer lengths. Consequently, trailers have become longer with more frequent use of the shorter, cab-over-engine tractors. Increased trailer length for singles combinations has become an issue of concern. While the most common trailer length observed in the exposure data (48%) was 40 feet (12.2 m), there appears to be a growing number of longer trailers in use. The 45-foot (13.7 m) trailer (18%) was the most common "long" trailer observed in the exposure sample. To determine the possible safety impact of increased trailer length for singles, a comparison was made of the accident rates of tractor/semi-trailer combinations with 40- vs. 45-foot (12.2 m vs. 13.7 m) trailer lengths. The results showed no significant difference in the accident rate of combinations with these two trailer lengths.

*FHWA Note:
Doubles, while approximately 10 feet longer than singles, do not experience increased offtracking compared to singles. Offtracking is primarily a function of the length of individual units.

Considerations: For all trucks combined and within each truck type, it would be erroneous to draw conclusions regarding the effect of length alone. The accident frequencies are certainly affected by other factors such as cargo area configuration. Further stratification of the data and/or more data points are necessary to control for these confounding factors.

Truck Width

Current Federal regulations and most state regulations limit truck width to 96 inches (2.4 m). Some states permit widths up to 102 inches (2.6 m), but with the stipulations that the width include safety devices, be measured from the outside edge of the tires, and/or be applicable only on certain highways.

From a safety point of view, truck width would appear to be the most critical of the three dimensions. While most major highways have lanes that are 12 feet (3.7 m) wide, there are numerous two-lane roadways with lane widths of 9-12 feet (2.7-3.0 m). Obviously, trucks with widths approaching these narrower lane widths would not allow much margin for changes in lateral placement. Consequently, wide trucks pose a potentially serious safety problem, particularly on two-lane roads with opposing traffic.* The trucking industry has proposed the width limitations be increased to 102 inches (2.6 m) to accommodate loads that are 96 inches (2.4 m) wide (e.g., 4x8 plywood). However, given safety concerns, the Federal government and most states have not looked favorably on these proposals.

To address the issue of truck width as it related to safety, widths were determined, when possible, for the straight truck or tractor, all trailers, and overall (the widest of the parts). Whether a truck was carrying a wide load (i.e., exceeding the limits) was also noted. The results of the accident analysis dealt only with overall width, and were essentially inconclusive. Within each truck type, trucks involved in accidents had widths which were concentrated in one three-inch width group (94-97 inches [2.4-2.5 m]). This simply reflects the fact that the vast majority of trucks are built to the maximum width limit (96 inches [2.4 m]), and these are the ones involved in accidents. Without a reasonable sample of trucks with a wider range of widths, it is impossible to determine the effect of width on accident frequency.

It is noteworthy that 22 percent of the straight truck plus dolly configuration accidents involved vehicles with widths equal to or exceeding 110 inches (2.8 m). This does not, however, mean an overinvolvement in accidents; 22 percent of this truck type's exposure data were also 110 inches (2.8 m) or more. Their accidents were not due solely to their width characteristics; width was not a factor in many of the accidents. Although not reported in a table, the data on oversized vehicles showed 0.8 percent of the accident-involved trucks having wide loads.

Truck Height

There are two reasons for limiting truck height. The most compelling reason is height rectrictions forced by overhead structures. Current Federal standards require a minimum clearance of 14 feet (4.3 m) on most highways. However, there are still many roadways with overhead structures that have lower clearances. A second reason for limiting height is to minimize the trailer's susceptibility to sway and rotation due to a higher center of gravity. In view of these factors, there have been no strong arguments raised for increasing current height limitations. In addition, height increases would not significantly expand payload capacity.

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*FHWA Note:
The safety problem associated with wider trucks is a perceived one. Research on wide vehicles has shown that there is no significant difference in the safety performance of 102-inch wide vehicles versus 96-inch wide vehicles on divided highways with 12-foot wide lanes (Reference: Pilkington, G.B., et al., *Safety of Wide Buses*. U.S. Department of Transportation, May 1973).

As with the other dimensions, truck height was determined, when possible, for the straight truck or tractor, trailers, and the overall height (the highest of the parts). No analysis was made of the accident data because of the interfering effect of cargo area configuration (e.g., enclosed van, platform) with varying heights which would confound the effect of height alone. For an individual cargo area configuration there was an insufficient distribution of height to distinguish any differences. Realizing these limitations, it was observed that higher trucks did not appear to be overinvolved in accidents relative to their exposure on the highways.

Information was also gathered on overheight loads. Those results showed that 2.4 percent of the accidents involved trucks with heights exceeding the limitation. In fact, "overheight" was a primary predisposing factor in 24 accidents, most of which (N = 20) occurred at a tunnel that has a height restriction.

Cab Type

Development of the cab-over-engine (COE) tractor grew out of the desire to maximize cargo carrying space within given overall length limits. COEs are generally shorter than cab-behind-engine (CBE) tractors; therefore, longer trailers could be hauled while staying within the legal length allowance. However, development of the COE has not been without its concerns. The two prime areas of concern have been:

- does the shorter wheelbase result in a higher accident rate because of handling difficulties or increased frequency of front tire failure (FTF)?
- is there greater truck occupant injury severity because of less "protection?"

The issue of front tire failure is not directly reported in the table presentations. However, the vast majority of the FTF accidents did involve cab-over-engine tractors. It is not known, and the data are only minimally available, whether the front axle load contributed at all to those accidents. Virtually no maneuverability data relative to cab type could be obtained during this study.

The rate analyses of cab type were made for singles combinations only. There were no differences in the accident rate or injury-accident rate (number of accidents with an injury of *any* severity) between COE and CBE tractors across all accidents. However, for single vehicle truck accidents, cab-overs did show a significantly higher proportion of accidents that produced truck driver injuries than did CBE tractors. This increase was only in the "possible" and "nonincapacitating" injury levels.

Cargo Area Configuration

One of the variables which potentially confounds other issues is the configuration of the cargo area of the truck/trailer. Aerodynamic, structural or operational qualities of particular trailer designs can offset or initiate the occurrence of an accident. For each of the major truck types, accident frequencies and rates by cargo area configuration were calculated. The specific problems of any one trailer design and truck type can only be answered with a more in-depth analysis of the accident data. However, accident rate data showed the following truck and trailer type configurations having particular problems:

- tankers for all truck types (straight trucks, straight plus full trailer, singles, and doubles)
- dump trailers for straight trucks, singles, and doubles
- doubles platforms
- vehicle carriers for straight plus dolly combinations and for singles
- pole/log carriers for straight plus dolly combinations.

For straight trucks, an interesting finding related cargo area configuration to gross vehicle weight. The data showed the *empty* dump trucks and the *loaded* fully-enclosed straight trucks had the major problems. These data may be reflecting problems when the trucks are operating outside their "design" mode (i.e., fully enclosed for lighter loads, and dumps for heavier loads).

Driver Characteristics

In accident analyses, the driver is frequently cited as contributing to the accident's occurrence. Three major characteristics of the driver were investigated in depth—age, professional driving experience, and rig experience.

Driver age data showed consistently across all major truck types that accident rates are significantly highest for younger drivers (either <20 or 20-29 years, depending on the truck type), decrease with age up to a point, and increase again with older drivers (>50 years). The 40-49 year old age group showed a significant underinvolvement in accidents. There is not, however, an equivalent trend for professional experience as a truck driver. Overall, the general trend is for a lower accident rate with increasing professional experience. Drivers with more than 10 years' experience, both overall and for individual truck types, had significantly fewer accidents than would be expected. Higher accident rates were seen for singles in the 1-3 and 5-10 years' experience levels; the doubles' drivers rates jumped in the 3-5 years' experience category. Rig experience data showed a significantly higher accident rate for doubles drivers with less than three *months* experience, after which it dropped off and remained fairly consistent. Other truck types did not show correspondingly high initial rates.

To test the hypothesis that the drivers of the various truck types themselves may be different, distributions of age, professional experience, and rig experience by truck type from the *exposure data only* were investigated. There were no differences in any of the distributions between singles and doubles drivers. Drivers of straight trucks are younger and less experienced than drivers of the articulated configurations.

Roadway Type and Geometrics

General analyses of accidents and accident rates by roadway type and specific roadway geometrics were made. The analysis of roadway type showed significant differences in truck accident rates across roadway types. In general, trucks as a whole have higher accident rates on urban roadways relative to rural roadways. However, this is not unexpected nor unusual. An analysis of nontruck and total traffic stream accident rates was also made. The total traffic stream, nontrucks, trucks overall, and singles, and doubles individually all showed similar patterns: increasing accident rates across rural-freeway, rural-nonfreeway, urban-freeway, and urban-nonfreeway roadway types. This sequence reflects the relative likelihood of having an accident. With higher exposure to other vehicles on urban roadways, the frequency of multi-vehicle collisions increases in those settings. The exposure to roadside objects and opposing traffic increases on nonfreeways relative to freeways.

In specifically comparing trucks and nontrucks with each other and with the total traffic stream, no significant differences were found based on data from 29 sites in California and Michigan.

In considering truck accidents in general on grades, it was found that trucks are more likely to have accidents on grades than on level terrain. Rural-*non*freeways had the worst grade accident experience—particularly downgrades. It is also the steeper downgrades on rural roadways, and again particularly nonfreeways, that had the greatest accident frequency.

Horizontal curvature and locational data showed that trucks had a higher percentage of accidents on right curves than on left curves. This is due to the frequency of accidents on freeway ramps. However, more accidents occurred on freeway off-ramps than on-ramps. This probably reflects a higher entry speed into the ramp from the throughway relative to the entry speed into the on-ramp from the interchanging highway.

KEY STUDY ISSUES

Table 6. Comparison of Accident Rates for Trucks, Nontrucks, and the Total Traffic Stream[1, 2]

Comparison	Mean	T-value	df	Significance
Truck	2.35	1.48	28	.15 (NS)
Nontruck	3.12			
Truck	2.35	1.45	28	.16 (NS)
Total	3.05			
Nontruck	3.12	1.52	28	.14 (NS)
Total	3.05			

Table 7. Distribution of Truck Accident Rates by Truck Type and Roadway Type[2, 1]

Truck Type	Rural Freeway[3]	Rural Nonfreeway	Urban Freeway[4]	Urban Nonfreeway
Straight Trucks	.43	1.11	.84	1.71
Singles	.77	.97	2.79	2.94
Doubles	1.29	4.34	4.49	5.24

[1] Based on California and Michigan data only.

[2] Accident rates per one million vehicle miles. They are calculated by dividing the sum of the accidents for any given cell by the sum of the vehicle miles for the same cell. In these instances where an ANOVA test is run, average rates are calculated by determining the rate for each site, summing the rates, and dividing by the number of sites. Those rates are not shown in the tables.

[3] Excludes Site 114 (Grapevine).

[4] Excludes Site 145 (Bay Bridge) and Site 241 (Harbor Tunnel).

Issue: Are accident rates affected by large type and roadway type, and how does the accident rate of large trucks compare to the rate for nontrucks?

Analysis: Nontruck and total traffic stream accident rate data were available for 29 sites in California and Michigan. Table 6 shows the mean values and the results of the paired t-tests[1] between the truck, nontruck and total traffic stream accident rates. The results indicate there were no significant differences between the mean accident rates of trucks, nontrucks and the total traffic stream.

Table 7 summarizes overall accident rates by truck type and roadway type. With one exception (straight trucks), the mean accident rate increased across the four roadway types from rural-freeway, rural-nonfreeway, urban-freeway, to urban-nonfreeway. These differences are not unexpected and reflect the characteristics of the traffic on each type highway. The results of the paired t-tests[1] indicated that the mean accident rate of doubles is significantly higher than either straight trucks or singles for all roadway types.[2] (.05 level)

In order to more accurately compare singles and doubles, rates were calculated using only data from California and Nevada (Table 8). These are the two States in the data base that allow the "western" (twin 27-foot trailer) double-trailer combination. There was a concern that comparing singles and doubles using data from locations where one didn't operate might bias the analysis. Analysis of these rates indicated that doubles had a significantly higher accident rate than singles. However, this result must be considered in conjunction with the results in the next Issue on truck weight, since there is an interaction between truck type and weight.

Table 8. Distribution of Accident Rates for
Singles and Doubles by Roadway Type (California and Nevada Only

	Rural Freeway	Rural Nonfwy	Urban Freeway	Urban Nonfwy
Singles	110	99	214	93
Doubles	228	468	388	428

Findings:

- In general, trucks, as is the case with nontrucks, have higher accident rates on the urban roadway system.
- Doubles have a higher mean accident rate than singles.

[1]See page 134 for statistical references describing the statistical procedures used.

[2]Triple-trailer combinations were also of concern during this study. However, no accidents involving triples occurred on any of the Nevada sites during the data collection period. Discussions with personnel in all States in which triples are operating indicated that they have had few accidents.

FHWA Note:

During the review, concerns were expressed over issues of truck type, site selection procedure, and the possibility that a site or group of sites may have biased the analysis of singles versus doubles. To resolve these issues, the FHWA reviewed the analysis that was conducted by BioTechnology and reanalyzed the data to test the strength of the conclusions.

Based on the FHWA review, it became clear that no one site or group of sites had biased the BioTechnology analysis. One comment received stated that the sites selected included a high proportion of "hazardous," i.e., high accident rate. sites with large proportions of doubles travel. It was assumed by the reviewer that when average rates were calculated this large amount of "hazardous" travel by doubles would make them look dangerous.

In fact, it is for the very purpose of explaining such situations that statistical tests are used to determine if true differences exist. To conduct the test, individual rates for each truck type at each site were calculated. The test then compared the distributions of these rates to determine if the mean rate (calculated as the average of the rates) of each distribution (truck type) is significantly different at some accepted confidence level. In fact, the wider the range of "hazardousness," i.e., high accident rates among sites, the larger the variance of each distribution and the more difficult it is to demonstrate significant differences.

In reanalysis conducted by the FHWA, comparisons of singles and doubles were made for all combinations of roadway types using a paired "t" test.* The results are in Table A. A level of significance of .1 was used for the test. Differences at the .10 level indicate a 90 percent confidence that the observed differences are real.

In those cases where there were significant differences, a check of the highest level of significance was made. These values are shown in Table A. In all cases, except urban primary highways, the accident rate for doubles was signficantly higher than that for singles. For urban primaries, no difference was observed.

In addition, specific comments were directed at the appropriateness of including site 114 in the sample due to its unusually high accident rate. Site 114 is a 15-mile section of Interstate 5 north of Los Angeles, which includes a steep downgrade known as the Grapevine. To address this comment, rural freeways were reanalyzed without site 114. As the last line in Table A indicates, even without this site, doubles have a significantly higher accident rate than singles on rural freeways.

At the request of the Deputy Secretary for Transportation, the Transportation Systems Center (TSC) reviewed this report and performed an analysis of the available data by using indirect stability tests and sensitivity analyses. Results of these analyses indicate that the known biases in the data base are not great enough to invalidate the conclusion that doubles have a higher accident rate. Copies of TSC review are available upon request.

*See page 134 for statistical references describing the statistical procedures used.

FHWA Note (cont.):

Table A. Results of Paired "t" Test
Singles Versus Doubles

	Level of Significance	Higher Accident Rate
Rural Freeways	.025	doubles
Rural Primaries	.005	doubles
Rural Secondaries	.1	doubles
Urban Freeways	.1	doubles
Urban Primaries	N.S.	—
Urban Secondaries	.05	doubles
Rural Non-Freeways	.1	doubles
Urban Non-Freeways	.01	doubles
Rural (all)	.1	doubles
Urban (all)	.01	doubles
All	.005	doubles
Rural Freeways (w/o site 114)	.05	doubles

As indicated in the foreword, three earlier studies also compared accident involvement rates of singles and doubles. These studies showed little difference in accident rates between the two types of combination trucks. Although no weight information was obtained for any of the three studies, FHWA has been informed that only 4 to 7 percent of the trucks in the first two studies (1)(2) were empty and these studies should properly be compared to the heavier weight sections of Figure A where the rates for doubles and singles are close. The third study was based on California accident and exposure data (3) and showed no significant differences between the accident rates of doubles and singles. In that study, however, the accident and exposure data were obtained from two different data bases.

