Characterizing commercial vehicle safety in rural Montana
by Patricia Walsh Burke

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University

Abstract:
This investigation focused on characterizing commercial vehicle safety in rural Montana on the basis of driver, vehicle, cargo, carrier, operating environment and crash characteristics using advanced statistical modeling methods. Montana, like other rural states experiences unique challenges in regards to commercial vehicle safety. Crashes typically involve a single vehicle, occur at higher speeds, are more severe and take longer to be detected.

In order to address these challenges, researchers utilized statistical modeling to characterize commercial vehicle safety levels on the basis of the various characteristics. Model interpretation was intended to assist public agencies in focusing scarce regulatory and enforcement resources on commercial vehicles highest at-risk for safety-related problems. The agencies would then be able to perform their duties more effectively and efficiently by addressing safety problems in a preventative rather than reactionary manner. An ordered probit model was used to model the 6524 crashes that took place over a seven-year period.

The results of this investigation were directly interpretable in regards to magnitude and direction. Independent variables that were found to have a significant influence on the severity of a crash included driver characteristics (age, condition-normal, condition-asleep, driver state residence), vehicle characteristics (vehicle configuration-single unit 2-axle), cargo characteristics (household goods), carrier characteristics (carrier physical address-Canadian Territories, number of trip leased and intrastate drivers, latest review-compliance review), operating environment characteristics (crash years 1996-1999, crash months-July, August, September and December, crash time-9am to 10am, light conditions-dark but lit) and crash characteristics (number of vehicles involved, specific crash counties). In addition, utilizing the ordered probit method to model crash severity proved to be successful as the significance of the variables were high as denoted through t-statistics and the overall goodness of fit was good (p2 = 0.57).

In conclusion, focusing enforcement efforts toward variables that were found to increase the severity of a crash including specific driver state residences, vehicle configurations, carrier physical addresses, number of trip-leased drivers and the months of July, August, September and December would be the most effective and efficient method to improve commercial vehicle safety in Montana.

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Patricia Walsh Burke

A thesis submitted in partial fulfillment
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APPROVAL

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Patricia Walsh Burke

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date April 18, 2001

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ABSTRACT

This investigation focused on characterizing commercial vehicle safety in rural Montana on the basis of driver, vehicle, cargo, carrier, operating environment and crash characteristics using advanced statistical modeling methods. Montana, like other rural states experiences unique challenges in regards to commercial vehicle safety. Crashes typically involve a single vehicle, occur at higher speeds, are more severe and take longer to be detected.

In order to address these challenges, researchers utilized statistical modeling to characterize commercial vehicle safety levels on the basis of the various characteristics. Model interpretation was intended to assist public agencies in focusing scarce regulatory and enforcement resources on commercial vehicles highest at-risk for safety-related problems. The agencies would then be able to perform their duties more effectively and efficiently by addressing safety problems in a preventative rather than reactionary manner. An ordered probit model was used to model the 6524 crashes that took place over a seven-year period.

The results of this investigation were directly interpretable in regards to magnitude and direction. Independent variables that were found to have a significant influence on the severity of a crash included driver characteristics (age, condition-normal, condition-asleep, driver state residence), vehicle characteristics (vehicle configuration-single unit 2-axle), cargo characteristics (household goods), carrier characteristics (carrier physical address-Canadian Territories, number of trip leased and intrastate drivers, latest review-compliance review), operating environment characteristics (crash years 1996-1999, crash months-July, August, September and December, crash time-9am to 10am, light conditions-dark but lit) and crash characteristics (number of vehicles involved, specific crash counties). In addition, utilizing the ordered probit method to model crash severity proved to be successful as the significance of the variables were high as denoted through t-statistics and the overall goodness of fit was good ($\rho^2 = 0.57$).

In conclusion, focusing enforcement efforts toward variables that were found to increase the severity of a crash including specific driver state residences, vehicle configurations, carrier physical addresses, number of trip-leased drivers and the months of July, August, September and December would be the most effective and efficient method to improve commercial vehicle safety in Montana.

CHAPTER 1

INTRODUCTION

Despite the fact that they are less frequent than other types of vehicular crashes, commercial vehicle crashes receive considerable attention in the U.S. due to their high severity and resulting economic loss. At a national level, the Federal Motor Carrier Safety Administration (FMCSA) has set stringent goals focused on enhancing commercial vehicle safety through reduced crash severity levels and improved: (1) consistency and effectiveness of enforcement, (2) identification and targeting of those at high-risk and (3) research efforts to enhance and promote commercial vehicle safety practices.

Montana, as with other predominantly rural states, faces somewhat unique challenges with respect to commercial vehicle safety. Unlike commercial vehicle crashes that occur in urban areas, rural commercial vehicle crashes typically involve a single vehicle, occur at higher speeds, are more severe and take longer to be detected and responded to. Further, available regulatory and enforcement resources for commercial vehicle safety monitoring are limited. Montana's large geographic expanse challenges post-crash improvements that could limit the occurrence of fatalities, such as reduced emergency medical response times to the crash. Hence, efforts to improve commercial vehicle safety in Montana must focus on commercial vehicle crash *prevention,* targeting those at highest risk for a severe crash.

The objective of this research is to characterize commercial vehicle safety levels in Montana on the basis of driver, vehicle, cargo, carrier and other characteristics (i.e., roadway geometry, traffic volumes, etc.) using advanced statistical modeling methods. As an example, if the commercial vehicle safety-related data were to indicate low safety levels for out-of-state drivers, carriers with small vehicle fleets and haulers of flatbed trailers, both roadside and on-site carrier-based safety inspections could be performed with these characteristics in mind. On the roadside, regulatory and enforcement personnel could adjust their selection of commercial vehicles for roadside safety inspections; currently vehicles are selected for safety inspections on the basis of historical accident or safety records. As part of a more detailed carrier-based safety inspection program, regulatory and enforcement personnel could increase the frequency of safety inspections for carriers possessing the characteristics that show a lower safety level.

Ultimately, an understanding of the driver, vehicle, cargo, carrier and other characteristics that are most likely to result in a crash, particularly a severe crash, can assist regulatory and enforcement agencies in addressing safety problems in a *preventative* rather than reactionary manner. An additional benefit of this effort, and certainly of concern to public agencies in predominantly rural states, is the ability to make better use of existing resources. Resources are typically more limited and geographic expanses greater in rural states. Having the ability to focus scarce regulatory and enforcement resources on commercial vehicles highest at risk for safety-related problems, public agencies can perform their duties more effectively and efficiently without additional personnel.

Note, that only large trucks having a gross vehicle weight (GVW) of 10,000 pounds or greater are considered in this investigation; buses are excluded. Differences with respect to cargo and passenger transport vehicles between safety protocol, regulation and enforcement activities for and vehicle-handling characteristics were thought to confound this investigation. Further, the proportion of bus-involved crashes is small compared to that of large truck-involved crashes.

This Chapter details the problem at hand nationally and with respect to Montana's commercial vehicle crashes, describes the study area, and provides background information pertaining to existing Federal, State and industry efforts to improve commercial vehicle safety.

Following this introductory material, Chapter 2 describes findings from recent literature pertaining to commercial vehicle safety. Chapter 3 describes this effort's methodology in identifying influential driver, vehicle, cargo, carrier and operating environment characteristics. Chapter 4 expounds on the findings of this investigation and Chapter 5 contains recommendations for implementation and future work.

Problem Description

In 1999, there were more than 452,000 traffic crashes involving large trucks in the U.S. These crashes accounted for approximately 13 percent of all traffic-related fatalities and 4 percent of all injuries. (1) Contributing to this elevated level of severity are the physical characteristics of large trucks: (1) the difference in mass between large trucks and non-trucks results in a near instantaneous velocity change upon impact, (2) the high rigidity of a commercial vehicle's structure results in energy dissipation through the collapse of the smaller vehicle, and (3) the height of the truck results in damage to the upper and weaker parts of the smaller vehicle.

Despite this high rate of severity, truck-involved crash *rates* (i.e., crash frequency) tend to be lower than that of non-trucks because:

- trucks typically travel more interurban miles,
- trucks register higher mileage in general,
- truck drivers are generally more skilled, and
- vehicle maintenance of trucks is generally stricter. (2)

Given these noted observations of truck crash severity and frequency, much of the effort towards improved commercial vehicle safety focuses on severity levels. In the FMCSA's draft *2010 Strategy*, the primary goals relate to improving commercial vehicle crash severity: (1) reduce the number of injuries in large truck-related crashes by 20 percent by fiscal year 2008 and (2) reduce the number of large truck-related crash fatalities 50 percent by fiscal year 2009.

Nationally, efforts to improve commercial vehicle safety will be challenged by contrary traffic and industry trends:

- increasing international trade will lead to more intermodal freight shipments and north-south, cross-border traffic for long haul trucks;
- continued and growing demand for real-time visibility of shipments and just-in-time freight delivery will heighten competitive pressures already placed on drivers and carriers;

- growth in e-commerce will impact truck distances traveled and travel patterns (e-commerce, particularly business-to-consumer, favors transportation in smaller lot sizes delivered by carriers with nationwide distribution systems); and
- declining availability of commercial vehicle drivers will result in more new drivers with less experience. (1)

The effectiveness of these safety improvement measures is further challenged in a predominantly rural state such as Montana that experiences significant commercial vehicle traffic, a large geographic expanse and limited regulatory and enforcement resources.

Uniqueness of Montana's Commercial Vehicle Crashes

Each year, approximately 1,000 commercial vehicle crashes occur within the State of Montana. Between January 1, 1993 and December 31, 1999, 6,583 commercial vehicle crashes occurred; 6,524 involving large trucks (see Figure 1). As noted previously, Montana's commercial vehicle crashes typically involve a single vehicle, occur at higher speeds, take longer to be detected and responded to and are more severe than nationally reported averages.

Vehicular Involvement. Given Montana's rural environment and low traffic volumes, one would expect a higher proportion of single-vehicle rather than multiple-vehicle crashes as compared to national averages. For the four-year time span (1993 to 1999) large truck-involved crashes in Montana comprised 46 percent single-vehicle crashes and

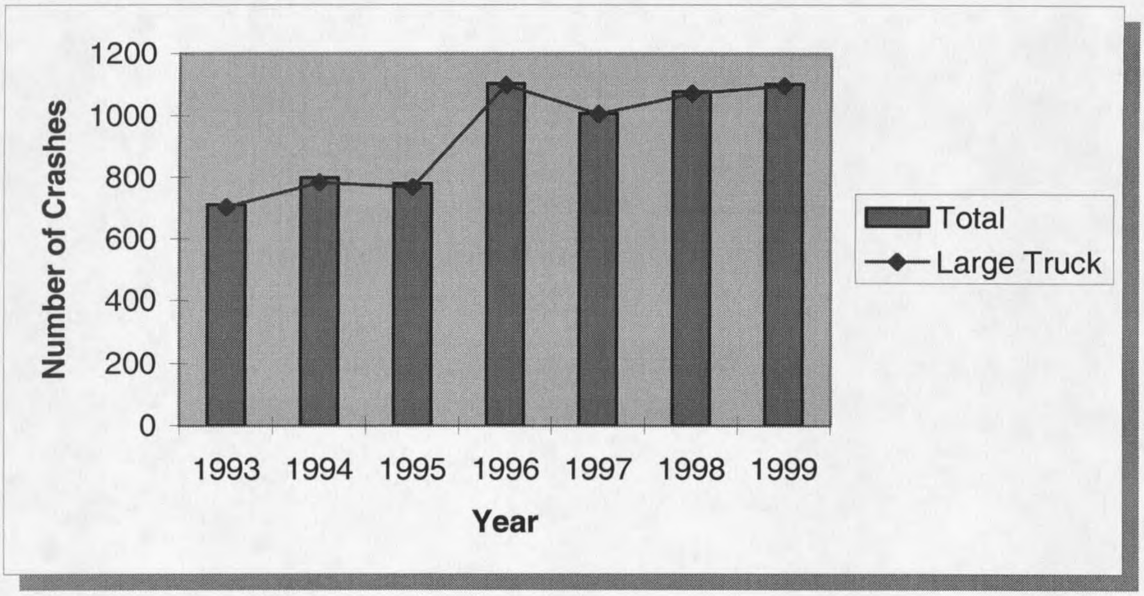

Figure 1. Montana's Commercial Vehicle Crashes, 1993-1999.