References

1. *Safety Comparison of Doubles vs. Tractor-Semitrailer Operation*, Bureau of Motor Carrier Safety, Federal Highway Administration, Washington, D.C., November 1977.

2. *Matched Pair Analysis*, John Glennon for Consolidated Freightways, c1979 mimeo.

3. *Comparison of California Accident Rates for Single and Double Tractor-Semitrailer Combination Trucks*, Federal Highway Administration, Washington, D.C., March 1978.

*See page 134 for statistical references describing the statistical procedures used.

Table 9. Distribution of Accidents and Accident Rates* by Gross Vehicle Weight and Truck Type

Gross Vehicle Weight (kips)	Straight Trucks N	Straight Trucks Rate	Singles N	Singles Rate	Doubles** N	Doubles** Rate
10-20	71	30	18	76	-	-
20-30	51	78	162	132	38	1215
30-40	13	111	92	63	26	416
40-50	7	129	71	72	11	156
50-60	-	-	66	80	6	77
60-70	-	-	70	59	7	69
70-80	-	-	118	46	27	71
80-90	-	-	8	59	7	149
90+	-	-	12	***	5	***

*Accident rate per 100 million vehicle miles.
**Includes all doubles in all states.
***Exposure values not available to calculate rates.

Issue: Do accident rates vary by truck weight?

Analysis: Table 9 displays the number of accidents and the accident rates by gross vehicle weight in increments of 10 kips (4.5 Mg) for the three major truck types. Using the z-statistic, significance tests were made comparing the proportion of accident-involved trucks by weight category with their proportion in the exposure (size and weight) data. For both singles and doubles, the 70-80,000 lb (31.8-36.3 Mg) weight category had significantly fewer accidents than would be expected based on their exposure. This was particularly true on rural roadways and freeways. At the other end, the low weight (20-30,000 lb [9.7-13.6 Mg]) singles and doubles had significantly more accidents. This was also primarily on rural roadways and freeways.

To specifically compare singles and doubles, California and Nevada data only were used. This was because only these two states in the data base allow the common twin 27-foot trailer combination to operate. (Michigan allows doubles but they are mostly unique multi-axle configurations. Only three of 50 Michigan double combinations in the accident data were the five- or six-axle twin 27-foot trailer truck type.) Because of the different operating conditions and accident reporting requirements among the states in question it was considered important to compare these vehicles only where they both operate.

Table 10 shows the singles and doubles accident rates for California and Nevada combined. As can be seen, doubles and singles appear to have a relatively similar accident rate except for the lowest weight categories. In the empty and near empty situation, doubles have a significantly higher accident rate than singles.

Table 10. Distribution of Accident Rates for Singles and Doubles by Weight Category (California and Nevada Combined)*

	Weight Category (KIPS)							
Truck Type	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Singles	291	136	49	61	37	44	45	–
Doubles	–	606	260	134	68	101	103	26[1]

*per 100 million vehicle miles.

Regression equations were calculated from three sets of data—accident rates for doubles in two states, accident rates for singles in two states, and accident rates for singles in all six states. These data are shown in Figure 4. The six-state curve was plotted to indicate the need to compare singles and doubles using only data from states where both operate. It is apparent from the figure that the six-state single curve is quite different than the two-state single curve. This is most likely due to different traffic conditions and different accident reporting levels among the states.

[1]Not plotted—rate based on one accident only.

The best fit for the two-State singles curve was a hyperbola; and for the two-State doubles curve was a quadratic equation. For the six-State doubles curve, the best fit was an exponential decay model. The equations are:

Two-State Doubles	$y = 1585.054 - 51.142x + .424x^2$
	$r^2 = .962$
Two-State Singles	$y = -45.144 + 4790.59/x$
	$r^2 = .814$
Six-State Singles	$y = 107.19e - .01x$
	$r^2 = .45$

Findings:

- Articulated configurations have higher accident rates when they are empty than when they are carrying cargo.

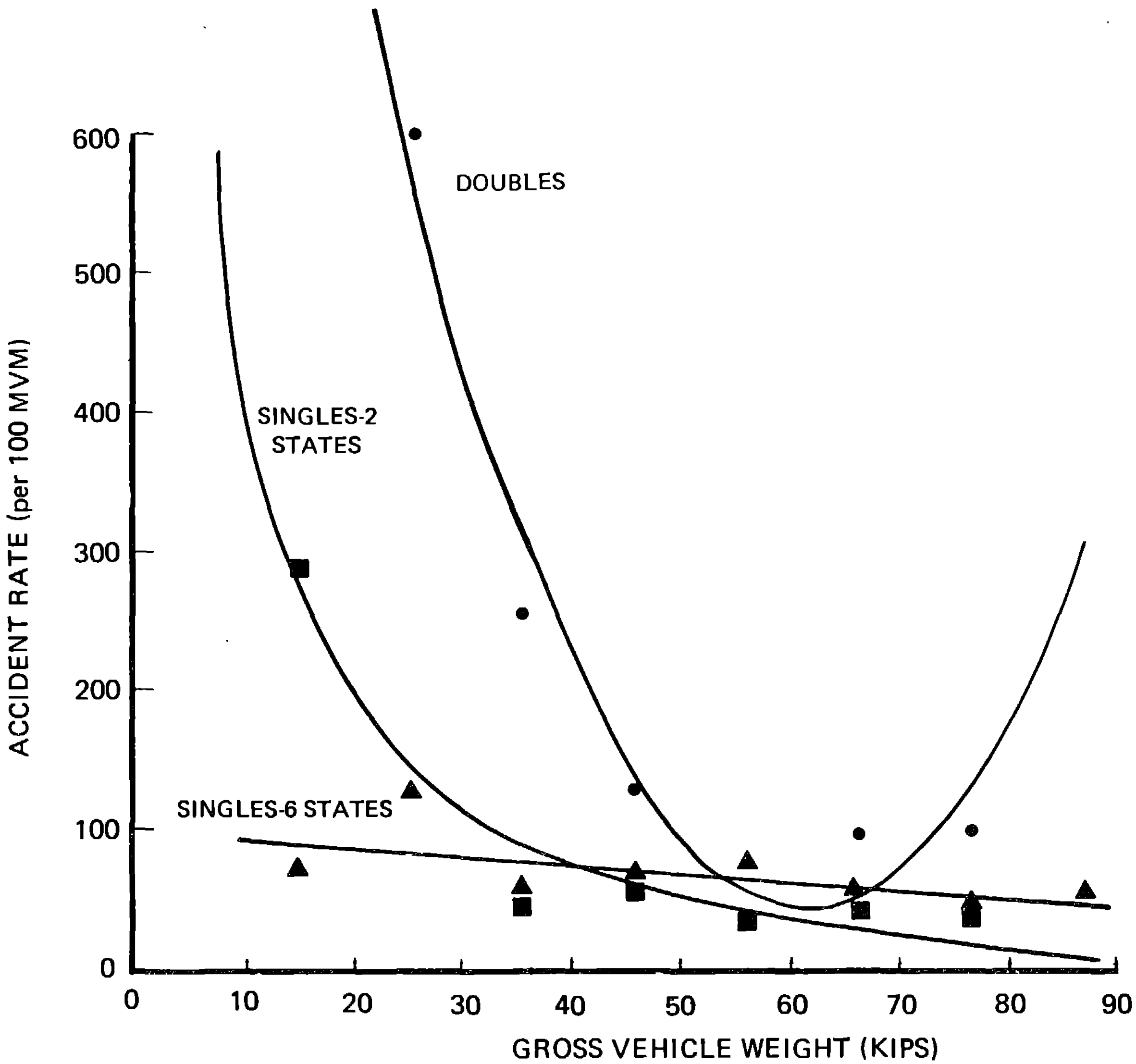

Figure 4. Plots of accident rates vs. gross vehicle weight.

FHWA Note:

During the course of the review, the issue of "empties" in California was raised. Weight data for the exposure calculations were obtained primarily from state scales. In California, "empties" may pass through the scales without being weighed to expedite the weighing process. During the data collection phase of the study, these "passed through" trucks were not included in the exposure data collection. Thus loaded vehicles were overrepresented and empty vehicles were underrepresented in the exposure data.

Accordingly, the FHWA determined the number of empty vehicles "passed through" the state scales in California. Information was requested from the State relative to the sites in question. For all truck types (straight and combination) the percent passed through ranged from less than one percent to nearly fifty percent. No detailed information about specific truck types was available although the verbal assessment provided by the State was that in general at those sites with high numbers of "empty" trucks, the empties were predominantly single unit vehicles. As an additional check, the 1977 loadometer survey information from the State of California was checked. This information showed that statewide singles and doubles were empty approximately 20-25 percent of the time. A value of 25 percent empty combination trucks was employed as the most representative figure for the "pass through" problem in California sites having pass through lanes.

The exposure for singles and doubles was recalculated assuming the 25 percent empty figure (which was distributed based on the loadometer survey distributions of empty truck weights). The accident rates for singles and doubles by weight were then recalculated and compared.

The results shown on Figure A indicate that for all weight classes doubles have a higher accident rate than singles.

Singles

Inspection of the data points for singles indicates accident rates decreasing with increasing weight. The best fit to the data points is a hyperbola with an R^2 of .85.

Doubles

A similar relationship between weight and accident experience for doubles also exists. Empty doubles, i.e., those below 30,000 lbs., have a significantly higher accident rate than other doubles. Rates consistently decrease with weight and between 30,000 and 60,000 lbs. For doubles in excess of 60,000 lbs., the accident rate increases moderately. The value of R^2 for the doubles curve shown in Figure A is .96.

Closer inspection of points in this graph indicates that the lowest accident rate occurs at weights between 50-60,000 lbs. The difference between the accident rate at this point and at other weight categories significantly influences the shape of this curve. The sample at this point was small. The best fit to the remaining points is an inverse indicating decreasing accident rates with increasing weights and leveling off at approximately 70,000 lbs. This representation is probably more representative of the relationship between rates and weights.

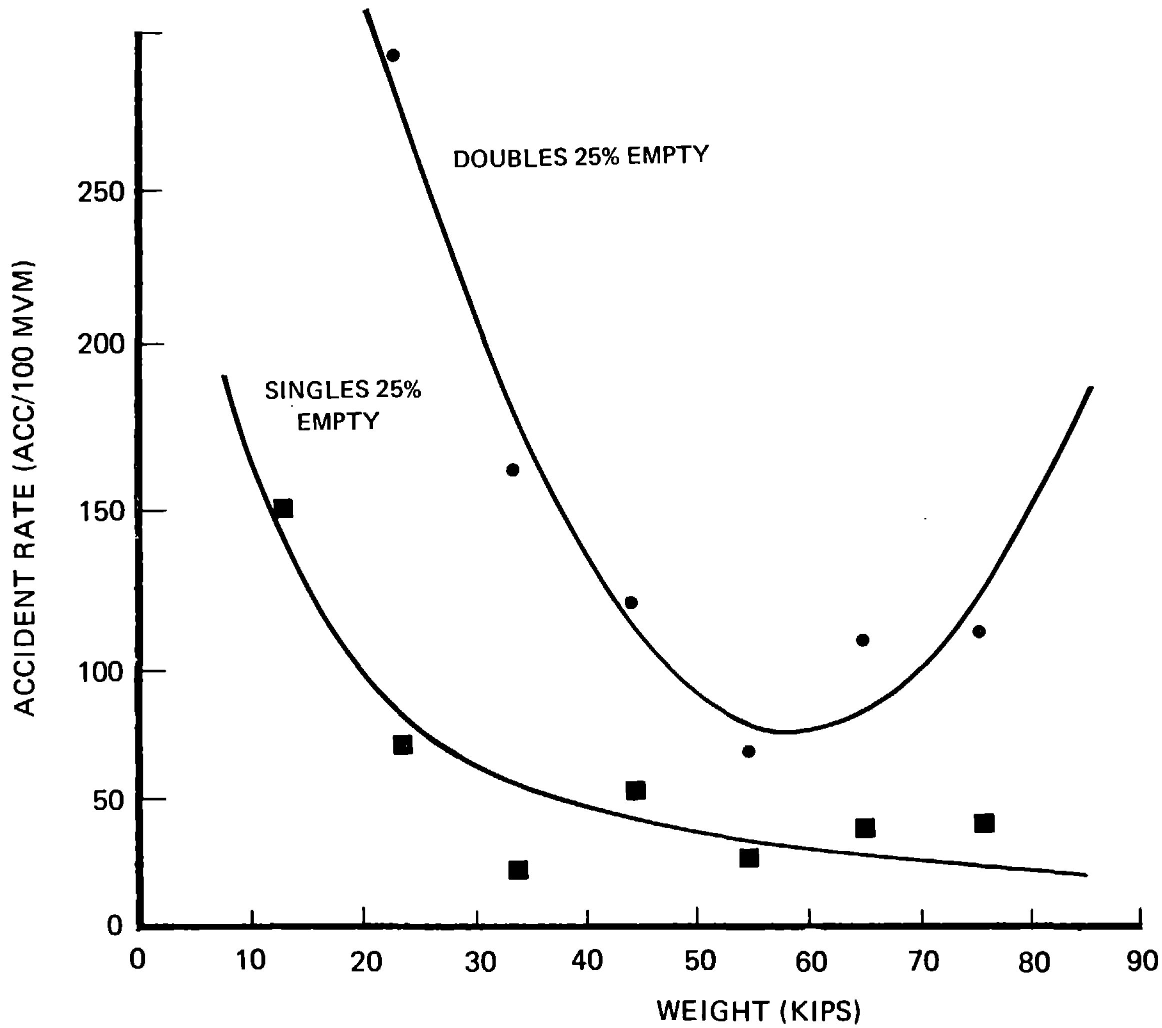

Figure A. Accident rates vs gross vehicle weight for two states, California and Nevada.

Supplementary Information on Data Collection For Sites in California and Nevada

Data for the study were collected at 20 sites in California and 11 sites in Nevada. At all sites classification data were collected using the photographic technique described in Chapter 2. It is important to note that the raw vehicle classification counts obtained from the film were adjusted to account for the probability of being sampled due to the number of axles on each vehicle, i.e., a five-axle truck would have five chances of having its picture taken while a three-axle truck would have only three chances of having its picture taken. At each site, photographic samples were taken for 1 week during each quarter. Thus during the 18 months of data collection, each site was instrumented six times. During each of the weeks of data collection, data were obtained 24 hours per day for each of the 7 days.

Size and weight information was collected at both State scales and at truck stops. Size information only was collected at toll booths. In all 17 sites in California and 8 in Nevada were used to obtain size and weight information.

Location	California	Nevada
State scale–size and weight	12	1
Truck Stop–size and weight	3	7
Toll Booth–size only	2	–
Total:	17	8

For each analysis performed by FHWA, only those sites on which data were collected were used. No attempt was made to estimate size and weight distributions for those sites where data were not collected.

Details of the data collected by site is available in Volume 4, "Truck Exposure Classification by Size and Weight," and the Appendix to Volume 3. Copies of these documents are available upon request to:

Environmental Division, HRS-43
Federal Highway Administration
Washington, D.C. 20590

Table 11. Distribution of Ton-mile Accident Rates* for Singles and Doubles by Roadway Type

Truck Type	Roadway Type: Rural Freeway	Rural Nonfwy	Urban Freeway	Urban Nonfwy
Singles	2	2	6	6
Doubles	4	8	6	7

*Accident rates per 100 million ton miles.