54 percent multiple-vehicle crashes. Figure 2 demonstrates the uniqueness of Montana's crashes as compared to national averages for this same time period. Nationally, large truck-involved crashes comprised only 28 percent single-vehicle crashes and 72 percent multiple-vehicle crashes. (3)

Speed. In general, vehicular crashes involving large trucks occur at higher speeds in Montana than they do nationally. Data from the Fatal Accident Reporting System (FARS) for the year 1999 illustrates that 60 percent of all fatal crashes in Montana occurred at speeds of 60 MPH or greater, while only 31 percent of fatal crashes nationally occurred at comparable speeds (see Figure 3). (3)

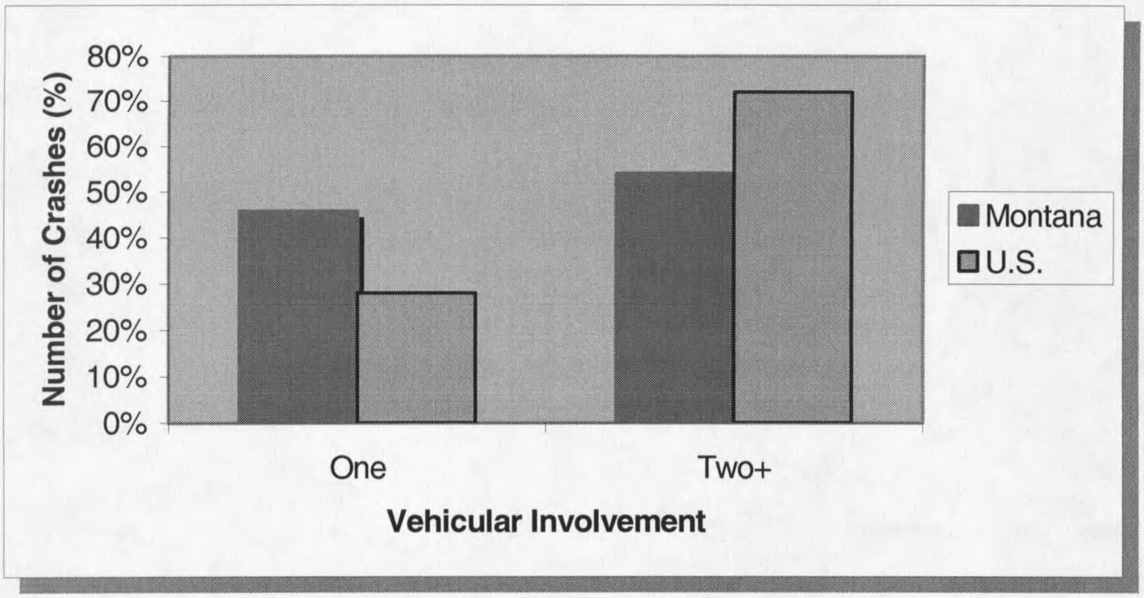

Figure 2. Comparative Vehicular Involvement, 1993-1999.

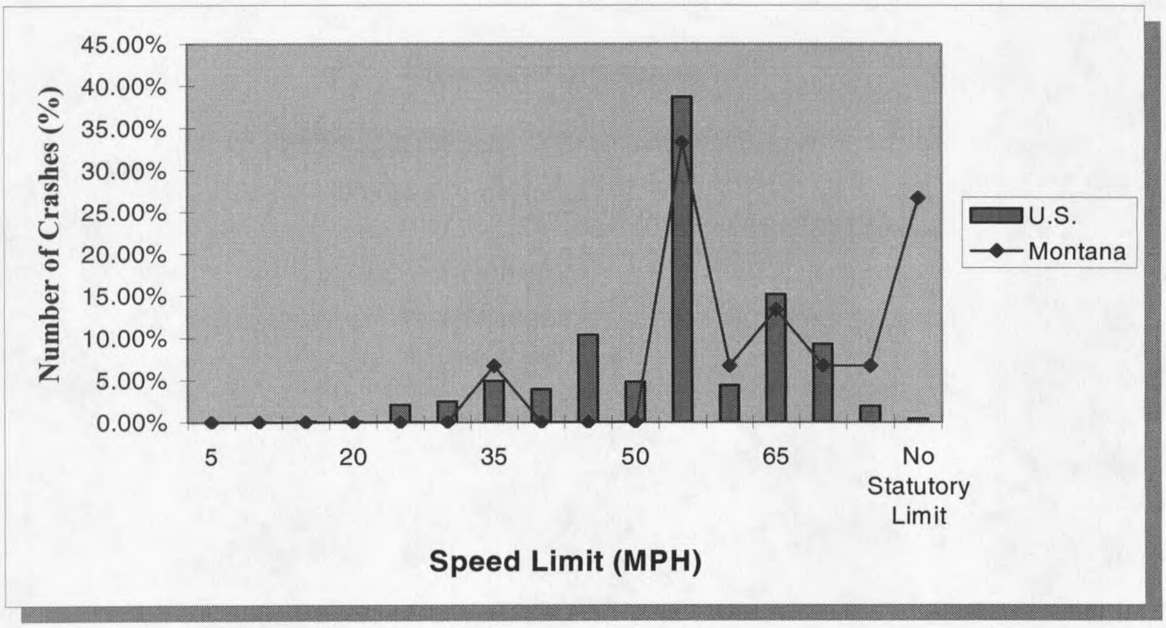

Figure 3. Comparative Fatal Crash Frequency by Speed, 1999.

Severity. The combination of higher speeds and single-vehicle involvement result in a higher overall fatality and injury rate in Montana than is seen nationally. In each case, the majority of crashes resulted in only property damage (PDO); 71.02 percent in Montana as compared to 75.58 percent nationally. Of more interest for this investigation is the difference in crash proportions resulting in fatalities or injuries. The proportion of crashes resulting in injuries is approximately 3.5 percent higher in Montana as compared to national averages between 1993 and 1999. More notably, the proportion of large truck-involved crashes resulting in fatalities in Montana is nearly double that of national averages (though the number of resulting fatalities are still relatively small) (see Figure 4). (3)

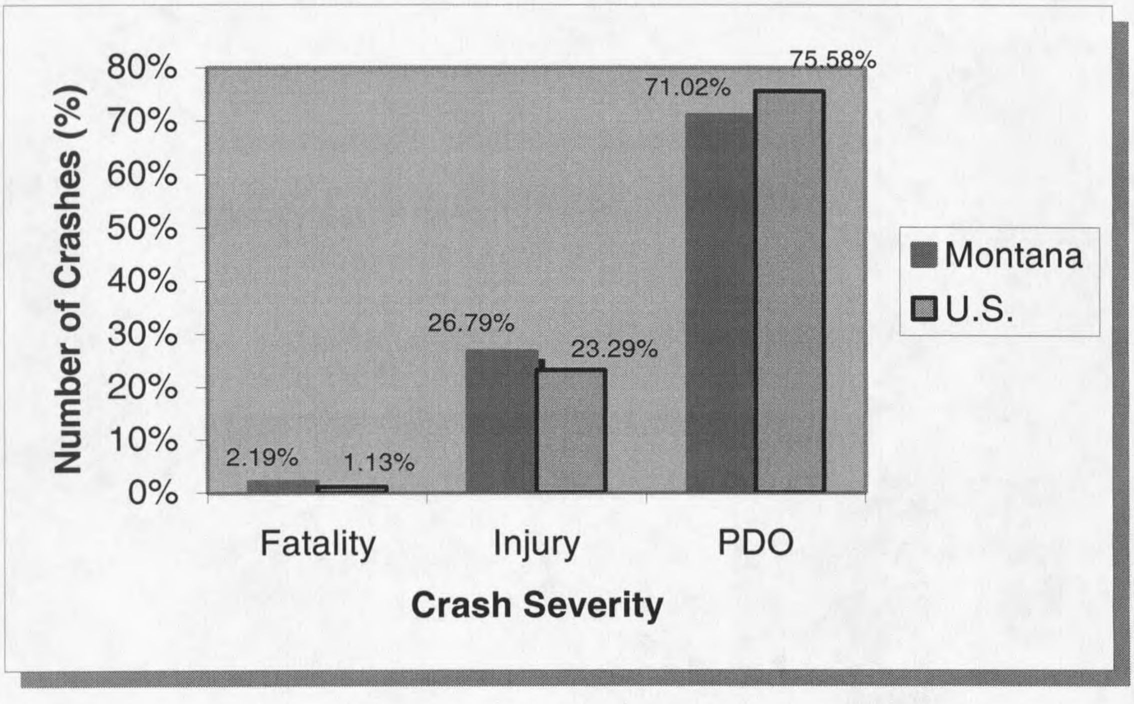

Figure 4. Comparative Crash Severity, 1993-1999.

Description of the Study Area

Montana is located in the Northwestern Region of the United States and shares its borders with Idaho, Wyoming and North and South Dakota, all of which are rural states. Montana shares its northern border with three Canadian Provinces: British Columbia, Alberta and Saskatchewan.

Demographics

Montana is the 4th largest state in the U.S. measuring approximately 500 miles east to west and 300 miles north to south (148,000 square miles). While 4th largest in size, the state is ranked 44th in population with a sparse 902,195 residents. (4) Comparing its geographic expanse to its population density results in an average population distribution of only 6 residents per square mile.

The largest population base is located in southeastern Montana; Yellowstone County has 127,000 residents. The City of Billings is the County Seat, as well as the largest city in the state with a population of 88,000 residents. Other population centers are located in the counties surrounding the cities of Missoula, Great Falls, Helena, Butte, Bozeman and Billings. These counties account for 50.6 percent of the population base while only accounting for 10 percent of the landmass. Accordingly, nearly 48 percent of the population lives and works in the rural areas of Montana. (5)

Economy

The primary forms of industry within the State are agriculture, lumber and wood products, tourism, food processing and mining. Agriculture products include cattle, hogs, wheat, barley, sugar beets, and hay. Transportation provides a critical link between these industries and their respective markets; 92 percent of all agricultural products and 82 percent of manufactured goods are transported by rail and truck, respectively. (4)

Roadways and Trade Corridors

Three interstate highways and numerous primary and secondary roadways comprise the nearly 70,000 miles of public roads in Montana. The north-south Interstate-15 connects the Alberta Province with the lower 48 states, while the east-west Interstates 90 and 94, in part, link the New England states to the west coast (see Figure 5). Figure 6 summarizes total traffic volume and truck traffic volume for major roadways in Montana.

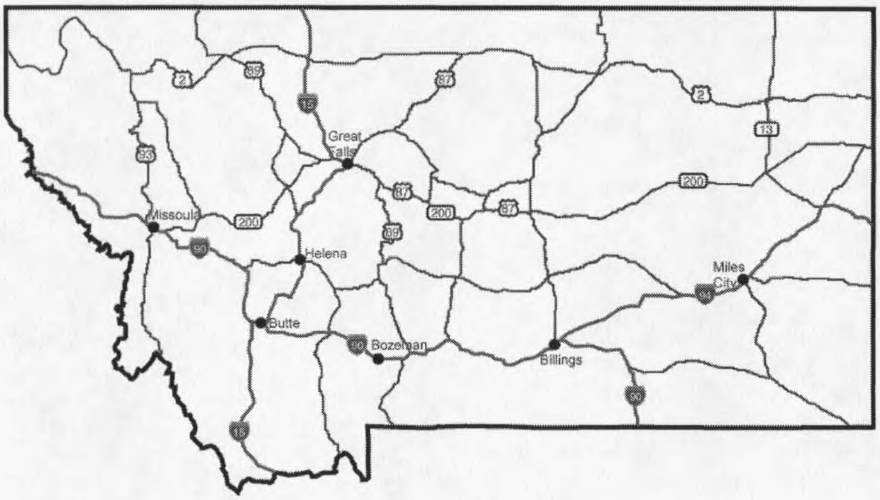

Figure 5. Montana's Interstate and Primary Roadway System.

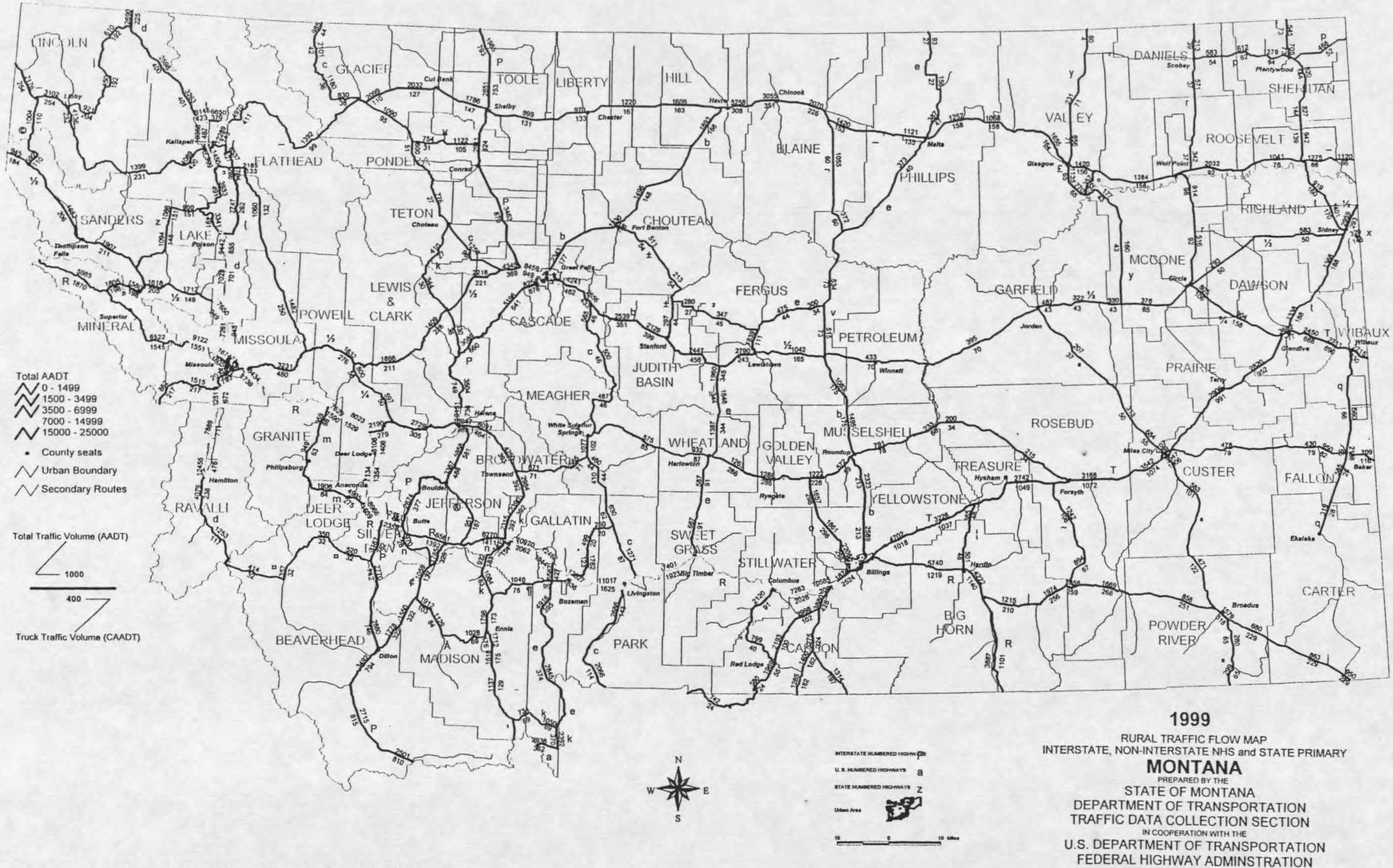

Figure 6. Rural Traffic Flow Map, 1999.

Existing Efforts to Improve Commercial Vehicle Safety

At the Federal level, safety regulation of the interstate trucking industry began in 1935 with the *Motor Carrier Act.* Since that time, several statutory milestones have helped shape the safety monitoring activities at both Federal and State levels.

- The *Motor Carrier Safety Act of 1984* required that regulations under the 1935 Act be revised, inconsistent state regulations be preempted and a procedure to determine the safety fitness of owners and operators of commercial vehicles operating in interstate commerce be developed. (6)
- The *Commercial Motor Vehicle Safety Act of 1986* required that all interstate truck drivers have a single commercial driver's license. (6)
- The *Motor Carrier Safety Act of 1990* required the publication of company names having unsafe motor carrier procedures, prohibited a company with an unsatisfactory safety rating from transporting hazardous materials or passengers and required enforcement action under certain circumstances. (6)
- As part of a department-wide initiative, the Federal Highway Administration (FHWA) in 1988 issued regulations requiring drug testing of truck drivers. (6)
- The *Motor Carrier Safety Act of 1999* created the Federal Motor Carrier Safety Administration (FMCSA) and required the U.S. Department of Transportation (USDOT) to develop a long-term strategy for improving commercial motor vehicle, operator and carrier safety. (1)

The requirements of each of these statutory regulations are carried out in partnership at Federal, State, and industry levels.

At the Federal Level, the FMCSA, formerly the FHWA - Office of Motor Carriers (OMC) and before that, the Interstate Commerce Commission (ICC) - Bureau of Motor Carrier Safety (BMCS), is the primary regulatory agency. FMCSA's primary mission is to prevent commercial motor vehicle-related fatalities and injuries. FMCSA ensures safety in motor carrier operations through: (1) strong enforcement of safety regulations, (2) targeting high-risk carriers and commercial motor vehicle drivers, (3) improving safety information systems and commercial motor vehicle technologies, (4) strengthening commercial motor vehicle equipment and operating standards, and (5) increasing safety awareness. The attainment of this mission is manifested in three activities: (1) roadside inspections, (2) compliance reviews and (3) educational contacts (detailed later in this Chapter). (1)

Motor Carrier Safety Assistance Program (MCSAP)

These three activities are largely supported through a federal grant program established by the *Surface Transportation Assistance Act of 1982*, the Motor Carrier Safety Assistance Program (MCSAP) (see Figure 7). States can apply for different levels of funding depending on conditions, performance or need. In addition to roadside inspections, compliance reviews and educational contacts, MCSAP also requires activities related to traffic enforcement and data collection.

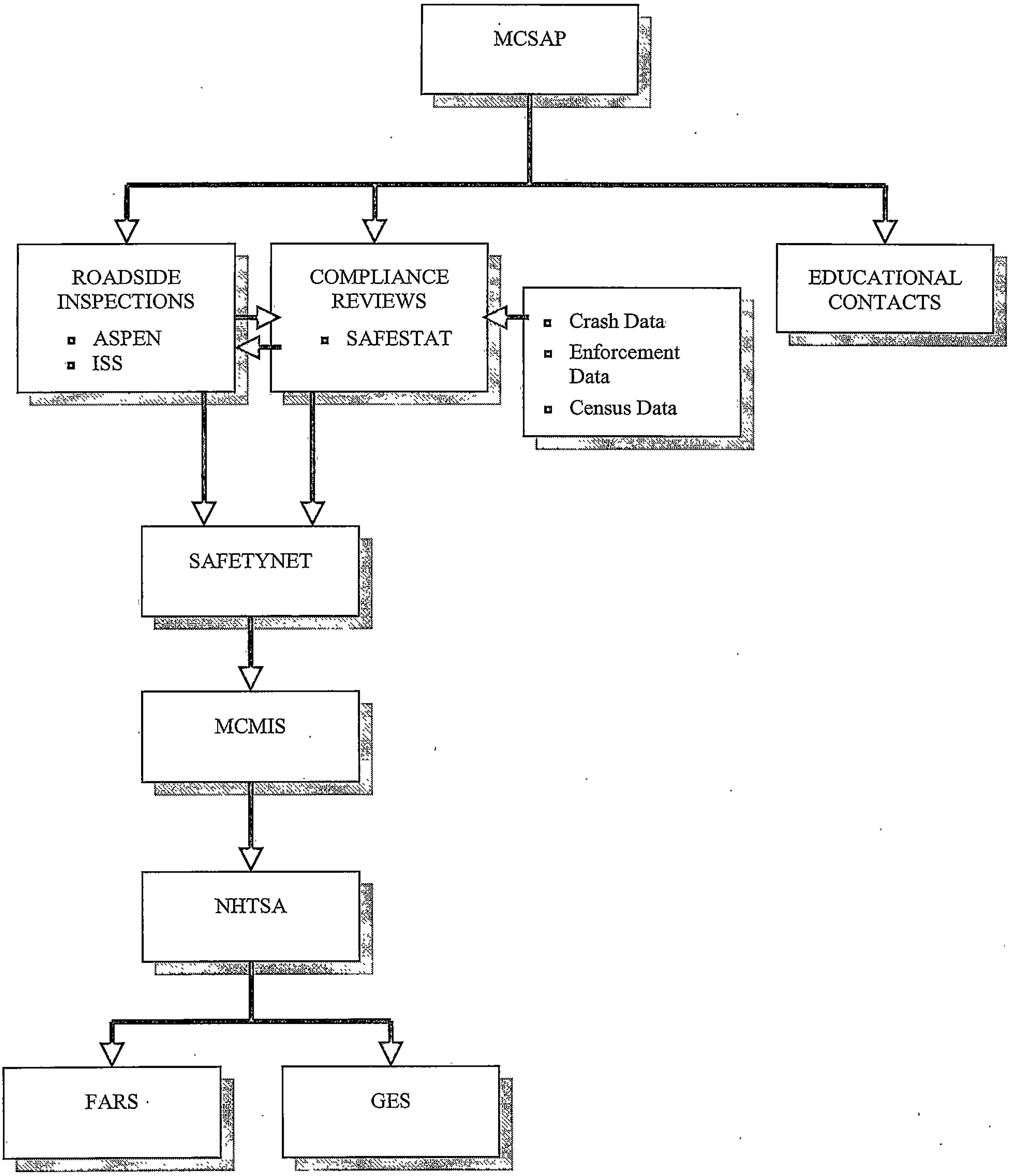

Figure 7. Existing Efforts to Improve Commercial Vehicle Safety.

In Montana, MCSAP activities are performed by the Montana Highway Patrol (MHP) in partnership with the Motor Carrier Services (MCS) Division of the Montana Department of Transportation (MDT). Personnel comprise:

- civilian MHP and MCS employees capable of performing roadside safety inspections;
- Uniformed, weapon-carrying MHP officers not dedicated to safety enforcement but capable of performing roadside inspections and
- FMCSA inspectors who oversee the MCSAP program and perform compliance reviews. (7)

Roadside Inspections

Roadside inspection procedures follow a standard known as the North American Driver/Vehicle Inspection Criteria established by the Commercial Vehicle Safety Alliance (CVSA). CVSA defined 6 levels of inspection (see Table 1):

LEVEL I: North American Standard (NAS) Inspection. Level I inspections include examination of all applicable driver and vehicle credentials as well as physical condition.

LEVEL II: Walk-Around Driver/Vehicle Inspection. Level II inspections include, as a minimum, each of the items specified under the Level I NAS Inspection. Additional items may be checked, though the walk-around driver/vehicle inspection should include only those items that can be inspected without physically getting under the vehicle.

Table 1. North American Driver/Vehicle Inspections.

	LEVEL					
	I	II	III	IV	V	VI
DRIVER						
Driver's license	✓	✓	✓	Special Inspections – Any Item may be Inspected		Radiological Shipments Only
Medical examiner's certificate and waiver	✓	✓	✓			
Alcohol and drugs	✓	✓	✓			
Driver's record of duty status as required	✓	✓	✓			
Hours of service	✓	✓	✓			
Seat belt	✓	✓	✓			
VEHICLE						
Vehicle inspection report	✓	✓	✓		✓	
Brake system	✓	✓			✓	
Coupling devices	✓	✓			✓	
Exhaust system	✓	✓			✓	
Frame	✓	✓			✓	
Fuel system	✓	✓			✓	
Turn signals	✓	✓			✓	
Brake lamps	✓	✓			✓	
Tail lamps	✓	✓			✓	
Head lamps	✓	✓			✓	
Lamps on projecting loads	✓	✓			✓	
Safe loading	✓	✓			✓	
Steering mechanism	✓	✓			✓	
Suspension	✓	✓			✓	
Tires	✓	✓			✓	
Van and open-top trailer bodies	✓	✓			✓	
Wheels and rims	✓	✓			✓	
Windshield wipers	✓	✓			✓	
Emergency exits on buses	✓	✓			✓	
Hazardous material requirements	✓	✓	✓		✓	

LEVEL III: Driver-Only Inspection. Level III inspections comprise a roadside examination of driver-related credentials and condition. Oftentimes however, the vehicle inspection report and hazardous material requirements (as applicable) will be examined in conjunction with the driver-related observations.

LEVEL IV: Special Inspections. Level IV inspections typically include a one-time examination of a particular item. These examinations are normally made in support of a study or to verify or refute a suspected trend.

LEVEL V: Vehicle-Only Inspection. Level V inspections include each of the *vehicle* inspection items specified under the Level I NAS Inspection. Level V inspections can be conducted at any location, with or without a driver present.

LEVEL VI: Enhanced NAS Inspection for Radioactive Shipments. Level VI inspections are conducted for select radiological shipments. Because of the sensitivity of the cargo, enhanced inspection procedures, radiological requirements, and the out-of-service criteria are used.

Under any of these inspections, if the driver or vehicle fails to meet the requirements of the out-of-service (OOS) criteria, the inspecting officer will not allow the vehicle to proceed until the requirements have been met. A citation may also be issued.

Historically, commercial vehicles were selected for roadside safety inspections either randomly or through visual verification of a CVSA decal that denoted a positive safety record (those without the decal displayed were selected for inspection). Advances in computer and communication technologies allowed for improvements to this selection method. ASPEN, a vehicle safety and inspection software package, allows electronic: (1) data collection and input by inspection officers, (2) roadside access to motor carrier safety and commercial driver's license information and (3) transmission of completed inspection data to the state-level safety information database, SAFETYNET, via a communication system and processor, AVALANCHE.

Inspection Selection System (ISS). The Inspection Selection System (ISS), an enhancement to the ASPEN system, was developed in response to a 1995 Congressional mandate calling for the use of prior carrier safety data to guide in the selection of commercial vehicles and drivers to undergo inspection. The ISS targets "problem carriers" on the basis of:

- poor prior safety performance shown by either: (1) higher than average driver or vehicle OOS rates as determined through roadside inspections or (2) an unsatisfactory compliance review rating;
- few or no roadside inspections in the previous two years (taking into account the size of the carrier) or
- a known history of regulatory violations (i.e., hours of service, etc.).

Ultimately, the ISS is designed to be incorporated into the pre-clearance process. Now, however, roadside inspectors must manually enter the carrier's USDOT number into an on-site computer utilizing the ISS software. After polling a centralized database of safety-related information, ISS provides the roadside inspector with an "inspection value." Higher values suggest the need for a roadside inspection. Note that the ISS selects on the basis of *carrier* performance and is not vehicle- or driver-specific.

In 1997, Lantz, et al. investigated the effectiveness of ISS in targeting problem carriers. Using inspection data from 1996 that comprised approximately 40,000 roadside inspections, the authors found the following:

- the vehicle OOS rate was 33.7 percent for ISS-targeted carriers versus 20 percent for non-targeted carriers and
- the driver OOS rate was 13.5 percent for ISS-targeted carriers versus 9.9 percent for non-targeted carriers.

While the ISS does show an improvement in enforcement efforts, the improvement is not as significant as one would hope. Secondly, a noted shortcoming in the ISS system is that it only calculates an inspection value for carriers that have had a minimum of three roadside inspections in the last two years. Two-thirds of all carriers are excluded on the basis of this criteria. (8)

Compliance Reviews

Compliance reviews, conducted at the carrier's place of business, consist of an audit of safety-related records. Compliance reviews are intended to determine a carrier's compliance with safety regulations and identify any apparent risk to highway safety posed by the carrier. Specifically, compliance reviews result in the assignment of a carrier-specific "safety fitness rating" of "satisfactory," "conditional," or "unsatisfactory." If satisfactory, compliance reviews may also allow a carrier's participation in voluntary compliance programs tied to monetary or time-savings benefits (i.e., pre-clearance). If conditional or unsatisfactory, compliance reviews may result in enforcement action and monetary penalties.

In 1993, the FHWA's Office of Motor Carriers (now FMCSA) began efforts to improve the assessment of a carrier's safety fitness. Noted shortcomings of the existing assessment procedure included the following:

- a carrier's safety fitness was based solely on a single, one-time, on-site compliance review;
- the safety fitness rating remained until another compliance review was performed;
- only carriers participating in compliance reviews received a safety fitness rating - out of 400,000 active interstate carriers, only approximately 10,000 are reviewed for safety compliance annually;
- the compliance review process was labor-intensive, usually taking several days per review and
- other related safety data, such as state-reported crash reports, roadside inspections, enforcement actions or moving violations, was not utilized to determine a carrier's safety fitness.