Issue: On a ton-mile basis, does the accident rate vary by truck type?

Analysis: A ton-mile comparison is important because, in general, with their longer lengths doubles can carry larger payloads than can singles. Because payload capacity is one of the key concerns with different configurations, an analysis of accidents per payload carried (i.e., ton-mile) is important.

Table 11 presents, by roadway type, the overall accident rates in millions of gross vehicle ton-miles for singles and doubles. No significant differences were found in the mean accident rates.

Findings:

- On a ton-mile basis, there is no significant difference in the accident rates of singles and doubles.

FHWA Note:

One review comment concerned the lack of significant differences in the ton-mile comparisons even though the average ton-mile accident rates of singles and doubles appeared quite different. To evaluate this concern the FHWA reviewed the procedure used to calculate the ton-mile rates.

The ton-mile rates quoted in this report were calculated by multiplying the total travel for each truck type at each site by the average weight of that truck type across all sites. This was then divided into the number of accidents for each truck type at each site.

In order to more accurately determine the ton-miles of exposure, the vehicle miles of travel by truck type and weight for each site were used to calculate ton-miles of travel. The vehicle-miles for each weight group were multiplied by the midpoint weight of that group. Once the ton-miles for each weight group were calculated, they were summed to determine the total ton-miles of travel for each truck type at each site.

The vehicle miles of travel used were adjusted for the missing empty vehicles in California that were discussed earlier. It was assumed that 25 percent of the singles and doubles "passed through" the California scales.

The results of these calculations are indicated in the table below. Recalculated in this manner it appears that on urban freeways and rural non-freeways doubles do have a significantly higher accident rate than singles. There is no significant difference on the other roadway types.

Comparison of Ton-Mile Accident Rates of
Singles and Doubles (California and Nevada)

	Rural Freeways	Rural Non-Freeways	Urban Freeways	Urban Non-Freeways
Singles	3.7	3.5	8.3	3.3
Doubles	6.9	16.7	11.8	11.5
Significance	N.S.	.05	.1	N.S.

NOTE: Rates shown are in terms of accident involvements per 100 million ton-miles.

Table 12. Distribution of Injury-Accident Rates by Truck Type and Roadway Type

Truck Type	Roadway Type Rural Freeway	Rural Nonfwy	Urban Freeway	Urban Nonfwy
Straight Trucks	26	45	34	50
Singles	34	39	98	96
Doubles	98	240	91	107

Table 13. Distribution of Most Severe Injury to Truck and Other Vehicle Occupant(s) by Truck Type

Straight Truck

	Fatal	Incap	Noninc	Pos	PDO	Total
SV–Truck	1(2)	4(8)	5(10)	8(17)	30(62)	48(100)
MV–Truck	- (-)	5(2)	7(2)	20(7)	248(89)	280(100)
MV–Other	- (-)	11(4)	27(10)	30(11)	212(76)	280(100)
						328

Singles

	Fatal	Incap	Noninc	Pos	PDO	Total
SV–Truck	6(2)	27(7)	40(10)	37(10)	278(72)	388(100)
MV–Truck	5(1)	18(2)	40(4)	43(5)	847(89)	953(100)
MV–Other	4(10)	58(6)	64(7)	109(11)	718(75)	953(100)
						1,341

Doubles

	Fatal	Incap	Noninc	Pos	PDO	Total
SV–Truck	- (-)	2(3)	11(14)	3(4)	61(79)	77(100)
MV–Truck	4(2)	8(4)	10(5)	12(6)	156(82)	190(100)
MV–Other	4(2)	11(6)	28(15)	19(10)	128(67)	190(100)
						267

N(%)

Issue: Does the injury accident rate vary by truck type and roadway type?

Analysis: Table 12 shows the overall injury accident rates (number of accidents resulting in an injury and/or fatality divided by the vehicle-miles traveled) by truck type and roadway type. The results of a two-way analysis of variance reveal no significant difference in injury accident rates among the four roadway types, a finding which is not unexpected. Speeds are generally higher on the rural roads, which should result in more injury accidents. However, there are more multi-vehicle accidents on urban roads, which should also result in more injuries. It is possible that these are counterbalancing each other to produce equivalent injury accident rates across all roadway types.

The analysis of variance also shows that the effect of truck type is not significant. To confirm this, paired t-tests between the total, straight truck, singles, and doubles injury accident rates were made. No significant differences (at the .05 level) were found between any of the truck types.

To test whether the severity of the accidents varies by truck type, Table 13 shows, for three truck types, the distribution of the most severe injury in an accident by three categories: truck occupants in single truck accidents ("SV—Truck"), truck occupants in multi-vehicle collisions ("MV—Truck"), and other vehicle occupant(s) in multi-vehicle accidents ("MV—Other"). The five severity codes are fatal, incapacitating, nonincapacitating, possible, and property damage only (PDO). For each accident, the most severe injury is coded. Thus, this is *not* a distribution of the number of each category of injury; it is a distribution of severity level in accidents. Percents are in parentheses.

For single vehicle truck accidents, the tables show that straight trucks have a higher percentage of injury accidents than either singles or doubles; singles are somewhat higher than doubles. For multi-vehicle collisions, there is no difference between the straight trucks and singles distributions for either involved vehicle. The significant difference of lower PDO accidents for doubles, relative to singles, is reflected in a higher percentage of the nonincapacitating (minor) injury level to the other vehicle occupant(s). The other severity levels do not differ between singles and doubles.

Using a chi-square analysis for combined truck types, only rural-nonfreeways (primaries) were significantly overinvolved in very severe (fatal plus incapacitating) injury accidents. Other roadway types showed no significant differences between severe, less severe, and property damage only accidents. However, small sample sizes, particularly when considering individual truck types by roadway type, may be contributing to the nonsignificant results.

Findings:

- Relative to singles and doubles, straight trucks have a higher percentage of injury producing accidents for single truck collisions; singles are higher than doubles (t-test).
- In multi-vehicle collisions, doubles produce a higher percentage of injury accidents to other vehicle occupant(s). However, the difference is in the nonincapacitating severity level (deductive).

Table 14. Distribution of Property Damage Only and Injury Accidents for Singles and Doubles by Weight Category

Weight Category (kips)	Singles PDO N	Singles PDO %	Singles Injury %	Singles Injury N	Doubles PDO N	Doubles PDO %	Doubles Injury %	Doubles Injury N
20-30	133	82	18	29	28	74	26	10
30-40	63	68	32	29	19	73	27	7
40-50	53	75	25	18	5	45	55	6
50-60	49	74	26	17	3	50	50	3
60-70	47	67	33	23	6	86	14	1
70-80	80	71	29	32	19	70	30	8

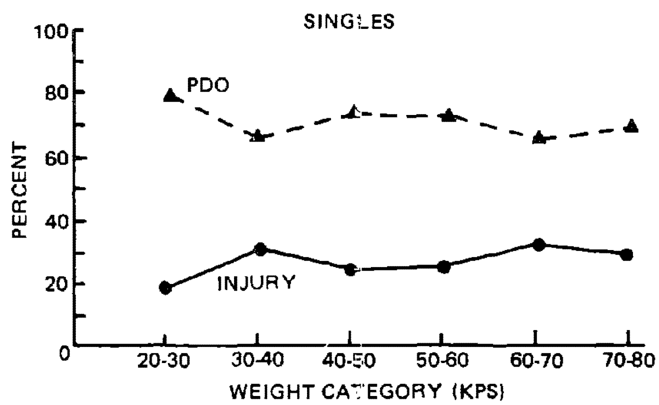

Figure 5. Plot of percentage of property damage only and injury accidents by weight category for singles only.

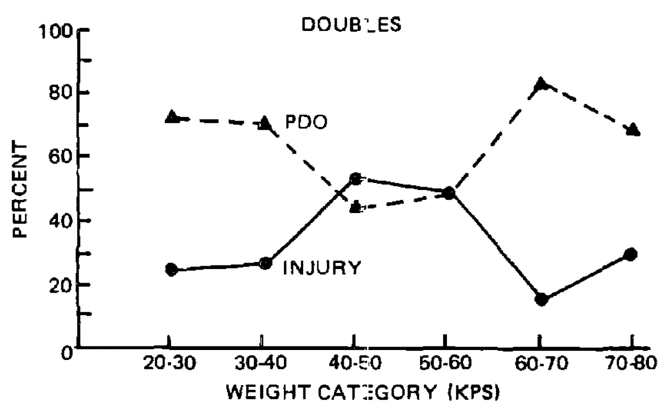

Figure 6. Plot of percentage of property damage only and injury accidents by weight category for doubles only.

Issue: Does the weight of the truck affect accident injury severity?

Analysis: Table 14 presents the distribution by weight category of property damage only (PDO) and injury accidents for single vehicle truck accidents and for truck and other vehicle combined in multi-vehicle accidents for singles and doubles combinations. Figures 5 and 6 illustrate the data in Table 14. As can be seen, for singles there is a slight but not significant trend that heavier trucks are more likely to produce injury accidents. For doubles, the data are very erratic. However, this is due more to the very few data points for each weight category. No definite pattern can be identified with these data.

Findings:

- Heavier singles tend to produce more injury accidents, but this trend is not significant. There were not enough data for doubles to discern a definitive pattern.

Table 15. Distribution of Accidents and Accident Rates* by Overall Length and Truck Type

Overall Length (feet)	Straight Trucks		Singles		Doubles	
	N	Rate	N	Rate	N	Rate
<20	37	1125	-	-	-	-
20-30	102	54	-	-	-	-
30-40	26	20	25	285	-	-
40-50	2	20	76	173	-	-
50-60	-	-	537	83	20	512
60-70	-	-	41	25	128	174

*Accident rates per 100 million vehicle miles.

Table 16. Distribution of Accident and Exposure Data for Singles Combinations with 40- and 45-foot Semi-trailers

Accident Data

	California	Maryland	Michigan	Nevada	Pennsylvania	Texas
40-foot	59 (46)	39 (44)	159 (43)	10 (43)	76 (43)	28 (47)
45-foot	70 (54)	50 (56)	215 (57)	13 (57)	101 (57)	32 (53)
	129 (100)	89 (100)	374 (100)	23 (100)	177 (100)	60 (100)

Exposure (Size and Weight) Data

	California	Maryland	Michigan	Nevada	Pennsylvania	Texas
40-foot	372 (39)	NA	1312 (42)	483 (43)	364 (43)	220 (47)
45-foot	573 (61)	NA	1798 (58)	580 (57)	491 (57)	251 (53)
	945 (100)	NA	3110 (100)	1018 (100)	855 (100)	471 (100)

Issue: Do accident rates vary by overall truck length?

Analysis: Table 15 shows the distribution of truck accidents and accident rates (those for which truck length was known) by three truck types and overall truck length in increments of 10 feet (3 m). The distributions for each truck type are obviously related to the physical characteristics of the truck. For example, tractors (data not shown) are rarely longer than 30 feet (9 m); consequently, there are no accidents involving bobtails longer than 30 feet (9 m). Except for unusual trailer configurations, doubles should have an overall length of at least 50 feet (15 m). Because of this, it is difficult to factor out length alone as it relates to accident frequency. Any analysis of length where all truck types are combined is confounded by the truck type factor. But even within particular truck types, there are differences in cargo area configurations which interact with length; and there is not a sufficient spread of lengths within particular configuration to note any differences. Nonetheless, the accident rates do show some consistency between overall length within a truck type.

For the straight trucks, the shortest truck lengths have the highest accident rates. However, the length of a straight truck is somewhat dependent on the configuration (e.g., the relatively short dump truck vs. the longer furniture hauler); the rate differences probably reflect this dependency.

The most interesting result is found with the singles combinations. It is observed that the accident rate decreases with increasing length. However, there were not enough data points for individual cargo area configurations to determine what influence it or any other truck factor has on this relationship. To address the specific question raised of whether different lengths of semi-trailers for singles configurations affected accident frequency, a comparison was made of 40-foot and 45-foot length trailer singles combinations. Table 16 shows the distributions from the accident and the exposure size and weight files of 40- and 45-foot semi-trailers across the six states, if available. The value in parentheses is the percent within the state. As can be seen, there is remarkable similarity in the distributions. In comparing the two lengths, neither is over(under)involved in accidents relative to its exposure on the highway. A similar comparison by roadway type (not shown) had the same results.

Findings:

- For singles, there is evidence of a decreasing accident rate with increasing length, but this result may be confounded by other truck factors.
- For singles, there is no difference in the accident experience of vehicles with 40-foot versus 45-foot trailers.

Table 17. Comparison of Accident and Exposure Distributions for Different Truck Widths by Truck Type

Truck Type		Overall Width (Inches) LE 93	94-97	GE 98	Total N
Straight Trucks	% Acc.	20	79	1	174
	% Exp.	32	67	<1	5,329
Singles	% Acc.	<1	99	1	698
	% Exp.	2	97	0	17,404
Doubles	% Acc.	0	100	0	149
	% Exp.	<1	100	0	5,091
Straight + Dolly	% Acc.	8	70	22	27
	% Exp.	16	61	22	214

Issue: What are the widths of trucks involved in accidents, and are wider trucks over-involved in accidents?

Analysis: Table 17 shows a distribution of truck accident and exposure data by overall truck cargo width and truck type. The dimensions refer to the width of the cargo-carrying unit or the cargo itself, whichever was wider. The current width limitation is 96 inches (2.44 m), which accounted for the fact that 95 percent of all accident-involved trucks were in the 94-97 inch (2.39-2.46 m) wide group. Only one percent involved trucks wider than 97 inches (2.46 m). It is noteworthy that 22 percent of the straight truck plus dolly combinations had widths greater than 110 inches (2.79 m); all of these were mobile/trailer homes.

Table 17 shows the distribution of widths from the exposure data as well as the accident data. Only the straight truck category has a significant difference between the two distributions with the 94-97 inch (2.39-2.46 m) group showing a higher percentage of accidents relative to their exposure. However, this result most likely reflects a difference in the data bases rather than an over-involvement in accidents. The exposure data base includes straight trucks that belong in a "large pickup" category, trucks that were eliminated from the accident data base during the review process.

The issue of whether wider trucks are over-involved in accidents cannot be conclusively resolved from these data. The majority of wide-load trucks are unusual combinations with unusual accidents, with the majority of these being mobile home straight truck plus dolly combinations. As seen in Table 17, 22 percent of this truck type's accident and exposure data had widths equal to or greater than 110 inches (2.8 m). While this may indicate that wide load mobile home carriers are not over- or underinvolved in accidents, width had no role in many of them. The oversized load data (not shown) indicated that only 0.8 percent of the total accident-involved trucks had wide loads.

Findings:

- The width of the truck does not appear to be a factor in accidents. However, the vast majority of accident-involved trucks were at the maximum legal width limit of 96 inches (2.44 m). For specific truck types, there is not enough variance in width to assess its effect on accident experience.

Table 18. Distribution of Accidents by
Truck Height and Truck Type

Truck Type		Overall Truck/Cargo Height LE 8* Feet	9 Feet	10 Feet	11 Feet	12 Feet	13 Feet	GE 14 Total	
Straight Trucks	N	48	19	28	29	32	12	2	170
	%	28	11	16	17	19	7	1	100
Singles	N	26	41	54	42	178	330	10	681
	%	4	6	8	6	26	48	1	100
Doubles	N	2	19	26	21	12	61	1	142
	%	1	13	18	15	8	43	1	100

*Up to 8 feet 11 inches.

Issue: What is the distribution of truck accidents by truck height?

Analysis: Table 18 is a distribution of 1,091 accidents for which height data were obtained grouped by overall truck/cargo height (in 1-foot [0.3-m] increments) and truck type. The data are presented without further analysis because it cannot be determined if and how truck height influences accident frequency. Within each truck type there are different truck cargo area configurations with varying heights, a fact which confounds the effect of height alone. For any individual cargo area configuration (e.g., fully enclosed van), there is not a sufficient distribution of heights to distinguish any differences.