<u>Safety Status Measuring System (SAFESTAT)</u>. In response to these shortcomings, the Safety Status Measuring System (SAFESTAT) was developed. SAFESTAT is a data-driven analysis system designed to improve the safety fitness assessment process by incorporating roadside inspection information and enforcement history with compliance

review information to measure an overall relative safety fitness of interstate carriers. SAFESTAT targets four areas: (1) accident history, (2) driver performance/condition, (3) vehicle performance/condition and (4) safety management measures. SAFESTAT can be used to target individual motor carriers for compliance reviews much in the same way that ISS is used to target carriers for roadside inspections. Benefits to SAFESTAT include its ability to incorporate all current safety-related data and to continually assess the safety status of carriers.

In 1988, Madsen and Wright evaluated the effectiveness of SAFESTAT in accurately assessing motor carrier safety fitness. Specifically, the authors considered whether SAFESTAT identified carriers that were indeed high safety risk carriers. Using historical data, the authors used SAFSTAT to identify carriers that were "at risk" and carriers that had less severe, yet poor safety fitness ratings and compared this identification with the historical crash experience. Carriers identified by SAFESTAT as "at risk" had a 169 percent higher crash rate than carriers not identified as high risk. Carriers identified as having poor safety fitness by SAFESTAT had a 41 percent higher crash rate than carriers not identified. (9)

Performance and Registration Information Systems Management (PRISM). SAFESTAT is currently being utilized as part of the Performance and Registration Information Systems Management (PRISM) program (formerly referred to as the Commercial Vehicle Information System (CVIS)). PRISM began as a mandate by Congress to explore the potential of linking the commercial vehicle registration process to motor carrier safety. The intent of Congress as stated in the Intermodal Surface

Transportation Efficiency Act (ISTEA) of 1991, was to "link the motor carrier safety information network system of the Department of Transportation and similar State systems with the motor vehicle registration and licensing systems of the states" to achieve two purposes:

- determine the safety fitness of the motor carrier prior to issuing license plates and
- cause the carrier to improve its safety performance through an improvement process and, where necessary, the application of registration sanctions.

The PRISM program includes two major processes - the Commercial Vehicle Registration Process, and the Motor Carrier Safety Improvement Process (MCSIP) - that work in parallel.

The Commercial Vehicle Registration Process provides the framework for the PRISM program. It serves two vital functions. First, it establishes a system of accountability by ensuring that no vehicle is license plated without identifying the carrier responsible for the safety of the vehicle during the registration year. Second, the use of registration sanctions (i.e., denial, suspension and revocation) serves as a powerful incentive for unsafe carriers to improve their safety performance.

MCSIP is the means by which carrier safety is systematically tracked and improved. MCSIP carriers that do not improve their safety performance face progressively more stringent penalties that may culminate in a Federal “imminent hazard” determination and possible suspension of vehicle registrations by the State. Within MCSIP, carriers with potential safety problems are identified and prioritized for an on-site review using the Motor Carrier Safety Status (SAFESTAT) prioritization program described previously.

Educational Contacts

Educational contacts, formerly termed "safety reviews," are conducted at a carrier's place of business with the intent to provide education and technical assistance to the motor carrier regarding safety compliance. Unlike the previous safety review procedure, the carrier is no longer assigned a safety rating during this activity.

The FMCSA has produced *A Motor Carrier's Guide to Improving Highway Safety* to support the education and technical assistance program. This booklet is comprised of thirteen parts, each containing a specific safety regulation topic that is covered in the Federal Motor Carrier Safety Regulations (FMCSRs):

- Part 382: Alcohol And Drug Testing Requirements,
- Part 383: Commercial Driver's License Standards: Requirements And Penalties,
- Part 385: Safety Fitness Procedures,
- Part 387: Minimum Levels Of Financial Responsibility For Motor Carriers,
- Part 390: Federal Motor Carrier Safety Regulations: General,
- Part 391: Qualification Of Drivers,
- Part 392: Driving Of Motor Vehicles,
- Part 393: Parts And Accessories Necessary For Safe Operation,
- Part 395: Hours Of Service Of Drivers,
- Part 396: Inspection, Repair, And Maintenance,
- Transportation Of Hazardous Materials,
- Motor Carriers Of Passengers and
- Accident Countermeasures.

Educational contacts typically receive lowest priority; roadside inspections and compliance reviews take precedence.

Data Management

At the state level, roadside inspection and compliance review information is entered into the SAFETYNET database. Each state's SAFETYNET data is then uploaded into the Motor Carrier Information Management System (MCMIS) which is maintained by FMCSA. Information from MCMIS and SAFETYNET, accessible from the roadside or other location, in turn also support inspection and review selection processes.

The Montana Highway Patrol (MHP) completes reports for all crashes on Montana's roadway system. Crash reports that involve a commercial vehicle are then forwarded to the Motor Carrier Services (MCS) Division of MDT and maintained in the SAFETYNET System (described below).

The SAFER system inspectors transfer data in a simple and universal manner between Federal and State inspectors and information systems such as ASPEN. SAFER also aids in the management of SAFETYNET.

SAFETYNET

SAFETYNET is an automated information management system that allows the safety performance of interstate and intrastate commercial motor carriers to be monitored (see Figure 6). Each state is required under MCSAP to enter and maintain all commercial vehicle crash reports in the SAFETYNET System. Each State uploads their information electronically.

Motor Carrier Management Information System (MCMIS)

MCMIS contains detailed vehicle crash and carrier data from 1989 to the present. Approximately, 375,000 active commercial motor carriers are monitored through MCMIS. Currently, this information is used in the field to determine which vehicles and/or carriers should be selected for safety inspections. This data is also available for other applications through the MCMIS Data Dissemination Program. The MCMIS Data Dissemination Program currently offers:

- census file extracts,
- crash file extracts,
- carrier safety profiles,
- personalized census reports,
- personalized crash reports,
- census count reports and
- crash count reports.

National Highway Traffic Safety Administration

NHTSA, a division within the USDOT is directly responsible for improving traffic safety. Information gathered from MCMIS is used by NHTSA to support the Fatality Analysis Reporting System (FARS) and the General Estimate System (GES) (see Figure 5). FARS records all fatal crashes and processes the information so that it is available and accessible to improve traffic safety. GES considers a representative sample from the

MCMIS data and estimates crash severities to form a basis for determining the cost/benefit of existing safety programs.

Implications for this Investigation

This introductory Chapter has detailed the problem at hand, both nationally and within Montana, described challenges related to the study area and summarized existing safety improvement measures at Federal, State and industry levels. Key implications for this investigation include the following.

- The uniqueness of Montana's commercial vehicle crashes may limit the universal application of these findings at a national level. However, these findings should be easily transferable to other predominantly rural states that face similar challenges related to single-vehicle, higher speed, and more severe commercial vehicle crashes.
- The geographic expanse of the study area, combined with constrained enforcement and regulatory resources, limit the choice of alternatives for improving commercial vehicle safety in Montana. Efforts to improve commercial vehicle safety, particularly crash severity, through speedier detection and response times to the scene are not feasible. Instead, efforts must focus on preventing the occurrence of commercial vehicle crashes altogether as a means to improve safety.
- A clear understanding of the safety efforts currently underway at Federal, State and local levels and, perhaps more importantly, the success of those safety efforts

in improving commercial vehicle safety are critical in determining potential confounding factors for this investigation and in estimating the potential magnitude to which this research can contribute.

- Lastly, a clear understanding of the national strategic direction for commercial vehicle safety at the onset of this investigation helps to focus and direct this research to ensure consistency with national directives.

CHAPTER 2

LITERATURE REVIEW

In conducting a comprehensive literature review, researchers considered both: (1) commercial vehicle crash frequency (most often expressed as a rate or risk of occurrence) and (2) commercial vehicle crash severity. In particular, researchers were interested in the characteristics previously identified as contributing - either positively or negatively - to commercial vehicle safety levels.

In reviewing previous efforts, numerous studies were uncovered that investigated commercial vehicle crash frequency and severity based on driver, vehicle, cargo, carrier and operating environment characteristics. However, few studies were found that addressed the effect of these characteristics *comprehensively* (i.e., in combination). Further, a disproportionate amount of the previous work focused on vehicle and, to a lesser extent, driver characteristics effecting on commercial vehicle safety rather than cargo, carrier and operating environment effects.

Findings from the literature are detailed below. Methodologies previously employed to *confirm* the influence of various characteristics on general commercial vehicle safety levels are detailed later in Chapter 3.

Driver Characteristics

Driver characteristics such as age, gender, residence/origin, condition (i.e., fatigued, under the influence of alcohol or drugs) and others are of interest when considering commercial vehicle safety. In reviewing the literature, a significant body of work has focused on the effects of fatigue on commercial vehicle safety and the factors contributing to fatigue (i.e., driving patterns). Limited work was uncovered that focused on the effects of driver age, experience, and condition on commercial vehicle safety (see Table 2).

Driver Fatigue

Fatigue is a physiological and psychological state that can be brought about by a number of factors. As noted by Dolyniuk (10), fatigue is greatly affected by external factors including shipper demands, travel speed, management and driver attitude, physical work involved, rates of pay, eating habits, shift start times, sleep cycles, time of day, the driver's mental and physical condition including sleep apnea, abuse to the hours of service regulations and enforcement or lack of enforcement.

Commercial vehicle drivers are susceptible to three types of fatigue: (1) industrial fatigue, arising from working continuously over an extended period of time without proper rest, (2) cumulative fatigue, arising from working too many days on any protracted, repetitive task without a prolonged break, and (3) circadian fatigue, caused by a deviation from the natural 24-hour rhythm of work that favors daytime over nighttime schedules. (11) Fatigue is manifested by a deterioration in performance including lapses in attention, lengthened and more variable reaction times, and poorer psychomotor control. (12) Linking this deteriorated performance with crash occurrence has been the focus of numerous historical investigations.

Table 2. Literature Related to Driver Characteristics.

FATIGUE		
1972	Harris and Mackie	*A Study of the Relationships Among Fatigue, Hours of Service and Safety of operations of Truck and Bus Drivers*
1978	Mackie and Miller	*Effects of Hours of Service, Regularity of Schedules, and Cargo Loading on Truck and Bus Driver Fatigue*
1985	AAA	*Report on the Determination and Evaluation of the Role of Fatigue in Heavy Truck Accidents*
1988	Hertz	*Tractor-trailer Driver Fatality: the Role of Non-consecutive Rest in a Sleeper Berth*
1990	Jones and Stein	*Effect of Driver Hours of Service on Tractor-Trailer Crash Involvement*
1991	Hertz	*Hours of Service Violations Among Tractor-trailer Drivers*
1991	Jovanis et al.	*Exploratory Analysis of Motor Carrier Accident Risk and Daily Driving Patterns*
1992	Kaneko and Jovanis	*Multi-day Driving Patterns and Motor Carrier Accident Risk: A Disaggregate Analysis*
1993	Lin et al.	*Modeling the Safety of Truck Driver Service Hours Using Time-Dependent Logistic Regression*
1995	NTSB	*Factors that Affect Fatigue in Heavy Truck Accidents*
1995	Dolyniuk	*Heavy Truck Accident Risk and the Role of Driver Fatigue – A Trucking Company Viewpoint*
1995	Saccomanno et al.	*Effect of Driver Fatigue on Commercial Vehicle Accidents*
1995	Smiley	*Fatigue, Truck Driving and Accident Risk*
1996	FHWA	*Commercial Motor Vehicle Driver Fatigue and Alertness Study*
1996	O'Donnell and Conner	*Predicting the Severity of Motor Vehicle Accident Injuries Using Models of Ordered Multiple Choice*
1997	Kreuger et al.	*Driver Loading and Unloading Study, Phase I, Tasks 1, 2, 3*
1999	Taylor and Sung	*A Study of Highway Rest Areas and Fatigue Related Truck Crashes*
AGE AND EXPERIENCE		
1982	Eicher et al.	*Large Truck Accident Causation*
1985	Chirachavala and Cleveland	*Causal Analysis of Accident Involvement for the Nation's Large Trucks and Combination Vehicles*
1991	Campbell	*Fatal Accident Involvement Rates by Driver Age for Large Trucks*
1994	Summala and Mikkola	*Fatal Accidents Among Car and Truck Drivers: Effects of Fatigue, Age and Alcohol Consumption*

To make such a link, Harris and Mackie (13) analyzed 500 crashes involving a large common carrier engaged in long-haul interstate operations during a one-year period. Researchers speculated that crash occurrence was affected not only by the number of hours driven (i.e., industrial fatigue) prior to the crash but also the expected length of trip, hence, incorporating the concept of crash exposure. They found that 62 percent of the crashes occurred in the second half of the trip, irrespective of trip duration.

Mackie continued this work with Miller (14) by examining data on 406 "dozing driver" crashes collected by the Bureau of Motor Carrier Safety (BMCS) in 1974. Expected and actual crashes percentages were compared for various driving times. Researchers were able to again confirm that significantly more crashes occurred during the second half of the trip suggesting the influence of industrial fatigue. However, unlike the work of Harris and Mackie (13), researchers found trip duration to be a significant determinant; trips of five or more hours in duration were found to have more crashes than expected. Researchers further discovered that crashes involving a dozing driver were seven times more likely to occur between midnight and 8 AM than in other hours of the day, with the highest risk occurring between 4 AM and 6 AM. This phenomenon is likely a result of circadian fatigue.

Rather than looking exclusively at fatigue-related crashes, the American Automobile Association (AAA) (15) reviewed 221 serious commercial vehicle crashes (where serious was defined as the truck being towed from the crash scene) to determine the likelihood of driver fatigue being the cause. For the purpose of this study, a crash was defined as "fatigue-related" if the driver's action was consistent with falling asleep (i.e., drifting across lanes) and if the driver exceeded a duty period of 16 hours. In-depth interviews with the truck drivers (if surviving) and a survey of logbooks and other receipts that could track actual driving time and routes were used to enhance the crash data. Even with the conservative definition of fatigue-related crashes, researchers found that fatigue was the primary cause in 40 percent and a contributing cause in 60 percent of serious commercial vehicle crashes.

In 1987, Jones and Stein (16) took a different approach to quantify the influence of fatigue on commercial vehicle crashes in a study conducted for the Insurance Institute for Highway Safety. Researchers, using driving time as a surrogate for fatigue (specifically industrial fatigue), conducted a case-control study to examine the relative crash risk associated with long hours of driving. For each commercial vehicle crash, three commercial vehicles were randomly selected from the traffic stream at the same time and place of the crash, but one week later. A sample of 332 tractor-trailer crashes, each with one, two or three control measures was extracted for analysis. Researchers found that drivers: (1) driving in excess of eight hours, (2) who violate logbook regulations, (3) age 30 and younger and (4) engaged in interstate carrier operations had an increased risk of crash involvement. In particular, the relative risk of crash involvement for drivers who reported a driving time in excess of eight hours was almost twice that of drivers who had driven fewer hours.

Jovanis, et al. (17) built upon this earlier work by Jones and Stein (16) by investigating the effects of driving at different times of day within one day and over several days on crash risk. Researchers analyzed crash and non-crash data from a less-than-truckload carrier representing 6 months of operation in 1984. Cluster analysis was used to extract a distinct pattern of driving over a 7-day period from a sample of 1,066 drivers. The analysis included clear interpretable driving patterns that could be associated with risk. Higher risk was generally, but not exclusively, associated with extensive driving in the two to three days before the day of interest. The two patterns with the highest risk of a crash were those that contained heavy driving the preceding three days (i.e., cumulative fatigue) and consisted of driving: (1) from 3 PM to 3 AM (Pattern 1) and (2) from 10 PM to 10 AM (Pattern 8) suggesting the effects of circadian fatigue. The lowest risk was associated with driving from 8 PM to 6 AM but with limited driving in the preceding three days. The findings suggest that despite the limitless possible combinations of driving schedules, it is possible to find and extract patterns of multi-day driving associated with different levels of crash risk.

Turning focus again to the effects of industrial and circadian fatigue rather than cumulative fatigue, Lin, Jovanis and Yang modeled the effect of driver service hours (18) and time of day (19) on heavy truck crashes using a time dependent regression model. Specifically, the models estimate the probability of having a crash at time interval, t, subject to surviving (not having a crash) before that time. Using the same sample of data from 1984, logistic regression models were estimated that included: (1) time-dependent effects (i.e., age, experience, multi-day driving pattern, off-duty time before the trip of interest, etc.), (2) time main effects (driving time) and (3) a series of time related interactions. In the first study, researchers found driving time to have the strongest direct effect on crash risk. The first four hours of driving consistently have the lowest crash risk. Crash risk increases significantly after the fourth hour by approximately 65 percent until the seventh hour and approximately 80 percent and 150 percent in the eighth and ninth hours, respectively. Multi-day driving patterns had a marginal effect on the subsequent crash risk although daytime driving, particularly in the three days before the trip of interest, resulted in the lowest crash risk. Also, driving patterns involving some type of nighttime driving had an elevated crash risk. In the second study, researchers found daytime driving, particularly between 10 AM and noon to result in a significantly lower risk of a crash. Drivers at one time of day, 4 PM to 6 PM, have a crash risk about 60 percent higher than those driving during the baseline. Drivers during three other times of day involving night or dawn driving, experience accident risks about 40 percent higher than the baseline. Rest breaks, particularly those taken before the 6th or 7th hour of driving, appear to lower crash risk significantly for many times of day.

Previous findings related to elevated crash risk during nighttime hours was confirmed by the National Transportation Safety Board (NTSB) in 1995. (20) NTSB examined commercial vehicle, single-vehicle crashes occurring only at night. Of the 107 crashes where the commercial vehicle driver survived and in which the previous 96 hours could be reconstructed, the study found that 58 percent of the crashes had fatigue, specifically circadian fatigue, as a probable cause.

Saccomanno et al. (11) carefully constructed a study to investigate the influence of both industrial and circadian fatigue. Since fatigue cannot be measured directly, circadian fatigue was inferred from nighttime driving. Industrial fatigue was measured in terms of driver-reported hours of driving without rest. Driving in remote areas was taken as a second surrogate for industrial fatigue. Researchers used data from four sources in Ontario: (1) motor vehicle crash data for 1988-1989, (2) geometric highway characteristics by section from the Highway Inventory Management System, (3) traffic volumes, directional splits and percentage commercial vehicle traffic from the Traffic Volume Information System and (4) a commercial vehicle survey conducted at 75 locations throughout the Province. Using Analysis of Variance (ANOVA), researchers confirmed that road sections in northern Ontario have higher fatigue-related commercial vehicle crash rates due to longer driving distances (i.e., industrial fatigue) and perhaps increased levels of circadian fatigue. An appreciable increase in crash rates was found to occur for more than 9.5 hours of driving without proper rest. Higher fatigue-related crash rates were also noted at nighttime (i.e., circadian fatigue) as compared to daytime over the entire highway network. Further, the effect of circadian fatigue seems to be additive to the effect of industrial fatigue. In the northern region where driving distances are longer, the nighttime single-vehicle crash rate is 3.3 times higher than the daytime rate. A similar relationship was found in the southern region; the nighttime single-vehicle crash rate is 2.3 times higher than the daytime rate.

In reviewing previous studies related to commercial vehicle driving hours, it is important to note that violations to hours of service regulations likely contribute to general levels of safety. In a study conducted in 1991, Hertz (21) investigated hours of work violations in the U.S. Commercial vehicle drivers were interviewed at inspection stations and later observed arriving at sites in two cities 1,200 miles from their initial inspection site. Assumptions were made about average travel speed based on literature and fleet manager's estimates. Even with the most liberal estimate of the speed that could be achieved, fully half of the drivers were in violation of work hour regulations. (21)

Though addressed cursorily, few previous studies have focused specifically on the effects of rest breaks or sleep habits on fatigue-related crashes. Hertz (22) examined the impact of the use of sleeper berths on crash causation by comparing sleeper berth use between a sample of 418 fatally-injured tractor-trailer drivers to that of 15,692 non-injured drivers involved in property damage only crashes. Hertz found that the use of a sleeper berth in two shifts increased the risk of a fatal crash by a factor of three and that the risk of a crash was as high for drivers driving alone as for drivers driving in a team. In other words, the risk due to sleeper berth use does not appear to arise because of sleep disturbance due to the motion of the truck but rather because of the splitting of sleep into two periods. Rural roads, clear weather and dark conditions, all of which contribute to reduced stimulation, were identified as contributing factors for sleeper berth use-related crashes.

Taylor and Sung (23) most recently evaluated the effects of rest area availability on fatigue-related commercial vehicle crashes. In this study, the occurrence of a nighttime crash was used as the surrogate measure for fatigue-related crashes. Researchers developed a statistical hazard model to measure the probability that a crash will occur in a designated distance interval to the last rest area, given that the crash has not occurred in a prior interval. The study considered rural interstates in Michigan totaling approximately 1,080 miles. The study found that the probability of a nighttime single-vehicle crash occurring on a rural freeway segment increases when the distance to the last rest area exceeded 30 miles. This phenomenon continues for a distance of at least up to 50 miles.

Age and Experience

A second area of focus for driver characteristics contributing to commercial vehicle safety levels in the literature found was driver age and related experience. Eicher et al. (24) found that young drivers are involved in a disproportionately high number of large truck crashes. Drivers under age 30 comprise less than 15 percent of all large-truck drivers but account for 30 percent of the drivers of large-trucks involved crashes.

Campbell (25) performed a study on the implications of lowering the minimum age for commercial vehicle drivers from 21 to 19. Utilizing Fatal Accident Reporting System (FARS) data and MCS-50T reports for the years 1980 to 1984, a relative risk analysis was performed whereby the percent of involvement (i.e., crashes) for a given age bracket was compared to the percent of total travel by that age group. Results of this study showed that the 19 to 20 age group had the greatest risk of being involved in a crash with a relative risk 6 times that of a driver over the age of 26. In general, it was found that drivers under the age of 26 are anywhere from one to six times as likely to be involved in a crash as a driver over the age of 26.

O'Donnell and Connor (26) employed ordered probit and ordered logit statistical techniques to model the linkages between road user attributes and the probability of being injured in a crash. The authors utilized approximately 18,000 records from the Road

Traffic Authority from the year 1991. As a benchmark for comparison, the authors considered the risk of a 33-year-old male driving a 10-year-old car in a head on collision while driving 42 km/hr (26 mph). Probabilities for this benchmark victim were then estimated to be almost zero for no injuries, 0.7 for the requirement of needing treatment from a medical officer, 0.3 for the need to be taken to a hospital, and almost zero for fatality. The analysis found that women are more likely to sustain serious injury than men, and that the probability of serious injury and death increases with the speed of the vehicle, age of the driver, and age of the vehicle. It was noted, however, that the effects of increasing the driver age from 33 years to 50 years were greater than the effects of increasing vehicle speed from 42 to 100 km/hr (26 to 62 mph).

Chirachavala and Cleveland (27) discovered that driver experience was more prominent for truck crash involvement rates than driver age. Specifically, drivers with less than a year of experience had higher crash involvement rates than drivers with two or more years of experience. Lin, Jovanis and Yang (18) supported this finding. The most experienced drivers, those driving more than ten years, had the lowest accident risk, while all other driver age groups had risks at least 67 percent higher than these safest drivers.

Driver Condition

Surprisingly few studies were uncovered that focused on driver condition for large truck involved crashes. Shao (28) analyzed crashes involving passenger cars and single-unit trucks in the Baltimore/Washington D.C. area utilizing FARS data from 1983 to

1984. The resulting 1697 crashes were analyzed using factor analysis with the crash data segmented into three groups: (1) driver conditions such as age, sex, and experience; (2) vehicle conditions such as no defects, or defects in the brakes, lights, etc. and (3) environmental conditions such as weather and road conditions. The resulting analysis showed both car driver condition and truck driver condition were among the top three explanatory variables. However, it was shown that for all cases approximately 10 percent of the car drivers were reported to have been in an unsafe driving condition while only 1.4 percent of truck drivers were in such a state.

All of the studies uncovered related to driver characteristics considered the effect of these factors on crash occurrence rather than severity.

Vehicle Characteristics

When considering the effects of vehicle characteristics on commercial vehicle safety, the vehicle's configuration, number of axles, cargo body type, gross vehicle weight rating and other factors may be of interest. In reviewing the related literature, the focus almost exclusively centered on vehicle configuration. A smaller body of literature was identified that focused on other aspects such as the effect of the vehicle's mechanical condition on safety (see Table 3).

Table 3. Literature Related to Vehicle Characteristics.

CONFIGURATION		
1984	Chirachavala and Kostyniuk	*Severity of Large-truck and Combination-vehicle Accidents in Over-the-road Service: a Discrete Multivariate Analysis*
1985	Chirachavala and Cleveland	*Causal Analysis of Accident Involvement for the Nation's Large Trucks and Combination Vehicles*
1986	TRB	*Special Report 211: Twin Trailer Trucks*
1987	Carsten	*Safety Implications of Truck Configuration*
1988	Campbell	*Analysis of Accident Rates of Heavy-duty Vehicles*
1988	Stein and Jones	*Crash Involvement of Large Trucks by Configuration: A Case-Control Study*
1989	Jovanis et al.	*Comparison of Accident Rates for Two Truck Configurations*
1989	Council and Hall	*Large Truck Safety in North Carolina: Phase I-Final Report*
1990	Mingo	*Safety of Multi-combination Vehicles*
1991	Blower	*Trucks Involved in Fatal Accidents, 1980-1988, by Power Unit Type*
1993	Blower et al.	*Accident Rates for Heavy Truck-Tractors in Michigan*
1997	Braver et al.	*Tractor-trailer Crashes in Indiana: A Case-Control Study of the Role of Truck Configuration*
SIZE AND WEIGHT		
1981	Vallette et al.	*The Effect of Truck Size and Weight on Accident Experience and Traffic Operations*
1983	Polus and Mahalel	*Truck Impact on Roadway Safety*
VEHICLE DESIGN		
1978	Philipson et al.	*Statistical Analysis of Commercial Vehicle Accident Factors*
1981	Campbell and Carsten	*Fleet Accident Evaluation of FMVSS 121*
MECHANICAL CONDITION		
1989	Jones and Stein	*Defective Equipment and Tractor-Trailer Crash Involvement*
1993	Gou et al.	*Effects of Heavy-Vehicle Mechanical Condition on Road Safety in Quebec*

Vehicle Configuration

Vehicle configuration is at the crux of an ongoing balance between efficient and economical freight movement and public safety. Efficiency proponents support the use of ever-larger trucks while safety proponents tout the risks involved. In line with this issue, a significant amount of literature focused on the use of twin trailer trucks (a truck-tractor pulling two trailers) as compared to traditional tractor semi-trailers (a truck-tractor pulling a single trailer) referred to from this point forward as "doubles" and "singles," respectively.

In 1986, the Transportation Research Board (TRB) published findings from 14 different historical studies that considered both vehicle handling characteristics and crash experience of singles and doubles in *Special Report 211* (see Table 4). (29) Of the 14 studies reporting crash rates for singles and doubles, only five: (1) were free from obvious methodological flaws, (2) made reasonable attempts to minimize the obscuring effects of the operating environment, and (3) reflected crash experience under all conditions typical of roads throughout the nation. These five studies, denoted with shading in Table 4, included:

- Yoo et al. (30),
- Chirachavala and O'Day (31),
- Glennon (32),
- Bureau of Motor Carrier Safety (BMCS) (33) and
- Graf and Archuleta (34).