Considering these analysis constraints, it is observed that when the distribution of accidents by height groups is compared to the distribution of heights in the exposure data base (Volume IV, Table 37), the highest trucks do not appear to be over-involved in accidents.

Findings:

- The height of the truck does not appear to be a factor in accidents as long as the trucks do not attempt to go under low overhead structures.

Table 19. Distribution of Accident and Injury-Accident Rates* by Cab Type for *Singles* Combinations Only

Cab Type	Accident Rate	Injury-Accident Rate
CBE	57	20
COE	54	21

*Accident and injury-accident rates per 100 million vehicle miles.

Table 20. Distribution of Most Severe Injury for Truck and Other Vehicle Occupant(s) by Cab Type for *Singles* Combinations Only

Cab Behind Engine

	Fatal	Incap	Noninc	Pos	PDO	Total
SV–Truck	2(2)*	6(7)	6(7)	5(6)	67(78)	86(100)
MV–Truck	1(0)	2(1)	6(3)	6(3)	193(93)	208(100)
MV–Other	1(0)	13(6)	13(6)	27(13)	154(74)	208(100)

Cab Over Engine

	Fatal	Incap	Noninc	Pos	PDO	Total
SV–Truck	1(1)	12(8)	21(14)	17(12)	96(65)	147(100)
MV–Truck	1(0)	5(2)	16(6)	10(3)	258(84)	290(100)
MV–Other	1(0)	19(7)	22(8)	39(13)	209(72)	290(100)

*N (%)

Issue: Is there a difference in accident rates, injury rates, or injury severity between trucks with cab-over-engines (COE) and cab-behind-engines (CBE)?

Analysis: Several factors can singly or in combination affect the injury severity of an accident. In order to address the issue of how cab type configuration (cab-behind-engine vs. cab-over-engine) affects severity without confounding the results with other variables, injuries for singles combinations only were analyzed. Cab type was not applicable for straight trucks, and there were not enough data for CBE tractors on doubles to use them in the analysis. (Length restrictions virtually dictate that doubles use COE tractors.) Table 19 shows the accident and injury-accident rates for the two cab types for singles combinations only. The values reflect the total number of accidents (injury-accidents) divided by the total vehicle miles traveled (VMT) for the sites where cab and truck type data were collected (49 sites). There is no difference in either of the rates between COE and CBE tractors.

The injury-accident rates are for all accidents resulting in any injury to a truck occupant and/or other vehicle occupant. To check the possibility that injury severity is dependent on whether single or multi-vehicle accidents are being considered, Table 20 was generated. The distribution of the most severe injury in an accident to a truck occupant (SV—Truck, MV—Truck) and other vehicle occupant (MV—Other) is shown. Cab type does not affect injury severity in the other vehicle in multi-vehicle collisions. Only the single truck (SV—Truck) accidents show any difference with cab-over-engine tractors having a higher percentage of injury-producing accidents. However, the difference is in the possible and nonincapacitating severity levels indicating the difference may not be very serious.

Findings:

- There are no differences in accident rates or injury-accident rates for cab-over and cab-behind singles combinations.
- When considering injury combined vs. PDO for single truck accidents, cab-over-engine tractors have a higher injury level than do cab-behind-engine tractors. However, when all severity levels are considered, the differences are in the lesser injury severities.

Table 21. Distribution of Accidents and Accident Rates* by Cargo Area Configuration and Truck Type

Cargo Area Configuration	Truck Type: Straight Trucks		Straight + Full		Straight + Dolly		Singles		Doubles	
	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate
Fully Enclosed	82	38	6	57	2	145	549	101	62	198
Enclosed Lowbed	-	-	-	-	-	-	26	59	6	192
Tank	8	122	23	76	-	-	52	197	30	767
Bulk Commodity	15	152	-	-	-	-	10	114	10	116
Pole/Log	-	-	-	-	5	413	5	19	-	-
Platform	41	52	18	49	10	148	154	100	74	286
Dump	43	221	7	48	2	165	29	330	14	298
Vehicle Carrier	-	-	-	-	9	470	33	188	-	-

*Accident rate per 100 million vehicle miles.

Issue: Do certain trailer configurations have higher accident rates?

Analysis: Table 21 shows the accidents and accident rates for five major truck types by cargo area configuration. For all straight truck configurations the cargo area refers to the straight truck itself; for singles and doubles it refers to the trailer(s). Blank cells indicate rare or nonexistent configurations.

Examination of the rates in Table 21 clearly indicates that trucks with certain cargo area configurations are more involved in accidents than are others. For the singles it was the dump configuration that experienced the highest rate; tankers and vehicle carriers were also high. Doubles had the cargo area configuration with the highest accident rate – the double trailer tanker with double dumps and platforms also high. For the straight truck plus dolly combination, both the vehicle carrier and the pole/log type had high accident rates.

For straight trucks, the dump configuration had the highest accident rate. However, within the straight truck category, it is likely that different configurations are actually different types of trucks. That is, dump trucks, which are designed to carry heavy loads, may be different than, for example, platforms, which would carry lighter payloads. To test this hypothesis, the accident rates of straight trucks by cargo area configuration and weight category were calculated. These are shown below in Table 22.

Table 22. Distribution of Accident Rates of Straight Trucks by
Cargo Area Configuration and Weight Category

Cargo Area	Weight Category (Kips) 10-20	20-30	30-40	40-50
Fully Enclosed	19	41	115	-
Platform	18	54	25	63
Dump	285	145	298	113

As can be seen, fully enclosed straight trucks have a definite problem as their weight increases. Dump trucks have their highest accident rate when they are empty and in the 30-40,000 lb. (13.6-18.1 Mg) weight groups. To some extent it may be that these two configurations are having problems when they are operating outside their "design mode." That is, dumps may be too "stiff" when empty; fully enclosed trucks may become too "cumbersome" when full.

In general, two cargo area configurations experienced high rates across nearly all truck types – the tanker and the dump. An examination of each accident would be necessary to ascertain what factors cause these trucks to have high rates.

Findings:

- Trucks with tanks or dump cargo area configurations generally have accident rates higher than other types.

Table 23. Distribution of Accidents and Accident Rates* by Age Group and Truck Type

Age Group	Truck Type: Straight Trucks N	Straight Trucks Rate	Singles N	Singles Rate	Doubles N	Doubles Rate	All Trucks N	All Trucks Rate
Under 20	22	669	9	**	2	**	37	887
20-29	124	88	353	191	83	505	603	192
30-39	70	85	400	130	70	280	591	122
40-49	40	68	275	108	50	246	407	102
50-59	44	134	187	142	45	320	299	140
60 +	12	122	34	194	6	384	56	196

*Accident rate per 100 million vehicle miles.

**Exposure values not available for calculating rates.

Issue: Is the driver's age related to accident frequency?

Analysis: Table 23 displays both the number of accidents and the accident rate distributions of driver age (in 10-year increments) by truck type. The z-statistic was used to determine if significant differences exist between the proportion of drivers by age group that are in the traffic stream (i.e., exposure data) to the proportion of accident-involved drivers by age group. The data for all trucks combined (last row) clearly indicate that young drivers, especially those under 20 years of age, have significantly higher accident rates than other age groups. This is true for singles and doubles separately and is consistent across individual roadway types (data not shown). For straight trucks the accident rate of 50-59 year old drivers is also significantly higher.

In general, comparing accident rates across the age groups by truck type, the trend of high accident rates for the young age group, low for the middle age group, and moderate for the older age group is fairly consistent. The 40-49 year old group frequently had significantly fewer accidents than their exposure would lead one to expect. This was consistent across truck types and roadway types.

Findings:

- Large truck accidents generally decrease with increasing driver age up to about age 50, and then increase.
- Truck drivers under 20 years of age have the highest accident rate, followed by the 20-29 age group and the over-59 age group.

Table 24. Distribution of Accidents and Accident Rates* by Driver Professional Experience and Truck Type

Professional Experience	Truck Type: Straight Trucks N	Straight Trucks Rate	Singles N	Singles Rate	Doubles N	Doubles Rate	All Trucks N	All Trucks Rate
Under 3 Mo.	10	76	5	57	1	**	18	148
3-5 Mo.	4	24	2	23	1	128	8	68
6-12 Mo.	11	37	17	97	2	256	31	120
1-3 Yrs.	31	63	33	90	16	292	117	146
3-5 Yrs.	28	50	76	87	23	420	139	140
5-10 Yrs.	22	52	141	94	21	192	205	123
>10 Yrs.	48	39	311	58	71	128	478	79

*Accident rate per 100 million vehicle miles.

**Exposure values not available for calculating rates.

Issue: Is the truck driver's professional experience related to accident frequency?

Analysis: The previous issue dealt with driver age, but since truck drivers enter the profession at different ages, it is appropriate to determine how experience as a truck driver is related to accident frequency. Displayed in Table 24 are the accidents and accident rates by truck type and driver's professional experience. The accident rates were calculated in the same way as those for driver age.

When considering all trucks (last column), it is seen that the general trend is that as a driver gains experience he is less prone to have an accident. Using the z-statistic analysis, drivers with 1-3 years' and 5-10 years' professional experience had significantly more accidents than would be expected. A subanalysis of this indicated that it is the singles drivers, particularly on rural freeways, that contributed most to this result. Drivers with greater than 10 years' experience, both overall and within the individual truck types, had significantly fewer accidents than would be expected. However, this trend of decreasing accident rate with increasing driver experience probably does not continue for older-experience groups (i.e., greater than 10 years). The previous analysis showed that drivers older than 59 years of age had a higher accident rate. If the experience levels had been further subdivided beyond 10 years, they may have shown drivers with 20 or more years' experience having a higher rate.

One of the more surprising results is the significantly higher accident rate for doubles drivers with 3-5 years' professional experience. This may reflect the time in their careers when they switch from other combinations to doubles. See the next issue on rig experience (Table 35) for a further elaboration of this possibility.

Findings:

- In general, drivers with greater professional experience have lower accident rates.
- Doubles drivers with 3-5 years' experience have significantly more accidents than would be expected by their exposure.

Table 25. Distribution of Accidents and Accident Rates* by Driver Rig Experience and Truck Type

Rig Experience	Straight Trucks N	Straight Trucks Rate	Singles N	Singles Rate	Doubles N	Doubles Rate	All Trucks N	All Trucks Rate
Under 3 Mo.	13	49	9	57	4	512	29	149
3-5 Mo.	7	30	6	34	2	128	18	194
6-12 Mo.	17	47	27	77	5	320	54	135
1-3 Yrs.	33	63	73	76	20	233	141	132
3-5 Yrs.	30	54	88	100	20	284	147	142
5-10 Yrs.	17	32	135	90	23	210	193	114
>10 Yrs.	41	50	280	58	62	130	424	78

*Accident rate per 100 million vehicle miles.

Issue: Is driver experience with the rig related to accident frequency?

Analysis: The issues of driver age and professional driving experience do not alone entirely answer how a driver may have contributed to an accident's occurrence. The driver's experience with the rig (truck type) he was driving at the time of the accident is also important. It is possible that there is some "break-in" time associated with each truck type. Table 25 presents the number of accidents and the calculated accident rate by rig experience and truck type.

The results of this analysis are similar to those for professional experience; accident rates tend to decrease with increasing experience with the particular rig. There was a consistent lower accident rate for all truck types with drivers having greater than 10 years rig experience. This is not surprising since the size and weight data (from which experience exposure was determined) show a high correlation between rig experience and professional experience (Volume IV, Table 49).

However, while professional experience showed the 1-3 year experience group having more accidents, it was the 3-5 year rig experience group, with one exception, that is highest. The exception is doubles drivers who had a higher rate in the less than 3 months experience group. Because this phenomenon does not show up for professional experience and doubles, it is probable that it is strictly rig-related. It may indicate that some training program emphasizing the dynamic differences between doubles and other configurations would be appropriate.

Findings:

- For all trucks combined, drivers with more rig experience had lower accident involvement rates.
- The data showed doubles drivers having a trend of higher initial accident rates. However, this is not significant because of the very few cases on which it is based.

Table 26. Distribution of Exposure Data Only by
Driver Characteristics and Truck Type

Age (%)

		<20 yrs.	20-30 yrs.	30-40 yrs.	40-50 yrs.	50-60 yrs.	60+ yrs.	-	Total
	Straights	1	43	25	18	10	3	-	100
Age	Singles	0	21	35	28	15	2	-	100
	Doubles	0	21	32	26	18	2	-	100
	Straights	4	5	9	15	17	13	37	100
Pro	Singles	1	1	2	8	10	17	61	100
	Doubles	0	1	1	7	7	14	71	100
	Straights	8	7	11	16	17	16	25	100
Rig	Singles	2	2	4	11	10	17	55	100
	Doubles	1	2	2	11	9	14	61	100
		<3 mos.	3-5 mos.	6-12 mos.	1-3 yrs.	3-5 yrs.	5-10 yrs.	10+ yrs.	Total

Driving Experience (%)

Issue: Are the drivers of the different truck types themselves different?

Analysis: To test the hypothesis that the drivers of straight trucks, singles, and doubles vary in their basic characteristics, distributions of age, professional experience, and rig experience from the exposure data *only* were made. These are shown in Table 26. There are no differences in the distributions of singles and doubles drivers.

Findings:

- In general, drivers of straight trucks are younger and less experienced than are drivers of articulated trucks.

Table 27. Distribution of Single Truck Accidents by
Accident Dynamics and Truck Type

Truck Type		Accident Dynamics: Ran Off Road*	Hit Ped/ Animal	Hit Obj. in Road	Hit Overhead	Jack-knife	Roll-over	Other	Total
Straight Trucks	N	22	-	1	2	-	21	2	48
	%	46	-	2	4	-	44	4	100
Singles	N	191	33	21	21	40	59	23	388
	%	49	9	5	5	10	15	6	100
Doubles	N	42	4	1	-	5	19	6	77
	%	55	5	1	-	6	25	8	100
Straight + Dolly	N	4	-	-	1	2	7	2	16
	%	25	-	-	6	13	44	13	100

*Includes Ran Off Road: Hit Fixed Object, and Ran Off Road: No Collision.

Issue: Do the accident dynamics for single vehicle truck accidents vary by truck type?

Analysis: Table 27 shows the distribution of accident dynamics for single vehicle truck accidents for four truck types. It must be realized, in reading this table, that the percentages reflect the relative distributions of codes within a truck type. For example, in comparing singles and doubles, the most notable difference is the rollover category. Doubles had 25 percent of their accidents classified as rollovers compared to only 15 percent for singles. Closer examination provides a reason for this difference. Singles had numerous accidents which involved hitting an object in the roadway or an overhead structure. Most of these accidents occurred in states where doubles are not allowed. The lower percentage of rollovers for singles in this distribution may simply be due to a wider distribution of accident dynamics for singles and not to some inherent dynamics of doubles. Table 28 corroborates this.

In Table 28, the most frequent accident dynamics for singles and doubles in California and Nevada only are shown. There are no significant differences between the two configurations.

Table 28. Accident Dynamics for Singles and Doubles
Single Truck Accidents in California and Nevada

Truck Type		Accident Dynamics: Ran Off Road	Hit Ped/ Animal	Jack-knife	Roll-over	Other	Total
Singles	N	28	2	3	18	16	67
	%	42	3	4	27	23	100
Doubles	N	29	3	5	16	9	62
	%	47	5	8	26	15	100

Table 27 also shows the accident dynamics distribution for straight truck plus dolly trailer configurations. Forty-four (44) percent of their accidents were rollovers. All of these were mobile/ trailer homes. The actual dynamics were blown over/apart by strong or gusty winds, rather than the rolled-over trailer typically associated with articulated combinations.