The relative crash rates of singles and doubles reported in these studies were extremely variable and conflicting. Note the following findings from three of the most comparable studies. Doubles have:

- 2 percent lower (31),
- 6 percent higher (32) or
- 12 percent higher (34)

overall crash rates than singles. Perhaps such large differences should not be surprising. The trucks included for study in each case differed with respect to the number of axles and trailer type. The range of highway types and geographical regions in which the trucks operated also differed from study to study. Lastly, the data for each study were often limited in both accuracy and quantity.

Using discrete-multivariate analysis, Chirachavala and Cleveland (27) considered the crash causation. Researchers used: (1) crash data from the BMCS comprising 74 variables (i.e., the place and time of the crash, events leading to the crash, crash consequences, driver and occupation, vehicle description, road condition and some environmental conditions) and over 30,000 reported crashes involving interstate carriers, and (2) truck mileage and use data from the Highway Cost Allocation Study (HCAS) which comprised 96 variables (i.e., vehicle factors, operating characteristics). The BMCS file served as the case sample and the HCAS file served as the control sample. The probability of crash involvement and the independent variables available in both files was quantified through the development of a log-linear regression model. The influence

Table 4. Comparative Studies of Singles versus Doubles. (29)

YEAR	AUTHOR	DATA SOURCE	DATA SPAN	COMMENTS
1969	FHWA	Consolidated Freightways and Pacific Intermountain Express, western states	1964-1968	Insufficient documentation, unavailable carrier data
1971	Scott and O'Day	Indiana Toll Road Commission	1966-1970	Limited data, five-axle twins not evaluated
1973	Zeiszler	Rural roads and incorporated freeways, California	1972	Questionable exposure estimates, possible operational differences
1975	Iowa Department of Transportation	Interstate carriers	1974	Insufficient documentation, unavailable carrier data
1978	Fleischer and Philipson	Main roads, two areas of California	1975-1976	Possible operational differences, uncertain exposure estimates, findings preliminary
1978	Yoo, et al.	Rural roads and urban freeways, California	1974	
1981	Campbell and Carsten	Nationwide intercity, ICC-authorized carriers, 1977 model-year tractors	1977	Limited data
1981	Chirachavala and O'Day	Nationwide intercity van trailers, ICC-authorized carriers	1977	
1981	Glennon	Consolidated Freightways, nationwide	1976-1980	
1981	Vellette et al.	Urban and rural freeways and non-freeways, California and Nevada	1976-1977	Unreliable exposure estimates
1982	Popoff	Provincial highways, Saskatchewan	1980	Limited data, possible operational differences, findings preliminary
1983	BMCS	Nationwide interstate carriers	1969-1980	
1983	Manning	Rural state highways, Idaho	1982	Possible operational differences, five-axle twins not evaluated separately, insufficient documentation
1985	Graf and Archuleta	Rural and urban roads, California	1979-1983	

of other factors missing from the HCAS file (control sample), such as road class, day-night, road surface condition, region of the country, loading status, driver age, driver experience, etc. were assessed using contingency table methods. Findings from this study for the subsets of straight trucks and combination vehicles are as follows:

For straight trucks, higher crash rates were noted for:

- 2-axle trucks,
- newer trucks engaged in local service and
- local service.

For combination vehicles, higher crash rates were noted for:

- single or double flatbeds engaged in over-the-road service;
- single vans engaged in local service;
- doubles for the majority of vans, tankers and flatbeds configurations;
- doubles with 2-axle tractors;
- singles with 3-axle tractors;
- newer singles engaged in local service and
- local service with vans and tankers.

In a study conducted by the University of Saskatchewan, Sparks and Beilka (35) compared single and double crash rates in Saskatchewan. Crash data, spanning 1983 to 1985, were obtained from two independent sources: (1) province-wide police crash reports and (2) crash reports from two large commercial fleets. Researchers found that uncertainties in the estimation of the percent of trucks in the traffic stream and the percent of doubles within the truck fleet have the greatest influence on the estimated crash rates.

Campbell et al. (25) considered only fatal crashes obtained from the TIFA database from 1980 to 1984. This crash data was supplemented with travel-related information from the TIUS from 1985 to 1986. In all, the sample comprised 16,260 single-trailer crashes and 829 double-trailer crashes. An obvious flaw in this study is noted at the onset; miles traveled by doubles increased rapidly after 1982. Therefore, the use of 1985-1986 travel data paired with 1980-1984 crash data may underestimate crash rates for doubles.

In 1988, Stein and Jones (36) again used a case-control methodology (previously used to determine the effects of fatigue on commercial vehicle safety) to compare crash involvement with doubles and singles in a second study sponsored by the Insurance Institute for Highway Safety. A sample of 676 truck crashes on Washington Interstates between June 1984 and July 1986 was considered. Of these 676 crashes, 467 involved singles and 152 involved doubles. The crash location, day of week and time of day were used to establish a control sample for comparison. The relative involvement of the case and control sample was used to calculate over-involvement ratios. Stein and Jones found that doubles were consistently over-involved in crashes by a factor of 2 or 3. The over-involvement of doubles was found regardless of driver age, hours of driving, cargo weight or type of fleet. While this matched, case-control approach overcame previous shortcomings by accounting for differences in travel patterns between single and double vehicles, the inconsistency of these findings when compared to previous findings raises doubt for this technique.

In a comparable study, Jovanis, Chang and Zabaneh (37) collected industry-supplied data from national, less-than-truckload carriers from 1983 to 1985. The researchers compared the crash experience of singles and doubles on the same routes for three years. This paired structure essentially controls for roadway, environment and traffic conditions. Further, separate comparisons of crash experience were conducted on access and non-access controlled highways, local streets and parking lots. The total sample comprised 376 single-trailer crashes and 507 multiple-trailer crashes. Using the paired t-test to investigate the mean difference in crash rates of singles and doubles, the researchers found that doubles experienced lower crash rates than singles in 1983 and 1985 but experienced higher crash rates in 1984 which was a year of greatly expanding doubles operation. These findings were consistent over all operating environments. However, large variations in year-to-year crash rates suggest potential small sample problems.

Council and Hall (38) considered all crashes in North Carolina between 1981 and 1987. Researchers compared proportions of crashes by specific type among different truck configurations. The study was inconclusive in determining whether multiple-trailer vehicles have an increased frequency of crashes.

Most recently, Braver et al. (39) conducted a case-control study that permitted the evaluation of crash experience of double- and single-trailer vehicles during October 1989 to March 1991 on Interstate highways in Indiana. Police reported truck-involved crashes provided the crash data while control observations were made using field tallies and video at the same site. In all, 2,033 crashes were recorded during the data collection period. During this same time period, 62,919 control tractor-trailers were observed at the site of the crash on the same day of the week at the same time of day one to four weeks following a crash. Some data was available on tractor-trailer ownership from published motor carrier directories or Interstate Commerce Commission (ICC) records. Also, some driver characteristics were obtained from the police records. A multivariate logistic regression model was used to (1) analyze the effects of a set of variables on the probability of a control tractor-trailer being a double or single trailer combination vehicle and (2) predict the probability of each case being a double based on the cases' characteristics. In the first step, researchers found the time of day, week or weekend day, urban or rural area and specific highway to be significant predictors of whether a control vehicle had one or two trailers. In the second step, this same logistic regression model was used to predict the probability of each case having two trailers based on whether the crash had occurred during the week or weekend, at what time of day, in an urban or rural setting, or on a specific highway. The standardized crash ratio was used as a comparison measure between observed and expected. Authors noted no overall increase in crash risk between doubles and singles. Because truck configuration was highly associated with driver age and work operation attributes in crashes, the absence of control data on these specific potential confounders limits the conclusions.

Thus far, vehicle configuration affects on crash frequency has been discussed. TRB also considered work to date on crash severity differences between singles and doubles (see Table 5). Of the studies completed, comparable studies found that double-unit trucks have:

- 7 percent lower,
- 5 percent higher or
- 20 percent higher (29)

fatality crash rates than single-unit trucks.

Analysis of crash severity is complicated by the absence of a commonly accepted measure of severity. For the purposes here, the more severe crashes are considered to be those with more deaths, more injuries, or more vehicles involved. A second complicating factor is that there is no commonly accepted collective severity measure for a set of crash data. Either of two approaches has been used. The first examines the distribution of crash types by severity level. For example a commonly used indication is the proportion of crashes that result in casualty. The second approach expresses the average consequence of a crash (i.e., the average number of deaths per crash).

In the limited number of studies in which crash severity has been expressed by deaths or by fatal crash involvements, crashes involving doubles have usually been found to be more severe than those of singles (29). The remaining comparisons that evaluate severity by the distribution of crashes by severity level suggest that crashes involving singles may be more likely to result in injury, as follows:

- a larger proportion of double crashes result in death than do single crashes and
- a larger proportion of single crashes result in nonfatal injury than do doubles. (29)

These findings related to crash severity are inconclusive for the following reasons:

- many of the reported differences between doubles and singles were not found to be statistically significant,
- the completeness of many of the databases, particularly the property damage only-crash components, is suspect,
- the number and overall quality of the investigations is limited and
- attempts to control for the influence of operating environment in the relative crash severity investigations were either limited or nonexistent. (29)

At the same time TRB was producing *Special Report 211*, Chirachavala was continuing work in this area with Kostyniuk (40) to investigate crash severity using 1980 BMCS data. The analysis was based on 19,263 crashes of vehicles engaged in over-the-road operation. A two-stage discrete multivariate analysis procedure was used. The first stage involved selecting significant independent variables from 18 candidate variables. The second stage involved modeling crash severity by using two independently estimated logit models: one for the probability of a reported crash being fatal and the other for the probability of a less-severe crash having non-fatal injuries.

Differences in the effect of the variables for four predominant truck types (straight trucks, singles with van, singles with flatbed or tanker, and doubles) led to their separate analysis. The crash severity model for each truck type shared common variables and interactions: the main effects of type of collision (i.e., single-vehicle or collision with car or commercial vehicle), road class (i.e., number of lanes, median separator and rural or urban setting) and environment (i.e., day or night, road surface wetness condition).

Table 5. Comparative Studies of Single versus Double Crash Severities. (29)

YEAR	AUTHOR	DATA SOURCE	DATA SPAN	SEVERITY MEASURE
1971	Scott and O'Day	Nationwide, BMCS	1969	Average number of deaths and injuries: ▫ per accident (all severities) ▫ per accident with automobiles (all severities)
1973	Zeiszler	Rural roads and incorporated freeways, California	1972	Average number of casualties and involved vehicles per casualty accident
1975	Iowa Department of Transportation	Interstate carriers	1974	Average number of deaths per accident (all severities)
1977	Hedlund	Nationwide, residential or business, rural, two lanes, four or more lanes	1973-1974	Odds of fatality to automobile occupant in automobile-truck accidents (all severities)
1978	Yoo et al.	Rural roads and urban freeways, California	1974	Average number of deaths and casualties per casualty accident (all severities)
1978	Philipson et al.	Conventional two-way roads, two areas of California	1975-1976	Fraction of accidents (all severities) resulting in major casualty to: ▫ automobile occupant ▫ truck occupant
1981	Chirachavala and O'Day	Nationwide intercity van trailers, ICC-authorized carriers	1977	Fraction of accidents (all severities) resulting in: ▫ death ▫ nonfatal injury ▫ casualty
1981	Glennon	Consolidated Freightways, nationwide	1976-1980	Average number of casualties per accident (all severities)
1981	Vallette et al.	Urban and rural freeways and non-freeways, California and Nevada	1976-1977	Fraction of single-vehicle and multiple-vehicle accidents (all severities) that result in casualty to: ▫ truck occupant ▫ occupant not in truck
1983	BMCS	Nationwide interstate carriers	1969-1980	Average number of deaths and casualties per accident (all severities)

The interactions involving road class and environment, and road class and collision type were most frequently significant. No driver characteristics were found to be significant. Particularly severe crashes were collisions involving passenger cars and doubles, straight trucks or loaded flatbed or tanker singles on undivided rural roads, collisions involving cars and van singles on undivided rural roads at night and collisions involving cars and doubles on divided rural roads.

Carsten (41) completed a study to address the safety implication of a truck's configuration, particularly focusing on the severity of a crash. The data used for the study was obtained from the University of Michigan Transportation Research Institute (UMTRI), the BMCS crash reports for 1982 and data from the National Accident Sampling System (NASS) for 1981 to 1884, the USDOT Office of Motor Carriers, Trucks Involved in Fatal Crashes (TIFA) for 1980 to 1982 and the Truck Inventory and Use Survey (TIUS) for 1982. Researchers qualitatively compared involvement rates per 100-million vehicle miles traveled by the number of trailers (i.e., single or double), fatal or injury, road type (i.e., urban interstate, urban non-interstate, rural interstate, rural non-interstate, or unknown), road class (i.e., divided or undivided), single- or multi-vehicle involvement, first and most harmful event (i.e., collision with motor vehicle in transport, collision with pedestrian, etc.), and rollover, jackknife or non-collision.

Highway experience did not show a higher fatal or injury crash involvement rate for doubles. Nevertheless, this finding must be tempered by the fact that doubles are used in safer operating environments. Also, double drivers may be able to compensate for different vehicle handling characteristics. The crash data does suggest, however, handling-related problems for doubles, particularly in one-vehicle collisions and rollovers.

Blower et al. (42) examined injury and property damage crashes obtained from Michigan State Police crash files for 1987 to 1988. Travel-related information was captured through a survey of 1,055 Michigan registered trucks over the same time period. The sample comprised 1,153 severe to moderate injury crashes and 4,026 property damage to minor injury crashes involving single trailer trucks and 144 severe to moderate injury and 365 property damage to minor injury double trailer trucks. Differences between single- and multiple-trailer vehicles were non-significant after adjusting for road type, time of day, and urban/rural locations though there was some evidence of doubles having increased injury crash risk on smaller roads.

Size and Weight

Closely related to vehicle configuration is the vehicles' size and weight. Vallette et al. (43) concluded that truck crash rates varied inversely with truck weight for both double and single trailer combinations. Among the effects surveyed were those of roadway geometry, roadside features and wide loads.

Polus and Mahalel (2) studied differences in safety performances between various gross vehicle weight (GVW) groups of trucks in Israel. The data used for this study included two sources: (1) the vehicle registration file and (2) the police crash file from 1979 to 1981. The following conclusions were drawn from this study:

- a decreasing trend in crash rate exists with increasing GVW,

- a crash in which a heavy truck is involved will likely be more fatal than a crash involving a light truck,
- the number of injuries in a crash involving truck is higher than for a non-truck involved crash,
- a decreasing truck driver injury trend exists with increasing GVW,
- the heavier the weight of the truck, the greater the proportion of interurban crashes in which it is likely involved and
- trucks are more likely to be involved in crashes at intersections, grades and curves given their weight, structure and operational characteristics.

Vehicle Design

Limited work has been done investigating the effects of vehicle design on commercial vehicle safety. Philipson et al. (44) investigated the effects of cab-over-engine versus conventional tractor designs and found that crashes involving cab-over-engine tractors are significantly more likely to result in a fatality or major injury. Campbell and Carsten (45) supported this finding; the fatal crash involvement rate is greater for cab-over-engine tractors than for conventional tractors.

Mechanical Condition

Jones and Stein (46) explored the relationship between defective equipment and crash involvement in Washington State. Logistic regression models were used to analyze data collected on truck components (e.g., brakes, steering, and tires) from June 1984 through

July 1986 on Washington's Interstate 90 and Interstate 5. Data on a total of 676 crashes involving 734 single trucks, as well as data from three random stops at each crash site one week after the incident, were used in the analysis. The authors found that 77 percent of single trucks involved in crashes had defective equipment warranting citation as compared to 66 percent of those randomly sampled and that 41 percent involved in crashes had defects warranting taking the vehicle out of service as compared to 31 percent of those not in crashes. Additional findings were that brakes were the most common defect, appearing in 56 percent of the crashes, while steering defects appeared in 21 percent of the crashes. The authors found no association between wheel and tire defects and vehicle crashes.

Gou et al. (47) also conducted a study of the effect of heavy-vehicle mechanical condition on road safety. In the Province of Quebec, 195 crashes were considered over a two-year time period. Looking descriptively at the data, the authors found that heavy vehicle mechanical condition is responsible for 10 to 20 percent of the crashes involving heavy vehicles in Quebec. Approximately 13 percent of crashes involving heavy vehicles result from non-compliant mechanical components on those vehicles and that the braking system is the most frequent cause of crashes involving mechanical defects. Furthermore, the study found that, disregarding crash causes, heavy vehicles with major non-compliant components have a propensity to be involved in a crash that is five times higher than that of compliant vehicles.

Other contributing factors identified in the crashes was direct or indirect human factors (73 percent), weather conditions (10 percent), and improperly secured or unbalanced loads (2 percent). Also of note, out of the 195 heavy vehicle drivers involved in crashes, almost 50 percent already had at least one demerit point in their personal files, four drivers did not have an appropriate drivers license, and three had suspended licenses. Also, bulk-transport heavy vehicles were found to comply less with standards than other vehicles.

Cargo Characteristics

Of interest with respect to cargo characteristics is whether commercial vehicle safety is affected by the cargo's presence (i.e., loaded or empty), type, method of containment, level of hazard or other. Limited literature was found to support investigation into any of these topics.

Chirachavala and Cleveland (27) found that tankers, flatbeds (singles and doubles) and straight trucks had a higher crash rate when loaded rather than empty. The proneness to crashes involving empty trucks varies from company to company depending on how much time they run empty trucks.

Carrier Characteristics

Carrier characteristics that may be of interest when considering commercial vehicle safety include the location of the carrier's base state, the type of classification of carrier, the carrier's type of operation, the fleet size, driver base and other. Few studies were found that actually investigated carrier-related characteristics and their effect on commercial vehicle safety.

In a survey conducted by Campbell and Carsten (45), the authors found that fleets with fewer than 50 trucks had an average fatal crash involvement rate more than twice that of fleets with more than 50 trucks. The authors also found that fatal and injury crash involvement rates are greater for ICC-authorized carriers than for non-authorized carriers.

In 1983, the BMCS confirmed that carrier characteristics are correlated to crash rates. In a survey of companies reporting truck crashes in 1982, firms operating between 45 and 1,000 trucks report 20 percent higher crash rates than firms operating over 1,000 trucks.

Most recently, McCarthy (48) used an aggregate time series model to determine the effect of a carrier's truck fleet size on crash severity. The study concluded that for a one-percent increase in truck fleet size, the fatality rate increased 0.612 percent. In addition, a one-percent increase in truck fleet size produced an increase ranging from a 0.83 to 0.93 percent increase in the fatality rates on roads disaggregated by type and environment. However, no effect with regard to fleet size was identified on rural non-interstate roadways.

Operating Environment

Obviously, other factors such as roadway, traffic, environmental and even crash characteristics contribute significantly to commercial vehicle safety levels, yet few studies have comprehensively addressed these confounding factors (see Table 6). The majority of these prior investigations has focused on the effects of roadway geometrics.

TRB's *Special Report 211* (29), which considered both vehicle handling characteristics and crash experience of singles and doubles, summarized the following findings related to the roadway. Crashes are more severe:

- on rural highways than on urban highways (49),
- on two-lane rural highways than on four-lane rural highways (49) and
- on undivided rural highways than on divided rural highways (40)

Table 6. Literature Related to Operating Environment.

ROADWAY CHARACTERISTICS		
1985	Graf and Archuleta	Truck Accidents by Classification
1985	Wright and Burnham	*Roadway Features and Truck Safety*
1986	Jovanis and Chang	*Modeling the Relationship of Accidents to Miles Traveled*
1986	TRB	*Special Report 211*
1986	Ervin et al.	*Impact of Specific Geometric Features on Truck Operations and Safety at Interchanges*
1989	Firestine et al.	*Improving Truck Safety at Interchanges*
1991	Miaou	*Development of Relationships Between Truck Accidents and Highway Geometric Design*
1993	Miaou and Lum	*Statistical Evaluation of the Effects of Highway Geometric Design on Truck Accident Involvement*
1994	Miaou	*The Relationship Between Truck Accidents and Geometric Design of Road Sections: Poisson Versus Negative Binomial Regressions*
1998	Chang and Mannering	*Analysis of Vehicle Occupancy and the Severity of Truck- and Non-truck-involved Accidents*
TRAFFIC CHARACTERISTICS		
1974	Hall and Dickenson	*Truck Speeds and Accidents on Interstate Highways*
1995	Liu et al.	*Effect of Road and Traffic Characteristics on Accidents Involving Heavy Goods Vehicles (HGVs)*

Fatal and injury crash involvement rates are greater:

- on rural highways than on urban highways (50),
- on two and three lane highways than on freeways (50) and
- for local movements than for intercity movements (45).

The odds of occurrence of a high-severity injury are greater:

- on conventional highways than on freeways or expressways (44)

Graf and Archuleta (34) found that combination-vehicle crashes over a five-year period on each of 18 road segments differed by a factor of six between the roads with the highest and lowest rates. The road type with the lowest rate is a rural interstate; the highest rural rate is for an undivided highway and the highest overall rate is for an urban non-interstate freeway.

Wright and Burnham (51) used multiple linear regression and factor analysis to study the effects of selected roadway features on truck crash and severity rates. Crash rate, expressed as crashes per hundred million vehicle miles traveled, served as the dependent variable. The results indicated increasing crash rates with increases in the percent of:

- total mileage with two lanes,
- two-lane mileage with substandard horizontal curvature,
- two-lane mileage with substandard vertical curvature and
- two-lane mileage with substandard pavement width.

Only one of these independent variables, percent of two-lane mileage with substandard vertical curvature, was found to be statistically significant at the 95-percent confidence level. Further, this overall relationship resulted in a R^2 value of 0.36

indicating limited explanatory ability. The appropriateness of using multiple linear regression was questioned due to its lack of ability to account for the non-negative nature of crash occurrence.

To overcome this model from shortcoming, Jovanis and Chang (52) modeled the effects of traffic volumes and weather on truck crashes using Poisson regression. Crash data was collected for trucks on the Indiana Toll Road in 1978. Exposure was estimated from the number of tolls collected at each exit booth. During the study period, a sample of 700 truck crashes was observed. Independent variables included vehicle-miles traveled for trucks and hours of snow and rain during the study. The dependent variable was expressed as the expected number of truck crashes per day.

Using a similar methodology, Miaou and Lum (53) demonstrated ways in which the Poisson regression model can be use to evaluate the effects of highway geometric design on truck crash involvement rates and estimate expected reductions in truck crash involvement from various improvements in highway geometric design. The data source used in this study was the Highway Safety Information System (HSIS). Among the five HSIS states available at the time of the study, Utah had the most complete information on highway geometric design and was selected for illustration. Five years of highway geometric, traffic, and truck crash data for rural interstate highways in Utah from 1985 to 1989 were used. The sample comprised 1,643 large truck crashes. With respect to traffic and roadway characteristics, the expected number of truck crashes increases as each of the following increases:

- average annual daily traffic (AADT),

- the degree of horizontal curvature,
- the product interaction of degree of horizontal curvature and length of curve,
- the vertical grade,
- the product interaction of vertical grade and length of grade and
- deviation of paved inside shoulder width from 12 feet.

The expected number of truck crashes decreased as the percent of trucks in the traffic stream increased.

Miauo (54) support many of these findings when he applied Poisson and negative binomial regression to explore the relationship between truck crash occurrence and highway geometric designs and other factors.

Most recently, Chang and Mannering (55) investigated the effects of vehicle occupancy and a variety of operating environment characteristics on crash severity for both trucks and non-trucks using data collected from reported traffic crashes occurring on principal arterials, state highways and interstate highways in King County, Washington during 1994. Using a nested logit model structure, the study found that for single-occupant truck-involved crashes, a property damage only crash is more likely to occur on the weekend and if the crash involved a truck and less likely to occur if the vehicle was making a left turn. A possible injury crash is more likely to occur:

- if the posted speed is 55 MPH or higher;
- at nighttime;
- if the driver is age 25 or younger;

- if a passenger car, small truck or truck was involved and as the number of vehicles involved increased;
- if the vehicle was making a right turn, if collision occurred from the opposite direction at an angle, was rear-ended, or was entering/leaving driveway;
- if the vehicle had defective equipment.

A possible injury crash is less likely to occur:

- during rush hour,
- in a rural area,
- if the vehicle was making a left turn or failed to grant right of way or
- if the driver was inattentive.

And an injury/fatality crash is less likely to occur if the driver was inattentive but more likely to occur:

- if the posted speed is 55 MPH or higher or if the driver was speeding;
- at nighttime;
- if the road surface is dry;
- if driver resides within 15 miles, was female or was not using restraint system or
- if crash was off the road, rear end, if collision occurred from the opposite direction at an angle.

Crash Characteristics

The specific circumstances of a crash, such as the number of vehicles involved, the collision type, etc. have a significant impact on crash severity levels. Golob et al. (56)

studied the relationships between the type of collision (e.g. head on, broadside, etc.) and crash characteristics such as severity and incident duration. The data used for this study included over 9,000 crashes involving large trucks that occurred during the two-year period on freeways in the Los Angeles area. The data was organized into three categories: (1) type of collision, (2) crash severity, and (3) incident duration and lane closures. Utilizing log-linear models to analyze the data, the authors found that single-vehicle crashes are generally more severe than two-vehicle crashes, and that hit-object collisions are the most severe. In terms of both injuries and fatalities the most severe crashes could be attributed to alcohol, while in terms of injuries, the most severe crashes were broadside collisions.

Implications for this Investigation

Recall that a primary intent of this literature review was to identify characteristics previously identified as contributing to commercial vehicle safety levels, either positively or negatively. Key findings from this investigation follow.

- With respect to driver characteristics, fatigue was found to be a noted contributor to large truck crash frequency, though this driver condition was difficult to measure and often defined differently study to study. Hours of service violations were determined in one study to approximate 40 percent, likely contributing to the effects of fatigue. Older, more experienced drivers were found to be safer drivers.

- The influence of alcohol and drugs were found to be a significant contributor to commercial vehicle crash rates, however, a very low proportion of commercial vehicle drivers were found to be in this state. No studies were uncovered that considered the effects of driver characteristics on crash severity. Also, no information was found relating to the effects of gender or driver origin on commercial vehicle crash safety.
- Conflicting findings related to both crash frequency and severity were found when investigation vehicle characteristics, particularly vehicle configuration, and their effect of commercial vehicle safety levels. With some consistency, higher crash rates were noted with 2-axle trucks, local service activities and flatbed trailers. The effects of gross vehicle weight on crash frequency and severity were in agreement between studies; a higher GVW results in lower crash rates but a higher crash severity. Defective vehicle equipment was found to be a common crash cause.
- Limited information was found related to the effects of cargo characteristics. A single study found that crash rates were higher for loaded trucks rather than empty trucks. This study however did not adequately control for the percent of time that trucks operate empty and loaded so these findings may be invalid. No information was found that investigated the effects of cargo type of method of containment on commercial vehicle safety.
- With respect to carrier characteristics and the effects of commercial vehicle safety, it was consistently found that smaller carriers have higher fatal crash

rates than larger carriers. The definition of a "small" carrier varied from study to study. No studies were uncovered that related to a carrier's base state or type of operation.