Findings:

- There were no differences in the distributions of accident dynamics between singles and doubles.
- For both singles and doubles, ran-off-roadway and rollover are the most common types of single vehicle accidents.

Table 29. Distribution of Multi-vehicle Accidents by Accident Dynamics and Truck Type

Truck Type		Angle	Side-Swipe	Rearend (T-O)*	Rearend (O-T)**	Hit Veh. Shoulder	Cargo Loss	Other	Total
		Accident Dynamics							
Straight Trucks	N	32	70	72	54	4	20	28	280
	%	11	25	26	19	1	7	10	100
Singles	N	85	344	266	152	17	29	60	953
	%	9	36	28	16	2	3	6	100
Doubles	N	13	49	49	56	1	7	15	190
	%	7	26	26	29	1	4	8	100
Straight + Trailer	N	4	13	8	23	2	9	8	67
	%	6	19	12	34	3	13	12	100

*Truck struck other vehicle.
**Other Vehicle struck truck.

Issue: Do the accident dynamics for multi-vehicle truck accidents vary by truck type?

Analysis: Table 29 shows the distribution of accident dynamics for multi-vehicle truck accidents by truck type. As with Table 27, only those dynamics which account for one percent of the total are listed separately. Also as with the previous table, the six state/two state problem again is apparent. Table 30 presents the most frequent multi-vehicle accident dynamics for California and Nevada only.

Table 30. Distribution of Multi-vehicle Accidents by Accident Dynamics and Truck Type (California and Nevada Only)

Truck Type		Accident Dynamics: Angle	Side-swipe	Rearend (T-O)*	Rearend (O-T)*	Cargo Loss	Other	Total
Straight Truck	N	6	29	23	22	8	13	101
	%	6	29	23	22	8	13	100
Singles	N	11	59	58	49	5	20	202
	%	5	29	29	24	2	10	100
Doubles	N	11	34	41	52	2	14	154
	%	7	22	27	34	1	9	100

*Truck struck other vehicle
**Other vehicle struck truck

In general there are no major differences in the distributions of accident dynamics except for the rearend categories. In comparing doubles with singles it is observed that doubles were hit from the rear more frequently (34% versus 24%). A roadway type look at these data showed that this difference occurred on rural-freeways. However, the sites had both singles and doubles traveling through them. It is unknown why this result exists.

Findings:

- Compared to singles, doubles have a larger percentage of accidents where the truck is hit from the rear.
- Straight trucks alone and pulling a trailer had a higher percentage of cargo loss accidents.
- Straight trucks pulling a trailer rearended other vehicles less frequently, but were themselves rearended more frequently than the other truck types.

Table 31. Distribution of Accidents by Vertical Slope Measurement and Truck Type

Truck Type		Vertical Slope Measurement Down -6,7%	Down -4,5%	Down -2,3%	Level	Up +2,3%	Up +4,5%	Up +6,7%	Total
Straight Trucks	N	3	8	30	234	30	7	5	317
	%	1	3	14	74	9	2	2	100
	(%)	(7	20	73)	-	(71	17	12)	-
Singles	N	27	49	152	851	151	44	20	1294
	%	2	4	12	66	12	3	2	100
	(%)	(12	21	67)	-	(70	20	9)	-
Doubles	N	20	23	16	163	19	11	10	262
	%	8	9	6	62	7	4	4	100
	(%)	(34	39	27)	-	(48	28	25)	-

Issue: Is the distribution of accidents on vertical grades affected by truck type and does the degree of the slope affect the distribution?

Analysis: Table 31 provides the distribution of accidents by slope measurement of the roadway at the accident site and truck type. Of particular importance is the relative distribution on up- and downgrades for the various truck types.

Across the slope measurements, the different distributions of the within up- or downgrade percentages (in parentheses) between singles and doubles (e.g., 70, 20, and 9 percent for slight to steep upgrades for singles, and 48, 28, and 25 percent for doubles) is not meaningful. This only reflects the fact that doubles do not run in the flatter states (i.e., with the slighter slopes) in the data base. When the upgrade/downgrade distributions are run on a per state basis (not shown), there were no differences between truck types.

However, within a truck type relative problems with up- or downgrades became apparent. Doubles had a higher percentage of downgrade than upgrade accidents (23% vs. 15%). In addition, the problem appears to be on the steeper and moderate downgrades (34% vs. 25% for the steep, and 39% vs. 28% for the moderate). Singles showed nearly equal distributions between and within up- and downgrades. The cause of this situation is addressed further under grade and weight issues.

Although not shown, straight truck plus dolly configurations had 28 percent of their accidents on downgrades, and virtually no problems on upgrades (8%). It is possible, and in fact likely, that this is a site specific situation. Most of the straight plus dolly configurations in the data base are mobile homes. These would be traveling in only one direction through a particular site. If that site had a downgrade in the travel direction, there would be no corresponding upgrade accidents.

Findings:

- Doubles appear to have more problems on downgrades than upgrades.

Table 32. Distribution of Accidents by Truck Defects and Truck Type

Defect	Straight Trucks N	Straight Trucks %	Straight Trucks (%)*	Singles N	Singles %	Singles (%)*	Doubles N	Doubles %	Doubles (%)*	Total N	Total %	Total (%)*
None Apparent	282	87	-	1202	91	-	217	82	-	1701	89	-
Steering System	-	-	-	7	1	6	-	-	-	7	0	3
Trailer Coupling	-	-	-	-	-	-	8	3	17	8	0	4
5th Wheel Hitch	-	-	-	7	1	6	2	1	4	9	0	4
Engine	-	-	-	3	0	2	-	-	-	3	0	1
Brakes: Tractor, Truck	16	5	37	29	2	24	9	3	19	54	3	26
Brakes: Trailer	-	-	-	15	1	12	14	5	30	29	2	14
Wheels	9	3	21	7	1	6	2	1	4	18	1	9
Tires	8	2	19	30	2	25	5	2	11	43	2	20
Electrical, lights	-	-	-	5	0	4	1	0	2	6	0	3
Structural Failure	1	0	2	5	0	4	2	1	4	8	0	4
Cargo Securer	2	1	5	3	0	2	1	0	2	6	0	3
Other	7	2	16	10	1	8	3	1	6	20	1	9

*Excluding "None Apparent."

Issue: Were there truck vehicle defects which contributed to the accidents?

Analysis: Table 32 presents the distribution of accidents where it could be determined if there was a vehicle defect by truck type. For all trucks combined, 11 percent of the accident-involved trucks had some type of defect. This is higher than the six percent reported by BMCS (1977). For those vehicles having defects (i.e., excluding the "none apparent" category), the most frequent defects cited were truck/tractor brakes (24%) and trailer brakes (14%). Defective tires were noted in 19 percent and defective wheels in 9 percent of the accidents. The latter defect was the most prominent for straight plus dolly configuration (not shown) and was invariably related to the dolly wheels. For doubles, the most prominent defect was the brakes on the trailer (30%), followed by brakes on the tractor (19%) and the trailer coupling (17%).

Two major differences are seen between singles and doubles: trailer-coupling and trailer brakes, with doubles having higher percentages of accidents. The doubles trailer coupling accidents were all failure of the connection between the semi- and full trailers. This was usually precipitated by the second trailer starting to sway and putting too much stress on the coupling. Singles, without such a coupling, do not have this potential problem. In the majority of the brake failure accidents for doubles, it was the second (full) trailer, rather than the semi-trailer, brakes that failed.

Findings:

- Eleven percent (11%) of all trucks involved in accidents had vehicle defects of one kind or another. These defects usually precipitated the accident.
- Defective brakes, either on the tractor or trailer, accounted for the largest percentage of the defects (38%).

Table 33. Distribution of Accident Rates by State and Roadway Type

State	Roadway Type				
	Rural Freeway	Rural Nonfwy	Urban Freeway	Urban Nonfwy	Overall
California	169	289	198	161	211
Maryland	51	168	383	356	278
Michigan	81	146	395	571	285
Nevada	42	102	174	64	95
Pennsylvania	100	81	313	141	154
Texas	32	44	66	172	70
Overall	91	150	237	293	

Issue: Do accident rates vary by roadway type and state?

Analysis: Table 33 presents the truck accident rates by state and roadway type for all six quarters of the study. The analysis of variance calculated for this distribution showed significant differences between roadway types, between states, and in the interaction between the two. The differences between roadway types were addressed earlier.

The significant differences between states reflect the site selection process to some extent but also different reporting thresholds. Because only one or two sites of a particular category were chosen in some states, the accident rate of these site(s) can (and did) significantly affect the analysis of variance. However, each of the states has slightly different reporting thresholds as well. California, for example, concentrates on injury and fatal accidents, while some other states attempt to respond to all property damage only as well as injury accidents. Using the total traffic stream and nontruck data from the 29 sites in California and Michigan, significant differences in the average site accident rates were found. The mean site rate (total traffic stream) in California was 153, while the rate for Michigan was 553. The difference is highly likely due to California's more severe reporting threshold. It is for these reasons—that individual sites varied considerably across states, and the reporting requirement differences, plus the fact that different truck types run in the different states—that some of the analyses (e.g., comparing singles and doubles) were made only with data from compatible states.

Findings:

- Significant differences between states and in the state-roadway type interaction are attributable to the nature of the data base, the site selection process, and the state reporting requirements.

Table 34. Distribution of Accidents by Vertical Slope Measurement and Roadway Type

Roadway Type		Down -6,7%	Down -4,5%	Down -2,3%	Level	Up +2,3%	Up +4,5%	Up +6,7%
		Slope Measurement						
Rural Freeway	N	43	52	93	388	95	38	36
	*%	6	8	12	51	13	5	5
Rural Nonfreeway	N	11	14	13	111	12	8	6
	%	6	8	7	63	7	5	3
Urban Freeway	N	-	18	103	675	104	22	1
	%	-	2	11	73	11	2	0
Urban Nonfreeway	N	-	-	3	185	7	-	-
	%	-	-	2	95	4	-	-
Total	N	54	94	212	1359	218	68	43
	%	3	5	10	66	11	3	2

*Row percentages

Issue: What is the distribution of truck accidents on vertical grades and does the slope of the grade affect accident frequency?

Analysis: Table 34 provides the distribution of accidents by seven categories of vertical slope measurement for four roadway types. For all roadway types combined, 34 percent of the accidents occurred on some portion of a vertical section (slope measurement equal to or greater than ±2 percent. Level roadway was defined as between a slope of ± 1½ percent). The data also show that *overall* there was an approximately equal distribution of downgrade (18%) and upgrade (16%) truck accidents. However, this distribution varied considerably across roadway types.

For the rural-nonfreeways, downgrades had a greater percentage of accidents (22%) than upgrades (15%). This difference was not reflected elsewhere. The within slope distributions also varied. For upgrades nearly half (12 of 26 accidents) occurred on slight upgrades (+2,3 percent); 23 percent occurred on steep upgrades. On downgrades, the distributions across slight to steep slope measurements were 34 percent, 37 percent, and 30 percent.

For rural freeways, the slope distributions also reflect higher accident percentages on steeper downgrades than for the corresponding upgrade. From slight to steep slopes the upgrade percentages were 56 percent, 22 percent, and 21 percent; on downgrades they were 47 percent, 31 percent, and 22 percent. Although not significant, it does indicate there may be more of a problem on downgrades. Of some concern is whether a specific site(s) with a particularly long and/or steep grade affects these overall results. To test this, Site 114, the "Grapevine" pass in California, was eliminated and the table rerun. No noticeable differences in the percentage distributions, particularly the up- and downgrade percentages, were seen.

Any findings relative to the differences in distributions across roadway types must take into consideration the nature of the sites. While not chosen with any regard to frequency of vertical curves, many of the sites were predominantly on flat terrain. This is true because of the nature of the terrain in general, particularly in Nevada, Michigan, and Texas. Therefore, assuming that the mileage of level roads exceeded that for nonlevel roads, it appears that there are more truck accidents on grades (both up and down). This finding seems plausible, given that trucks on grades cause more perturbations in the traffic flow. (Volume II of this final report addresses this issue more carefully.) To accurately address the issue of whether or not truck accidents occur more frequently on vertical curves would require knowing the mileage of level and vertical sections in order to calculate the relative exposure. Such data were not available for this analysis.

Findings:

- Trucks were more likely to have accidents on vertical grades than on level terrain.
- The ratio of truck accidents on upgrades to downgrades was about one except on rural nonfreeways, where downgrades had a higher percentage (25% vs. 15%).
- Steep downgrades on rural roadways, particularly nonfreeways, appeared to have greater accident potential than the lesser slopes, and the corresponding upgrades.

Table 35. Distribution of Accidents by Horizontal Curvature and Roadway Type

	Roadway Type							
	Rural Freeway		Rural Nonfwy		Urban Freeway		Urban Nonfwy	
Curvature	N	%	N	%	N	%	N	%
Left	64	8	23	13	81	9	10	5
Tangent/No Curve	593	77	116	66	764	81	184	93
Right	117	15	36	21	95	10	3	2

Issue: What is the distribution of truck accidents by horizontal curvature?

Analysis: Shown in Table 35 is a distribution of truck accidents classified by the degrees of horizontal curvature and four roadway types. For all site types combined (data not shown), 80 percent of all the accidents occurred on straight sections of roadway. However, since the mileage of curved or straight sections is not known, it is not possible to determine whether the 20 percent for curved sections is an over- or underinvolvement.

The data show that 12 percent of the truck accidents occurred on right curves, while only 8 percent occurred on left curves. There is no particular reason why trucks would have more problems on a right curve. The difference is attributable to the incidence of truck accidents on freeway off- and on-ramps which are usually righthand curves. The next *Issue* (Table 36) elaborates on this phenomenon.

Findings: No significant findings.

Table 36. Distribution of Accidents by Location on Rural and Urban Freeway Sites

		Location				
		Not Interchange Related	Mainline Lane Drop	Interchange Related	On Ramp	Off Ramp
Rural	N	708	-	39	9	33
	%	90	-	5	1	4
Urban	N	733	11	112	31	59
	%	77	1	12	3	6
Total	N	1441	11	151	40	92
	%	83	1	9	2	5

Issue: On the controlled access sites (freeways), where did the accidents occur?

Analysis: Table 36 provides the distribution of truck accidents occurring on rural and urban freeway sites classified by their proximity to an interchange, a mainline lane drop, on an off-ramp or on-ramp, or none of the above (not interchange-related). It should be recalled that there were 20 rural-freeway sites with a combined length of 501 miles (806 km) and 29 urban-freeway sites with 125.8 miles (202.4 km).

Comparing the rural and urban distributions, significantly more truck accidents are urban interchange-related (12%) than rural interchange-related (5%). (Interchange-related means the accident occurred *not* on a ramp itself, but was caused by some vehicle making a maneuver relative to the interchange/ramp.) When the on- and off-ramp accident percentages are also considered, the values are 21 percent for urban and 10 percent for rural. This result only reflects the higher frequency of, and therefore exposure to, interchanges in urban areas.

The data also show that trucks have more accidents on off-ramps than on-ramps, regardless of urban/rural location. This result is consistent with other research studies (e.g., Cirillo, 1968), which showed that the accident rate for off-ramps in most cases is higher than the rate for on-ramps. Although not shown, a large percentage of the ramp accidents were rollovers. The higher off-ramp frequency probably reflects a faster entry speed onto off-ramps from the freeway than onto on-ramps from the interchanging roadway.

Findings:

- Trucks have more accidents at off-ramps than on-ramps.

Table 37. Distribution of Accidents by Location on Rural and Urban Nonfreeway Sites

		Location			
		Not Intersection Related	Mainline Lane Drop	Intersection Related	Intersection Accident
Rural	N	137	-	23	18
	%	77	-	13	10
Urban	N	69	1	58	70
	%	35	1	29	35
Total	N	206	1	81	88
	%	55	0	22	23

Issue: On the nonfreeway sites, where did the accidents occur?

Analysis: Table 37 shows the distibution of the truck accidents occurring on rural and urban nonfreeway sites classified by their proximity to an intersection (either in the intersection, or intersection-related), a mainline lane drop, or none of the above (not intersection-related).

In comparing the distributions, there are significant differences between the rural and urban settings. At the urban sites, a majority of the truck accidents occur at, or are related to, an intersection (65% vs. 23% for rural sites). This result merely reflects more intersections per mile in urban areas than in rural areas.

Findings:

- In urban areas, 65 percent of the truck accidents on nonfreeways occur in, or are related to, intersections.
- In rural areas, 23 percent of the truck accidents on nonfreeways occur in, or are related to, intersections.

Table 38. Distributions of Single and Multi-vehicle Truck Accidents by Roadway Type

Roadway Type		Accident Grouping					
		Single Truck	Multiple—Other Hit Truck	Multiple—Truck Hit Other	Multiple—Truck Hit Truck	Multiple—Other	Multiple—Indeterminable
Rural Freeway	N	324	240	109	83	33	-
	*%	41	30	14	11	4	-
Rural Nonfreeway	N	64	53	41	14	6	-
	%	36	30	23	8	3	-
Urban Freeway	N	162	250	425	57	40	12
	%	17	26	45	6	4	1
Urban Nonfreeway	N	14	64	103	8	6	4
	%	7	32	52	4	3	2
Total	N	564	607	678	162	85	16
	%	27	29	32	8	4	1

*Row percentages

Issue: What is the distribution of collision type of single truck and truck-vehicle accidents by roadway type?

Analysis: Table 38 provides a distribution of accidents classified as to whether they were single vehicle or multi-vehicle truck accidents, grouped by four roadway types. An example of the "multiple other"category is where the truck's cargo fell off and caused an accident. A "multiple-indeterminable" accident is one where it could not be determined who struck whom.

The data show that, in aggregate, 27 percent of the truck accidents are single trucks; there was no collision with another vehicle. This value compares favorably with the 25 percent reported by the Bureau of Motor Carrier Safety (BMCS, 1977). The percentage of single truck accidents is higher for rural roads compared to urban roads. Forty percent (40%) of the accidents occurring on rural roads were single trucks.

For multi-vehicle truck accidents, trucks hit vehicles more often than they are hit. On the average, other vehicles hit trucks 29 percent of the time, and this did not vary significantly by roadway type. Trucks hit other vehicles (nontrucks) 32 percent of the time, but this value varied between the rural and the urban sites. In urban areas, trucks hit other vehicles on an average of 46 percent of the time; in rural areas, trucks hit other vehicles in only 16 percent of the accidents.

Findings:

- The percentage of single truck accidents varies between rural and urban highways. On rural highways, 40 percent of the truck accidents involved a truck only; on urban highways only 15 percent were noncollision accidents.
- On the average, trucks hit nontrucks 32 percent of the time; they were hit 29 percent of the time.
- Trucks hit other vehicles in 46 percent of the urban area accidents; but only in 16 percent of the accidents on rural roadways.

Table 39. Distribution of Single Truck Accidents by Accident Dynamics and Roadway Type

Roadway Type		Accident Dynamics						
		Ran Off Road*	Hit Ped/ Animal	Hit Obj. in Road	Hit Overhd	Jack-knife	Roll-over	Other
Rural Freeway	N	156	25	17	-	31	72	23
	%***	48	8	5	-	10	22	7
Rural Nonfwy	N	29	10	-	-	4	19	2
	%	45	16	-	-	6	30	3
Urban Freeway	N	82	3	9	24**	12	21	11
	%	51	2	6	15	7	13	7
Urban Nonfwy	N	9	1	-	-	2	2	-
	%	64	7	-	-	14	14	-
Total	N	276	39	26	24	49	114	36
	%	49	7	5	4	9	20	6

*Includes Ran Off Road: Hit Fixed Object, and Ran Off Road: No Collision.
**Most of these were at the Baltimore Harbor Tunnel which has a height restriction.
***Row percentages.

Issue: What are the accident dynamics for single vehicle truck accidents by roadway type?

Analysis: Table 39 provides a breakdown of the accident dynamics of 564 single truck accidents by roadway type. The data show that the most frequent dynamics are: ran off roadway (49%) (subcategorized by hit fixed object 36 percent; no collision 13 percent [not shown]), rollover (20%), and jackknife (9%).

A comparison of the accident dynamics frequencies for the urban and rural sites show differences related to the nature of the road types. For example, there is a higher incidence of trucks hitting animals in rural areas, a higher incidence of trucks hitting fixed objects in urban areas, and a higher incidence of rollovers in rural areas. The 24 accidents where an overhead structure was hit were almost entirely located at a tunnel which had a height restriction.

Finding:

- A majority of the single vehicle truck accidents consists of hitting fixed objects (36%), rollover (20%), ran-off-roadway without hitting object (13%), and jackknifing (9%).

Table 40. Distribution of Multi-vehicle Truck Accidents by Accident Dynamics and Roadway Type

Roadway Type		Accident Dynamics: Angle	Side-swipe	Rearend (T.O.)*	Rearend (O.T.)**	Hit Veh. Shoulder	Cargo Loss	Other
Rural Freeway	N	30	116	113	142	20	25	19
	%	6	25	24	31	4	5	4
Rural Nonfwy	N	24	15	28	15	1	5	26
	%	21	13	25	13	1	4	23
Urban Freeway	N	52	311	230	121	4	31	35
	%	7	40	29	15	1	4	4
Urban Nonfwy	N	57	53	43	17	-	5	10
	%	31	29	23	9	-	2	5
Total	N	163	495	414	295	25	66	90
	%	11	32	27	19	2	4	6

*Truck struck other vehicle.

**Other vehicle struck truck.

Issue: What are the accident dynamics for multi-vehicle truck accidents by roadway type?

Analysis: Table 40 provides the distribution of accident dynamics for multi-vehicle truck accidents by roadway type. Only those collision types which accounted for one percent or more of the total are listed. The "other" category combines 15 collision dynamics which collectively account for only six percent of all accidents.

The table shows that, overall, three collision types accounted for 78 percent of the accidents: sideswipe—same direction (32%); rearend—truck into other (27%); and rearend—other into truck (19%). However, the relative frequencies vary considerably by roadway type. This merely reflects the geometric and traffic characteristics of the roadway classifications. For example, one would not expect many angular collisions on freeways, and this is supported by the data. Also, there is a higher incidence of "sideswipe—same direction" accidents on the urban roadways compared to rural roadways which reflects heavier traffic densities on urban roads which induce a higher probability of sideswipe accident experience.

Findings:

- The most frequent accident dynamics for multiple-vehicle truck accidents are sideswipe—same direction (32%), which occur most frequently in urban areas; rearend—truck into other vehicles (27%), evenly distributed across roadways; and rearend—other vehicle into truck (19%), much higher on rural-freeways.

Table 41. Distribution of Accidents by Collision Type and Slope Measurement

Slope Measurement		Collision Type: Single Truck N	%*	Multiple—Other Hit Truck N	%	Multiple Truck Hit Other N	%	Multiple—Truck Hit Truck N	%	Multiple—Other N	%	Multiple—Indeterminable N	%
Down	N	26	5	17	3	2	0	8	5	1	1	-	-
-6,7%	**%	48		31		4		15		2		-	
Down	N	39	7	32	5	7	1	13	8	2	3	1	7
-4,5%	%	41		34		7		14		2		1	
Down	N	74	13	48	8	64	10	19	12	6	7	1	7
-2,3%	%	35		23		30		9		3		0	
Level	N	333	61	358	61	518	78	77	50	61	76	12	80
	%	25		26		38		6		4		1	
Up	N	61	11	73	12	53	8	23	15	7	9	1	7
+2,3%	%	28		33		24		11		3		0	
Up	N	12	2	27	5	17	3	9	6	3	4	-	-
+4,5%	%	18		40		25		13		4		-	
Up	N	5	1	31	5	2	0	5	3	-	-	-	-
+6,7%	%	12		72		5		12		-		-	

*Column percentages
**Row percentages

Issue: What are the collision types by slope measurement?

Analysis: Table 41 provides a distribution of who struck whom on level terrain and various degrees of vertical slope measurement. Of particular interest are the first four rows which show distributions for single vehicle truck, other vehicle hitting truck, and truck hitting other vehicle/other truck accidents.

Single truck accidents occur more frequently on downgrades (25%) than on upgrades (14%). This result reflects the fairly common occurrence in the accident file of "runaway" large trucks on moderate and steep downgrades. Within the grades it is seen that as the slope of the downgrade increases, the greater the percentage of single truck accidents; just the reverse is true for single truck upgrade accidents.

For the "other vehicle hit truck" situation, accidents occurred more frequently on upgrades (22%) than downgrades (16%). This is attributable to slower trucks being rearended on upgrades. In fact, 72 percent of the accidents on steep upgrades (+6,7 percent) were "other vehicle hit truck." The majority of the 61 percent that occurred on level terrain reflect the nature of the study sites: primary congested urban roadways.

For "truck hit other vehicle" or "truck hit truck" accidents, a larger percentage occurred on level terrain (73%) compared to the other collision types (61% each). On level terrain this frequently occurred in urban areas when the truck did not stop quickly enough in backed-up traffic conditions. This is especially true for "truck struck other (nontruck) vehicle." Only one percent of this collision type involved the truck striking a nontruck on a moderate or steep downgrade. However, for "truck struck another truck," grades do enter into the picture. "Truck hit truck" occurred on level terrain only 50 percent of the time; with 23 percent of the accidents occurring on moderate to steep up- and downgrades.

Findings:

- Single vehicle truck accidents are more likely to occur on downgrades than on upgrades. This phenomenon increases as the slope increases.
- Trucks are more likely to be hit on the upgrades than downgrades.
- The majority of "truck hit other vehicle" accidents occur on level terrain and with equal probability on the upgrades and downgrades.

IV. PRESENTATION OF FINDINGS: SUPPLEMENTAL DATA

In addition to the key issues addressed in the previous chapter, numerous other data were also collected during the course of the accident investigation study. Without any summary discussion, the data are presented in the "Issues—Analysis—Findings" format of Chapter III.

The general sequence of the tables and discussions is as follows:

- When: time and environmental data
- Who: driver data
- What: cargo data
- How: accident and collision data, culpability.

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Table 42. Distribution of Accidents by Month and Season of the Year

Month	%	N	ΣN	%	Season
		Accident Frequency			
December	11	154*			
January	10	151	431	30	Winter
February	9	126			
March	10	143			
April	7	100	352	24	Spring
May	7	109			
June	7	107			
July	8	120*	361	24	Summer
August	9	134*			
September	8	114*			
October	7	105*	315	22	Fall
November	7	96*			

*Average of same month in two consecutive years.

Issue: What was the distribution of truck accidents by month and season of the year?

Analysis: Table 42 is a breakdown of the truck accidents by month. Percent distributions are shown for both months and the four seasons of the year. Because the data were collected over a 1½ year period, months with two values were averaged.

December, January, and March experienced the highest number of accidents during the year. Although the percentages were slightly different, the BMCS (1977) accident data (not shown) did show these three months to be the highest also. On a seasonal basis, winter experienced the highest number of accidents; fall the lowest.

Findings:

- The months of December, January, and March experienced the highest number of truck accidents.
- The three winter months—December, January, and February—experienced 30 percent of all truck accidents over the year.

Table 43. Distribution of Accidents by
Day of Week and Roadway Type

Roadway Type		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		Day of Week						
Rural Freeway	N	58	137	130	152	112	132	68
	*%	7	17	16	19	14	17	9
Rural Nonfreeway	N	8	31	35	27	36	25	16
	%	4	17	20	15	20	14	9
Urban Nonfreeway	N	37	162	173	166	169	183	56
	%	4	17	18	18	18	19	6
Urban Nonfreeway	N	10	34	32	40	41	26	16
	%	5	17	16	20	21	13	8
Total	N	113	364	370	385	358	366	156
	%	5	17	18	18	17	17	7

*Row percentages

Issue: What was the distribution of truck accidents by day-of-week?

Analysis: Table 43 provides a distribution of the truck accidents by day-of-week for four roadway types and all sites combined. Overall, the distributions clearly show each weekday having a nearly equal share of accidents. Weekend days have significantly fewer accidents than weekdays. The daily distributions shown are nearly identical to those reported in BMCS (1977).

There is a slight difference in the day-of-week distributions between rural and urban sites. Sixteen percent of the truck accidents on rural sites were on Saturday or Sunday; urban sites had only 10 percent on the weekend.

Findings:

- There is an equal distribution of truck accidents for the five weekdays.
- The frequency of truck accidents for each weekday is greater than for Saturday or Sunday.
- Rural roadways have a higher frequency of weekend accidents than urban roadways.

Table 44. Distribution of Accidents by Time of Day and Roadway Type

Time of Day		Rural Freeway N	Rural Freeway %*	Rural Nonfreeway N	Rural Nonfreeway %	Urban Freeway N	Urban Freeway %	Urban Nonfreeway N	Urban Nonfreeway %
0000-0300	N	83	11	15	8	39	4	6	3
	**%	58		10		27		4	
0300-0600	N	120	15	29	16	39	4	7	4
	%	62		15		20		4	
0600-0900	N	103	13	23	13	131	14	23	12
	%	37		8		47		8	
0900-1200	N	111	14	28	16	198	21	42	21
	%	29		7		52		11	
1200-1500	N	99	13	29	16	177	19	49	25
	%	28		8		50		14	
1500-1800	N	98	12	25	14	214	23	44	22
	%	26		7		56		12	
1800-2100	N	71	9	21	12	90	10	19	10
	%	35		10		45		9	
2100-2400	N	104	13	8	4	58	6	9	5
	%	58		4		32		5	

*Column percentages read down
**Row percentages read across

Issue: What was the distribution of truck accidents by time of day?

Analysis: Table 44 shows the distribution of truck accidents by time-of-day (in increments of 3 hours) for four roadway types. In examining the distributions, it is observed that rural freeways and nonfreeways have more evenly spread distributions than the corresponding urban facilities. For the rural roadway types combined, 37 percent of the truck accidents occurred between the hours of 2100-0600; it was only 14 percent for urban roadways. This difference obviously reflects the differences in the amount, type, and hourly distribution of truck traffic between urban and rural roads.

For comparison purposes, Table 45 shows the time-of-day percentage distribution for this data base, the Bureau of Motor Carrier Safety accident data base (1977), and data from 17 states for all accidents reported by the National Safety Council (1977). This table shows that hourly distributions for the truck accident data bases are practically equal; but they both differ slightly from the all-vehicles data from NSC. The main difference is a higher percentage of accidents during the night (2100-0600) for trucks than for all vehicles.

Table 45. Comparison of the Hourly Distribution of Accidents from Three Data Bases

Hour-of-Day	2,112 Truck Accidents (BTI)	BMCS Truck Accidents	17 State — All Vehicle Accidents (NSC)
0000 - 0300	6.8	9.0	8.2
0300 - 0600	9.2	9.8	2.9
0600 - 0900	13.3	13.2	9.8
0900 - 1200	17.9	16.1	12.6
1200 - 1500	16.7	16.6	17.5
1500 - 1800	18.0	17.0	24.0
1800 - 2100	9.5	9.4	14.1
2100 - 2400	8.5	8.2	10.9

Findings:

- The hourly distribution of truck accidents is different for urban and rural roads, with the latter experiencing a much higher percentage during nighttime hours.
- The hourly distribution of accidents involving large trucks tends to be more evenly spread over the entire day than for all vehicles.

Table 46. Distribution of Accidents by Lighting Condition and Roadway Type

Roadway Type		Lighting Condition: Daylight	Dawn/ Dusk	Dark, Ambient	Dark, Street Lights	Dark, No Lights
Rural Freeway	N	375	56	10	13	335
	%	48	7	1	2	42
Rural Nonfreeway	N	104	14	-	1	59
	%	58	8	-	1	33
Urban Freeway	N	685	45	16	142	58
	%	72	5	2	15	6
Urban Nonfreeway	N	161	6	2	21	9
	%	81	3	1	11	5
Total	N	1325	121	28	177	461
	%	63	6	1	8	22

Issue: What are the lighting conditions during the accident?

Analysis: Table 46 provides a breakdown of truck accidents by lighting conditions for four roadway types and all types combined. For all sites, 63 percent of the accidents occurred during daylight conditions; this is nearly identical to the distribution of accidents between 0600-1800 hours (Table 44). However, as with the time-of-day issue, there are differences between rural and urban roadways. At the rural sites, 41 percent of the accidents occurred when it was dark and there was no street lighting. In the urban areas, only 6 percent of the accidents occurred under the same conditions; another 16 percent occurred when it was dark with street or ambient lighting. These results reflect two situations. The first is obvious: there is much more use of highway lighting in urban areas. However, only 22 percent of the urban accidents occurred during nondaylight, compared to 41 percent in rural sites. This reflects a higher percentage of trucks on the road in rural areas at night than in urban areas.

Findings:

- Sixty-three percent (63%) of all truck accidents occur during daylight conditions.
- Rural roadways experience a higher frequency of truck accidents during dark conditions than urban roadways.

Table 47. Distribution of Accidents by Weather Conditions and State

Weather Conditions	California N	California %*	Maryland N	Maryland %*	Michigan N	Michigan %*	Nevada N	Nevada %*	Pennsylvania N	Pennsylvania %*	Texas N	Texas %*	Total N	Total %*
Clear, Cloudy	560	88	162	84	492	69	64	91	239	65	111	83	1628	77
Rain	62	10	25	13	73	10	1	1	59	16	19	14	239	11
Snow	1	0	5	3	122	17	-	-	45	12	-	-	173	8
Sleet, Hail	1	0	-	-	2	0	-	-	10	3	1	1	14	1
Reduced Visibility	10	2	-	-	6	1	3	4	20	5	-	-	39	2
Gusty, Windy	7	1	1	1	36	5	2	3	5	1	2	2	53	3

*May total greater than 100 percent because of multiple coding.

Issue: What were the weather conditions during the accidents?

Analysis: Table 47 is a distribution of all truck accidents by the various weather conditions, grouped by state. The states selected for the study were not chosen to be a representative sample of geographic (and therefore climatological) areas. Therefore, the distributions for all states combined should not be considered representative of the entire country. Nonetheless, the distribution found for all sites is very similar to that reported by BMCS (1977). For example, the data in Table 47 show that 8 percent of the truck accidents occurred when it was snowing; BMCS data indicate 6.8 percent. In general, 23 percent of the truck accidents occurred under some adverse weather condition.

There are notable differences in the distributions of the six states. These relate to their different climates and to specific sites in those states. The effect of snow is evident in Michigan (17%), Pennsylvania (12%), and Maryland (3%). Gusty winds are a particular problem in Michigan and at some sites in California which are flat and prone to high winds.

Findings:

- Nearly a quarter of all truck accidents occurred during adverse weather conditions. However, in the states where snow was not a problem, it was only 13 percent.

Table 48. Distribution of Accidents by Pavement Condition and State

State		Dry	Wet	Snowy/ Icy	Flooded	Other
		Pavement Condition				
California	N	562	74	1	-	2
	%	88	12	0	-	0
Maryland	N	147	41	5	-	-
	%	76	21	3	-	-
Michigan	N	412	128	164	2	2
	%	58	18	23	0	0
Nevada	N	65	2	2	-	1
	%	93	3	3	-	1
Pennsylvania	N	222	71	71	-	1
	%	61	19	19	-	0
Texas	N	109	21	3	-	-
	%	82	16	2	-	-
Total	N	1517	337	246	2	6
	%	72	16	12	0	0

Issue: Was the pavement condition a factor contributing to the accidents?

Analysis: A factor which may have contributed to truck accident occurrence is the condition of the pavement. Shown in Table 48 is the distribution of accidents by pavement condition and state. More than anything else the distribution reflects the general climate differences in the six states seen in Table 46. For example, 96 percent of the snowy/icy accidents occurred in Michigan and Pennsylvania—the heavy snow states of the data base. Unfortunately, no data could be obtained indicating the exposure of trucks during the various weather and pavement conditions. The relatively high percentage of accidents during snowy/icy pavements for Michigan (23%) and Pennsylvania (19%) may indicate that trucks are particularly susceptible to accidents during these conditions.

For all states combined 16 percent of the accidents occurred during wet pavement conditions. This did not vary much across the states except for Nevada which does not experience much rain.

Findings:

- Overall, 28 percent of the accidents occurred on adverse roadway pavements with 16 percent on snowy/icy and 12 percent on wet roadways.

Table 49. Distribution of Accidents by Temporary Roadway Features and Roadway Type

Temporary Features	Roadway Type: Rural Freeway N	%	Rural Nonfwy N	%	Urban Freeway N	%	Urban Nonfwy N	%	Total N	%
None	684	87	143	80	557	59	155	78	1539	73
Foreign Material	21	3	4	2	21	2	2	1	48	2
Holes, Ruts	8	1	2	1	2	0	1	1	13	1
Temp. Construction	8	1	5	3	53	6	8	4	74	4
Previous Accident	31	4	7	4	50	5	1	1	89	4
Stop & Go, Backup	2	0	3	2	217	23	25	13	247	12
Disabled Vehicle	6	1	3	2	35	4	5	3	49	2
Animate Object	29	4	11	6	8	1	1	1	49	2
Other	-	-	-	-	3	0	1	1	4	0

Issue: Were there temporary roadway features which contributed to the accident?

Analysis: A factor which may contribute to the occurrence of an accident is the presence of temporary roadway features, such as potholes, construction, a previous accident, etc. Table 49 presents the distribution of accidents by temporary roadway features for the four roadway types. The data reveal that overall, slightly more than a quarter of the accidents were precipitated or predisposed by a temporary roadway feature. The most frequently cited features were: backed-up/stop-and-go traffic (12%), a previous accident (4%), and a lane reallocation, a lane-drop usually necessitated by roadway construction or maintenance activity, (3%).

These factors varied by roadway type, however. On urban freeways, 41 percent of the accidents involved a temporary feature with the predominant feature being backed-up/stop-and-go traffic. On rural roads, the predominant features were a previous accident, an animal, or foreign material in the roadway.

Findings:

- In urban areas, 38 percent of the truck accidents involved a temporary roadway feature, with the most frequent being: backed-up traffic (21%), a previous accident (5%), lane reallocation (5%), and disabled vehicle (3%).
- In rural areas, 15 percent of the truck accidents involved a temporary roadway feature, with the most frequent being: the presence of an animal (5%), a previous accident (4%), and foreign material in the road (3%).

Table 50. Distribution of Accidents by Truck Driver Condition and Roadway Type

Truck Driver Condition	Rural Freeway N	Rural Freeway %*	Rural Nonfwy N	Rural Nonfwy %*	Urban Freeway N	Urban Freeway %*	Urban Nonfwy N	Urban Nonfwy %*	Total N	Total %*
Apparently Normal	655	90	151	93	787	98	156	98	1749	94
Fatigue	8	1	3	2	2	0	-	-	13	1
Sick	-	-	1	1	-	-	1	1	2	0
Had Been Drinking	15	2	3	2	3	0	-	-	21	1
Apparently Asleep	39	5	4	2	6	1	-	-	49	3
Distraction	9	1	2	1	9	1	3	2	23	1
Other	1	0	1	1	-	-	-	-	2	0

*Sum is greater than 100 percent because of multiple coding.

Issue: What was the physical and/or mental condition of the truck driver prior to the accident?

Analysis: The physical and/or mental condition of the driver, although not necessarily a precipitating cause, may predispose a driver to have an accident (i.e., increase the probability of the accident's occurrence). Table 50 shows, by roadway type, the distribution of the condition of the truck driver. The table reveals that overall, the truck driver was in a physical and/or mental condition *other than* "apparently normal" in only 7 percent of the accidents. This is slightly higher than the 4 percent reported by BMCS (1977). However, examination of the distributions by roadway type indicates that the incidence of a non-normal condition is greater on rural highways (9%) than on urban highways (2%). The most prevalent non-normal condition was being asleep, which occurred frequently on rural freeways (5% of the rural freeway accidents). One might expect a higher incidence of adverse driver conditions on rural roadways because truck travel on these routes is more frequently the long-haul type associated with fatigue, boredom, drinking, etc.

Findings:

- "Non-normal" conditions of the truck driver were associated with 7 percent of the truck accident involvements.
- A "non-normal" truck driver condition was more prevalent on rural roads than urban roads with apparently asleep, had been drinking, and fatigue being the primary factors.

Table 51. Distribution of Accidents by
Other Driver Condition and Roadway Type

Other Driver Condition	Roadway Type: Rural Freeway N	%*	Rural Nonfwy N	%*	Urban Freeway N	%*	Urban Nonfwy N	%*	Total N	%*
Apparently Normal	328	77	72	77	638	92	150	90	1188	86
Fatigue	6	1	1	1	-	-	-	-	7	1
Sick	-	-	-	-	1	0	-	-	1	0
Had Been Drinking	37	9	10	11	40	6	10	6	97	7
Drugs, etc.	-	-	1	1	-	-	-	-	1	0
Apparently Asleep	37	9	5	5	2	0	1	1	45	3
Distraction	15	4	2	2	10	1	4	2	31	2
Other	5	1	2	2	2	0	1	1	10	1

*Sum may be greater than 100 percent because of multiple coding.

Issue: What was the physical and/or mental condition of the other driver prior to the accident?

Analysis: In addition to the truck driver's condition, another factor that may have contributed to accident occurrence was the condition of the other driver in multi-vehicle accidents. Table 51 shows the distribution of accidents by other driver condition and roadway type.

The data reveal that the incidence of a non-normal condition (14%) is more prevalent for other vehicle drivers than for truck drivers (7% in Table 50). The most prevalent non-normal condition of the other vehicle driver was "had been drinking," which occurred in 7 percent of the cases and was fairly consistent across roadway types. The incidence of a non-normal condition is significantly higher for the rural roadways (22%) than for urban roads (8%). In addition to a drinking condition there was a high incidence of "apparently asleep" and "distraction" on rural roadways, especially the freeways.

Findings:

- Other vehicle drivers were in a physical and/or mental condition other than normal in 14 percent of the accident involvements.
- "Had been drinking" was the most prevalent adverse condition.
- A non-normal driver condition of the other vehicle was more prevalent on rural than on urban roadways.

Table 52. Distribution of Accidents by Roadway Familiarity and Roadway Type

Familiarity	Roadway Type: Rural Freeway N	Rural Freeway %	Rural Nonfwy N	Rural Nonfwy %	Urban Freeway N	Urban Freeway %	Urban Nonfwy N	Urban Nonfwy %
First Time	18	5	5	4	12	3	3	4
Once/Year	10	3	2	2	3	1	1	1
LT 1/Mo.	39	11	11	9	35	8	4	5
Once/Month	29	8	13	11	25	6	1	1
LT 1/Week	41	12	13	11	33	7	6	7
Once/Week	50	14	14	12	57	13	6	7
GT 1/Week	117	33	26	22	155	35	30	36
Daily	50	14	32	28	122	28	33	39

Issue: Were the truck drivers involved in accidents familiar with the roadway?

Analysis: Table 52 indicates how familiar (or unfamiliar) the truck drivers involved in accidents were with the roadways on which the accidents occurred. The distribution of various degrees of familiarity across the four roadway types is shown.

Not only is the difference between urban and rural highways evident, but also differences between freeway and nonfreeway roads are seen. The data show a higher degree of familiarity for urban roadways which can be expected due to more local trips. The data also show a high degree of familiarity for the nonfreeways compared to the freeways, which is true for both the urban and rural sites. This is also to be expected, because they are the roads necessary to get to many of the pickup and delivery points.

Relatively few accidents occur where the driver is totally unfamiliar with the roadway. Even in the rural areas, only 8 percent of the accidents involved drivers who were driving through the site for the first time, or no more than once a year.

Findings:

- In the majority of the truck accidents, drivers are familiar with the roadway.

Table 53. Distribution of Accidents by Distance Driven Prior to Accident by Roadway Type

Distance Driven (miles)	Roadway Type: Rural Freeway N	%	Rural Nonfwy N	%	Urban Freeway N	%	Urban Nonfwy N	%	Total N	%
LT 50	71	22	31	28	181	45	50	60	333	36
51-100	78	24	24	22	106	26	15	18	223	24
101-150	57	17	14	13	49	12	10	12	130	14
151-200	40	12	8	7	21	5	5	6	74	8
201-300	47	14	21	19	23	6	1	1	92	10
301-400	17	5	11	10	18	4	2	2	48	5
401-500	10	3	1	1	6	1	-	-	17	2
GT 500	6	2	-	-	2	0	-	-	8	1

Issue: How many miles had been driven after a rest of six or more hours prior to the accident?

Analysis: Federal Motor Carrier Safety Regulations include limits on the hours of service of truck drivers. With some exceptions, drivers are not to operate their trucks for more than 10 hours following 8 consecutive hours off duty. To determine if there was a high incidence of accidents after long hours of driving, information was obtained on how far the driver had driven prior to the accident. The question was stated in terms of miles, rather than hours, to reduce the likelihood of a driver not admitting he had exceeded the hours-of-service regulation.

Table 53 shows the distribution of miles driven for four roadway types. Allowing for an overall average speed of 50 mph (80 km/h), any distance beyond 500 miles (804.5 km) would exceeed the 10-hour restriction. The data show that only one percent of all the truck accidents involved a driver who had driven further than 500 miles (804.5 km) without a rest of six hours or more. Even allowing for some erroneous answers by the drivers, the occurrence of accidents with long hours of driving does not appear to be prevalent.

There are differences in the distributions across the roadway types and these differences are attributable to the nature of the truck traffic. On urban nonfreeways, travel tends to be local delivery trips; hence, there is a high percentage (50%) of accidents within the first 50 miles (80 km). For each of the roadway types, at least 45 percent of the accidents occurred within the first 100 miles (161 km) of travel. Nearly three-quarters of the accidents overall, and at least 63 percent on rural roadways, occurred within the first 150 miles (241 km). However, because trip lengths on rural freeways are long; the distribution is spread over longer distances.

Multiplying the miles driven categories with the frequencies gives the *average* distance driven before an accident occurred, as follows:

- rural freeway = 145 miles (234 km)
- rural-nonfreeway = 134 miles (223 km)
- urban-freeway = 94 miles (151 km)
- urban-nonfreeway = 66 miles (110 km)

Unfortunately, these data alone cannot address the issue of fatigue as it relates to accident causation because corresponding exposure data were not collected. However, the truck driver condition, which includes fatigue, was discussed above.

Findings:

- On rural roadways, 47 percent of the accidents occurred within the first 100 miles (161 km).
- On urban roadways, 47 percent of the accidents occurred within the first 50 miles (80 km) of travel; 72 percent were within the first 100 miles (161 km).

Table 54. Distribution of Accidents by Cargo Type and Truck Type

Cargo Type	Straight Truck N	Straight Truck %	Singles N	Singles %	Doubles N	Doubles %	Total N	Total %
Empty	55	26	212	28	76	42	343	30
General	27	13	168	22	21	12	216	19
Furniture	6	3	23	3	1	1	30	3
Reefer–Produce/Frozen	10	5	50	7	3	2	63	5
Food/Farm Products	8	4	45	6	33	18	86	8
Hanging Goods	1	0	12	2	-	-	13	1
Beverage	3	1	14	2	-	-	17	1
Livestock	2	1	2	0	2	1	6	1
Metal–Sheet/Coil	3	1	41	5	4	2	48	4
Metal–Bulk	2	1	26	3	2	1	30	3
Heavy Machinery	5	2	20	3	2	1	27	2
Solids–Bulk	42	20	47	6	14	8	103	9
Gases–Bulk	1	0	2	0	-	-	3	0
Liquid–Haz/Flam.	6	3	15	2	7	4	28	2
Liquid–Nonflam.	3	1	15	2	5	3	23	2
Vehicles	3	1	27	4	1	1	31	3
Logs/Poles	-	-	16	2	2	1	18	2
Lumber Products	10	5	18	2	6	3	34	3
Tow Truck	16	8	-	-	-	-	16	1
Other–Haz/Flam.	4	2	2	0	-	-	6	1
Other	2	1	3	0	-	-	5	0

Issue: What was the distribution of the type of cargo carried by accident-involved trucks?

Analysis: Table 54 provides the distribution of truck accidents by truck type and cargo type. An interesting result is that overall, 30 percent of the accidents involved a truck that was empty. Without exposure data, it is impossible to determine if any of the cargo types are over- or under-involved in accidents. Next to the empty trucks category, trucks hauling general freight have the highest frequency. Although general freight was somewhat of a catch-all category, it is probably also the most common hauling operation.

The data indicate that 3 percent of all accidents involved trucks carrying flammable liquids; another one percent carried other hazardous cargo.

Findings:

- Thirty percent (30%) of all trucks involved in accidents that have cargo units are empty.

Table 55. Distribution of Accidents by Other Related Truck Factors and Truck Type

Other Truck Factors	Straight Trucks N	Straight Trucks %	Singles N	Singles %	Doubles N	Doubles %	Total N	Total %
None Apparent	306	93	1274	95	238	89	1976	94
Unit Separation	1	0	10	1	11	4	27	1
Cargo Spillage	14	4	22	2	5	2	45	2
Cargo Shift	6	2	15	1	4	1	29	1
Trailer Ran Off Roadway	-	-	14	1	8	3	25	1
Trailer Skid Off Track	-	-	-	-	1	0	1	0
Blown By Wind	-	-	2	0	-	-	4	0

Issue: Were there truck factors other than vehicle defects which contributed to the accident?

Analysis: Table 55 shows the distribution of accidents by truck type of contributing factors other than vehicle defects. For all trucks combined, only 6 percent of the accidents had some other factor contributing to the accident. However, there may be some under-reporting of these factors. In many cases the field investigator could not determine for sure if any of the factors noted, particularly cargo shift in tankers and any blown by wind, were present. Still, there does not seem to be any single factor which contributed significantly to truck accidents. Cargo spillage (*before* the accident, *not* as a result of the accident) was the most frequently cited factor, accounting for 2 percent of the accidents. Trailer ran off roadway and unit separation were common for double combinations (8%). The cargo area configuration was a factor in "cargo shift," where several tankers were affected; and with "blown by wind," where mobile homes and fully enclosed vans were frequently affected.

Findings: No significant findings.

Table 56. Distribution of Accidents by
Truck Prior Movement for Single Truck Accidents

Prior Movement	Single Truck Accidents N	%
Going Straight	132	23
Out of Control	132	23
Out of Control—Jackknife	72	13
Drove Off Roadway (Deliberate)	40	7
Ran Off Roadway	39	7
Slowing/Stopping	32	6
Runaway	29	5
Going Straight on Curve	27	5
Speeding	20	4
Changing Lanes/Drifting	10	2
Forced Off Roadway	9	2
Other (N=7)	22	6

Table 57. Distribution of Accidents by
Truck Prior Movement for Multi-vehicle Truck Accidents

Prior Movement	Multi-vehicle Accidents N	%
Going Straight	632	41
Changing Lanes/Drifting	239	15
Slowing/Stopping	158	10
Driving Slowly	88	6
Passing/Being Passed	85	5
Stopped In Roadway	83	5
Out of Control	69	4
Stopped Off Roadway	36	2
Turning	34	2
Other (N=13)	124	8

Issue: What were the truck movements immediately preceding the collison?

Analysis: Tables 56 and 57 present the distributions of truck movements prior to the collision for single (Table 56) and multi-vehicle (Table 57) truck accidents. Truck prior movement describes the action of the truck immediately preceding the collision.

In single vehicle truck accidents the major portion of the trucks involved were "out of control" prior to the collision (23% plus 13% totaling 36%). (Out of control meant the driver had no control of the vehicle's direction of travel and/or speed [e.g., the truck was going downhill without brakes, or sliding on an icy surface]. The Coding Manual in Appendix C to this volume fully defines the various codes.) Just "going straight" was the next most frequent prior movement (23%).

For multiple accidents, going straight (41%) was the most frequently occurring prior movement. Changing lanes or drifting (15%) and slowing/stopping (10%) were a distant second and third.

Findings:

- The most frequently occurring movement prior to a single vehicle truck accident was the truck being out of control.
- Other than proceeding straight, which was the truck's prior movement in 41 percent of the multiple vehicle accidents, no particular movement occurred significantly more frequently than other movements.

Table 58. Distribution of Accidents by
Truck Prior Movement and Truck Type*

Prior Movement		Truck Type			
		Straight Truck	Single	Double	Total**
Going Straight	N	118	483	97	762
	%***	36	36	36	36
Out Of Control	N	25	128	30	200
	%	8	10	11	9
Out Of Control, Jackknife	N	-	76	15	95
	%	-	6	6	4
Changing Lanes	N	29	153	18	210
	%	9	11	7	10
Slowing/Stopping	N	44	113	13	189
	%	13	8	5	9
Run Off Roadway	N	5	28	3	40
	%	2	2	1	2
Drove Off Roadway	N	8	33	9	54
	%	2	2	3	3

*Includes only the most frequently occurring prior movements.
**See "Distribution, Field 146" in Appendix E for a complete list.
***Column percentages.

Issue: Do truck movements preceding a collision differ by truck type?

Analysis: The purpose of this analysis is to determine if the type of truck affects the prevalence of particular prior movements. Table 58 lists the seven most frequent prior movements (which account for 76 percent of the total from Tables 56 and 57) for the three major truck types.

If the distribution of prior movements is similar across truck types, then the column percentages would be similar for each prior movement. This is, in fact, what is shown by the data.

Findings:

- No truck type appears to have a higher incidence of any particular prior movement compared to other truck types.

Table 59. Distribution of Accidents by Point of Impact and Accident Type

Location On Truck	Accident Type: Single Truck Accident N	%	Truck Hit Vehicle N	%	Vehicle Hit Truck N	%
Left Side	105	26	116	16	176	29
Right Side	117	29	200	27	109	18
Front	145	36	408	55	24	4
Rear	2	0	16	2	296	49
Top	24	6	-	-	1	0
Underneath	13	3	-	-	-	-

Issue: Where was the initial point of impact on the truck?

Analysis: Table 59 shows the distribution of the point of impact on the truck for three types of accidents: single truck, truck hits vehicle, and vehicle hits truck. The distributions reflect what can be expected. For single truck accidents, the front of the truck is the most frequent impact point (36%), moderately greater than the left (driver's) side and right side, which are almost equally involved (26% and 29%). The two most frequent single truck accident dynamics (Table 39) are: hit fixed object, usually done with the front; and rollover, onto either the right or left side.

When a truck hits a vehicle, it does so most frequently with the front (55%). The right side of the truck hits other vehicles more often than the left side. This is attributable to the truck driver having limited visibility on his right side. The truck changing lanes is a frequent prior movement in multi-vehicle accidents (Table 57) and other vehicles were often cut off and collided.

When a vehicle hits a truck, the point of impact is usually the rear of the truck (49%). The second most frequent POI is the truck's left side. This is due to the fact that trucks spend most of their driving time in the right lane of traffic, thus exposing the left side to collisions more often than the right side.

Findings:

- In single truck accidents, the point of impact is more frequently the front of the truck. The left and right side are about equally distributed.
- When a truck hits another vehicle, it usually does so with its front.
- When trucks are hit by other vehicles, they are usually rearended, or struck in the left side.

Table 60. Distribution of Accidents by the Initial Point of Impact on the Truck and Truck Type

Point of Impact	Truck Type							
	Straight Truck		Singles		Doubles		Total	
	N	%	N	%	N	%	N	%
No Impact	25	8	155	12	27	10	207	11
Left Side	62	19	247	18	53	20	362	19
Right Side	64	20	296	22	53	20	413	21
Front	114	35	444	33	77	29	635	33
Rearend	60	18	163	12	56	21	279	14
Top	3	1	21	2	-	-	24	1
Underside	-	-	13	1	1	0	14	1
Windshield	-	-	2	0	-	-	2	0

Issue: Does the point of impact vary by truck type?

Analysis: Table 60 presents the distribution of the point of impact on the truck by truck type. The data are for single and multi-vehicle collisions combined. As can be seen, the distributions are quite similar. Virtually all of the 3 percent of the singles accidents where the point of impact was the top or the underside were unique to specific sites in states where doubles do not run. They are not, therefore, truck type related.

Findings:

- There are no differences in the distributions of the point of impact on the truck across truck types.

Table 61. Distribution of the Point of Impact for Truck-Hit-By-Vehicle Accidents

Truck Type		Impact Location: Tractor	Straight Truck	Semi-trailer	Full trailer	Combi-nation
Straight Truck	N	-	113	-	-	-
	%	-	100	-	-	-
Single	N	115	-	226	-	1
	%	33	-	66	-	0
Double	N	23	-	7	63	1
	%	25	-	7	67	1

Issue: What section of the truck was involved in the collision?

Analysis: The purpose of this analysis is to determine whether any particular section of the various truck combinations is more prone to be hit in a collision. The issue deals with sections or units in general, rather than the exact locations addressed in the previous table.

Table 61 shows the distribution of impact location for three truck types. The data are only for collisions in which the truck was hit by another vehicle. The distributions reflect two obvious facts. First, the largest section of the truck (the straight truck itself or the trailer of a tractor-trailer combination) was most prone to be hit. Second, because the most frequent collisions in which the truck was hit were rearend impacts, the last section was most commonly hit.

Findings:

- The largest and/or last unit of the truck was most likely to be hit.

Table 62. Distribution of Accidents by Vision Obstruction and Truck Type

Driver Vision		Straight Trucks	Singles	Doubles	Total*
Vision Not a Factor	N	120	496	97	784
	%**	37	37	36	37
Vision Not Obstructed	N	153	624	135	994
	%	47	47	51	48
Potential Visibility Problem	N	30	118	19	174
	%	9	9	7	8
Obscured/ Obstructed	N	21	89	15	140
	%	6	7	6	7

*Includes all truck types.
**Column percentages.

Table 63. Distribution of Accidents by Factors Causing Blocked Vision and Truck Type

Vision Blocked By	Straight Trucks N	Straight Trucks %	Singles N	Singles %	Doubles N	Doubles %	All Trucks N	All Trucks %
Own Truck	14	66	59	66	8	53	86	61
Fog, Haze, etc.	2	10	9	10	2	13	17	12
Other Moving Vehicles	3	14	6	7	1	7	12	9
Rain, Snow, etc.	1	5	6	7	3	20	11	8
Roadway Geometry	0	0	6	7	0	0	8	6
Other	1	5	3	3	1	7	6	4
Total	21	100	89	100	15	100	140	100

Issue: Was obstruction of the truck driver's vision a factor in accidents?

Analysis: This issue addresses whether vision obstruction is a significant factor contributing to truck accidents in general or for particular truck types. Table 62 presents the distribution of accidents by the truck driver's vision and truck type. Vision was coded as: not a factor in the accident, not obstructed, potential vision problem, and definitely obstructed or obscured. The data indicate that restricted vision was a real or potential problem in 15 percent of the accidents. There were no differences between the three major truck types.

For those accidents in which the driver's vision was obstructed or obscured, Table 63 lists the five most prevalent factors causing the visibility problem. The samples are too small to place any confidence on the distributions, but it appears that the truck itself is a primary factor in vision obstruction. The high percentage of doubles drivers (although N=3) affected by rain and snow only reflects that the non-doubles' states had generally clearer, drier weather than did doubles' states (particularly Michigan).

Findings:

- Real or potential vision obstruction problems were a factor in 15 percent of the truck accidents with no differences between truck types.
- The primary factor obstructing the driver's vision was the truck itself. However, obstruction of vision, by any means, was not a significant factor contributing to truck accidents.

Table 64. Distribution of Accident Culpability Factors

Culpability Code	N	%
Indeterminable	29	1.4
Truck Driver	559	26.5
Other Driver	487	23.1
Noncontact Vehicle Driver	110	5.2
Defective Truck Equipment	177	8.4
Defective Other Equipment	30	1.4
Environment: Weather, Lighting, Pavement	166	7.9
Temporary Roadway Features	100	4.7
Truck Cargo	56	2.7
Truck Driver and Other Driver	59	2.8
Truck Driver and Defective Truck Equipment	29	1.4
Truck Driver and Environment	62	2.9
Other Driver and Environment	41	1.9
Noncontact Vehicle Driver and Environment	31	1.5
Other Combinations (N=26)	176	8.3
Total	2,112	100.0

Table 65. Distribution of Nine Possible Culpable Agents by Single Truck and Multi-vehicle Accidents

	Single Truck		Multi-vehicle	
	N	%*	N	%*
Indeterminable	6	1	23	1
Truck Driver	174	31	596	39
Other Vehicle Driver	-	-	636	41
Noncontact Vehicle Driver	58	10	132	9
Defective Truck Equipment	138	24	92	6
Defective Other Vehicle Equipment	-	-	64	4
Environment: Weather, Lighting, Pavement	166	29	170	11
Temporary Roadway Features	82	15	77	5
Roadway Design	10	2	5	0
Truck Cargo	37	7	43	3
Total	564		1,548	

*Totals greater than 100 percent because of multiple culpabilities.

Issue: What factor (individual or agent) was most responsible for the occurrence of the accident?

Analysis: Table 64 lists those factors, individuals, and/or agents identified as being most responsible for the occurrence of the accident. Unique factors, either singly or in combination, which accounted for at least one percent of the total are included. The culpability coding was done by two members of the in-house review staff. To assure consistency, periodic intercoder reliability checks were made (with high results) and discrepancies were resolved and corrected. Culpability was assigned only after a thorough review of the accident data. Culpability codes are not simply a transfer of the police-identified "cause," which is frequently a violation citation. The culpable agent is that factor that was responsible for the accident-precipitating event.

Although Table 64 lists all codes for all accidents, the analysis of culpability must consider single and multi-vehicle accidents separately. This is because, for example, the other vehicle/driver does not exist for single truck accidents. Table 65 presents a distribution of nine possible culpable agents for single truck and multi-vehicle accidents. As can be seen, the two distributions are quite different.

For single truck accidents, the truck driver (31%) and the environment (29%) are about equally culpable. Defective truck equipment was the third highest single factor, accounting for 24 percent of the single vehicle accidents. For multi-vehicle accidents, the truck driver and the other vehicle driver were culpable, either singly or in combination with other factors, in about the same percentage of accidents. Together together they are responsible for 80 percent of the accidents. The environment is a very distant third, with 11 percent.

Findings:

- For single truck accidents, culpability was placed on the truck driver in 31 percent of the accidents, on adverse environment 29 percent, and on defective truck equipment 24 percent.
- For multiple-vehicle truck accidents, culpability was placed on the other vehicle driver in 41 percent of the accidents and on the truck driver 39 percent. Adverse environment was the third most frequent factor, with 11 percent.

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

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Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

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This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.