- Investigation of operating environment effects on commercial vehicle safety was typically performed as a secondary exercise to limit confounding factors. Nonetheless, some consistency was noted in the effects of roadway and traffic characteristics. Both commercial vehicle crash frequency and severity were found to vary by roadway type; rural roadways experience more severe but less frequent crashes. The higher degree of either horizontal or vertical roadway curvature results in a higher crash frequency. Crash frequency was noted to increase as traffic volumes increase.

This information from previous efforts to investigate commercial vehicle safety supports this investigation by ensuring that no key factors are omitted from consideration at the onset and that wildly conflicting results are further investigated before the study in completed and the results made public.

CHAPTER 3

METHODOLOGY

Incompatibility in the findings of past commercial crash vehicle analysis studies stems from the following. (1) Most studies only examined a special population of trucks (i.e., from certain companies, states, or regions of the country). Often the selection of the samples was not random; thus, it is difficult to use or extrapolate their findings at the national level. (2) And methods of analyzing crash rates, (i.e., t-tests and/or analysis of variance) in which one or two variables were investigated at a time, have shortcomings.

One of these is the implicit assumption that these tests were carried out for "homogeneous" populations. That is, there were no other significant "confounding" factors at play. This assumption gives rise to model misspecification and possible incorrect findings. (29) While the first shortcoming is difficult to overcome since Montana specific activity is of interest, the second shortcoming is more easily addressed through a well-developed methodology.

Though much of the previous work has focused on crash frequency, this investigation from this point forward will consider only crash severity as a surrogate measure of commercial vehicle safety. This approach, which considers crash-specific details, allows for a more thorough investigation of contributing factors and better control of confounding factors. Further, by focusing on crash severity, the results of this investigation will better align with National directives to improve commercial vehicle safety.

This Chapter describes: (1) data collection efforts undertaken as part of this investigation, (2) data collection challenges, (3) a review of previous methods to model crash severity and their related shortcomings in support of the chosen methodology and (4) the recommended methodology for this investigation.

Data Collection

In recent years, advances have been made through the development of such centralized databases such as MCMIS, to improve both the availability and quality of commercial vehicle safety data. This section will review the data collection process including data sources and the specific data elements of interest.

Data to support this investigation considers a seven-year time span from January 1, 1993 to December 31, 1999. During this time, 6,583 total commercial vehicle crashes occurred in Montana; 6,524 of which involved large trucks. Data sources and specific elements of interest are detailed below.

Data Sources

Two types of data were required to perform this investigation: (1) historical crash information for commercial vehicles in Montana and (2) carrier profile information describing size, operation, etc. (The historical crash information also contained information related to driver, vehicle, cargo and operating environment characteristics.)

These two types of data were collected from three sources:

- historical crash information was obtained electronically from MHP,

- carrier profile information for *interstate* carriers was obtained electronically from MCMIS and
- *intrastate* carrier profile information was obtained in hard copy format from MHP.

This data was combined into a single data set using common data elements such as USDOT number.

Data Elements

Recall that the intent of this investigation is to characterize commercial vehicle safety levels on the basis of driver, vehicle, cargo and carrier characteristics while controlling for effects of operating environment. As such, data elements in each of these categories were needed to support this investigation. Crash severity, serving as a surrogate measure for commercial vehicle safety, is classified at the following three levels:

1. fatality: a fatality of the driver and/or a passenger resulted from the crash,
2. injury: any driver or passenger was injured to the point of requiring medical attention in the crash or
3. property damage only: damage resulting from the crash was limited to the vehicles involved or nearby property.

Table 7 summarizes the combined set of data elements available for this investigation from the MHP and MCMIS. While the list of available data elements was encouraging, the completeness of the data across all elements was lacking.

Table 7. Combined Data Elements.

DRIVER CHARACTERISTICS

- Driver Last Name
- Driver First Name
- Driver Middle Initial
- Apparent Driver Condition
- Driver License Number
- Driver License State
- Driver Date of Birth

VEHICLE CHARACTERISTICS

- Vehicle Identification Number
- Vehicle License State
- Vehicle License Number
- Vehicle Configuration
- Number of Axles Including Trailers
- Gross Vehicle Weight Rating
- Cargo Body Type
- Truck or Bus

CARGO CHARACTERISTICS

- Cargoes Carried
- Hazardous Materials (HM) Carried
- HM Shipped
- HM Placard (Y/N))
- Four-digit HM Number
- Name of HM
- One-digit HM Class Number
- HM Cargo Release (Y/N)

CARRIER CHARACTERISTICS

- Legal Name
- Doing Business As Name
- Street
- Mexican Neighborhood
- City Code
- City Name
- County Code
- County Name
- State
- Zip Code
- Nationality
- Source of Carrier Name
- USDOT Number
- ICC Number
- State Issuing Carrier SN Value
- State-issued Carrier Number
- FHWA Region Number
- FHWA Officer-in-charge Number
- Type of Carrier
- Classification
- Carrier Operation
- Shipper Operation
- Equipment Owned
- Equipment Term-Leased
- Equipment Trip-Leased
- Fleet Size Code
- Drivers Subject To FMCSR
- Number Of Drivers With CDL's
- Number Of Trip Leased Drivers
- Type Of Latest Review
- Recordable Crash Rate
- Preventable Recordable Crash Rate
- Date Of Latest Review
- Safety Rating
- Annual Mileage

Table 7. Combined Data Elements (Continued).

OPERATING ENVIRONMENT CHARACTERISTICS

- Trafficway
- Access Control
- Weather Condition
- Road Surface Condition
- Light Condition
-

CRASH CHARACTERISTICS

- Crash Report Number
- First Event in Crash
- Description of First Event if Other
- Second Event in Crash
- Description of Second Event if Other
- Third Event in Crash
- Description of Third Event if Other
- Fourth Event in Crash
- Description of Fourth Event if Other
- Agency Reporting Crash
- Officer Badge Number
- Crash Date
- Crash Time
- Crash State
- Crash FIPS County Code
- Crash State County Code
- Crash City Code
- Crash City Name
- Street or Highway of Crash
- Number of Vehicles in Crash
- Number of Fatalities
- Number of Injuries
- Any Vehicle Towed Away (Y/N)
- Federally Recordable (Y/N)
- State Reportable (Y/N)

Data Collection Challenges

Because of recent efforts to centralize and improve motor carrier data, the data collection level of effort for this investigation was assumed to be a relatively minor task. However, as this investigation progressed, shortcomings in both the data quality and accessibility made the data collection process quite complex and labor-intensive.

Crash Data

A complete computer file of crash data complied in the SAFETYNET System was obtained from the MHP. Overall, this information was very accessible and complete, likely because this data-reporting task is required under the conditions of MCSAP.

The most significant shortcomings related to the crash data result from the subjectivity of officer to officer responses and the completeness of all data elements requested on the crash report form. The officer's level of discretion in determining the cause of the crash, the weather conditions, the driver's condition, road surface condition, etc. may result in data inconsistencies. In addition, by the time the crash is reported, weather or road surface conditions may have drastically changed from the time of crash occurrence, particularly in rural areas where response times are higher.

Carrier Data

Unlike the crash data, which had relatively few challenges in collection, the carrier data was extremely difficult to collect and utilize in this investigation.

Interstate Carrier Information. Originally, interstate carrier profile information was to be collected locally from the Federal Highway Administration - Motor Carrier Division. After some confusion and resultant delay, it was determined that this database was simply for informational purposes and was not, transferable to other computer programs without extensive data input. Consequently, the data for the most recent years was ultimately purchased for a fee from MCMIS.

While the above limited data accessibility, data availability was also found to be limited. The requested MCMIS file contains only active carriers at the time the data is requested. Hence, matching carrier information from 2000 to crashes occurring between 1993 and 1999 resulted in missing carrier information (it was deemed to o costly and labor intensive to purchase and match carrier profile data for each of the years between

1993 and 1999). Also, because only the most recent year's carrier profile was available, carrier characteristics may not match characteristics at the time of the crash (carriers may have increased fleet size, changed type of operation, etc.).

Intrastate Carrier Information. The intrastate carrier information was not available electronically, was incomplete and was difficult to use. First, the carrier-specific data elements were filed individually rather than in carrier-specific folders. Intrastate carriers that had never had a safety or compliance review were particularly lacking in information.

Second, the data for intrastate carriers was inconsistent with the national data required for interstate carriers (i.e., common data elements had different categorical choices between the two data sources). This introduced potential subjectivity and bias to the data set as researchers tried to match the categorical entries. Lastly, the number of data elements collected from intrastate carriers was not as extensive as that collected for interstate carriers. Consequently, much of the data set relating to intrastate operation was treated as missing data.

Review of Previous Method to Model Crash Severity.

Though not all specific to commercial vehicle crashes, numerous studies have been performed to investigate crash severity. Both basic and advanced statistical methods have been used in the crash severity context. Basic statistical methods include univariate methods that consider one variable singularly and multivariate methods that consider several variables concurrently. Advanced statistical methods include log-linear, logit and ordered probit regression.

Univariate Methods

Univariate statistical methods used in earlier studies include cross-tabulation, correlation analysis and hypothesis testing using the mean and variance of specific factors (57). Cross-tabulation methods and the chi-squared test have been used by Brorsson et al. (58) and Holubowycz et al. (59) to compare the distributional differences among crash severity levels to identify high-risk groups. In particular, Holubowycz investigated the relationship between severity levels, blood alcohol concentration (BAC), and various age and gender categories using the chi-square and t-test to confirm whether the noted differences were significant in comparison to the total population. Mercer (60) used correlation analysis to examine the relationship between crash severity levels and alcohol and restraint device use to identify factors significantly contributing to specific severity levels. A study by Malliaris et al. (61) used hypothesis testing with the mean and variance of light-vehicle occupant ejection factors, to test for significant differences among crash severity levels.

Although, the use of univariate statistical methods for analyzing one variable is very acceptable, there are limitations when applying a univariate method to situations where there are multiple variables that interact with one another. Since crash severity is assumed to be effected by several factors, univariate statistical methods are thought to be limited in their ability to describe crash severity.

Multivariate Methods

Multivariate statistical methods allow analysis of several variables concurrently, overcoming the shortcoming of univariate methods. Shao (28) used multivariate analysis techniques to identify a set of variables that assist in distinguishing crash severity levels. Evans (62) used double-pair comparisons to determine the affect of vehicle occupant characteristics on the fatality risk in traffic crashes and Lassarre (63) used time series approaches to develop a predictive model of crash severities utilizing traffic volume, speed and seat belt use.

Log-linear Methods

Log-linear methods have been used more frequently than univariate and multivariate methods; however, this statistical method has several disadvantages when used in crash severity analysis. Log-linear modeling is most appropriate for discrete data sets and particularly small data sets due to extensive computations with the chi-square method. Also, log-linear models do not provide a direct indication of a specific variable impact on crash severity.

Logit Models

Several variations of logit models have been utilized to analyze crash severity including, binomial, multinomial, nested and ordered logit.

Binomial logit regression has been used frequently to analyze crash severity (64, 65, 66). However, this method does not have the ability to compare between more then two levels of severity. For example, binomial logit models in the case of crash severity, can only distinguish between fatal and non-fatal severity levels. This does not allow for analyzing fatal, injury and property damage only (PDO) severity levels, which is typically how crash severity is categorized.

Although multinomial logit models predict crash severity effectively, a problem was discovered related to the independence of error terms between severity levels. In order to address this inadequacy, the nested logit model was utilized in studies completed by Shankar, Mannering and Barfield (67) and Chang and Mannering (55). This model grouped the possible correlated error terms into a "nest" by estimating a model when only individuals choosing the nested alternatives were included. (57).

Yet another variation, O'Donnell and Conner (26) used the ordered logit model to identify the factors that increase the probabilities of serious injury and death. In the same study, researchers applied ordered probit methods to the same set of data to directly compare between the two model forms.

Ordered Probit Models

Ordered probit regression requires that the discrete dependent variable be ordered in nature. O'Donnell and Conner (26) found that the main difference in theory between using the ordered probit model and the ordered logit model was in the error assumptions. In addition, although both methods developed comparable results in regards to crash severity (magnitude and direction of significance), the logit model always had higher coefficient estimates than the probit model. This led the researchers to the determination that the probit model would always predict a lower severity.

Most recently, Blomquist and Carson (57) investigated the use of ordered probit and multinomial logit models to identify specific weather related impacts on crash severity. The nature of the debate over the appropriate analytical method for modeling crash severity data centers on whether the data classification indicates an order of response (i.e., there is a progression in the rank of the severity of an crash in such a manner that a fatality crash is considered more severe than an injury crash which is in turn more severe than a property damage only crash). Though intuitive that some inherent order exists in crash severity data, multinomial logit regression has been more widely applied.

> "Both models produced probabilities that were similar in order and magnitude to each other and were relatively accurate when compared to observed crash severity. With neither model showing much of a clear quantitative edge over the other, judgment as to which is more appropriate for modeling crash severity was based primarily on qualitative assessments. These qualitative assessments included ease of model estimation, ease of interpretation of results and the relative effect any of the specification issues may have had on model results. Regarding ease of model estimation and interpretation of results, the ordered probit model was superior to the multinomial logit model. The process of estimating the ordered probit model was much less time consuming than that for the multinomial logit model. Additionally the coefficients reported for the ordered probit model could be directly interpreted as a result of its simpler model form." (57)

Recommended Methodology

Prior to crash severity or frequency model development, general descriptive statistics describing commercial vehicles crash characteristics were examined. The descriptive statistics considered crash, driver, vehicle, cargo, carrier and operating environment characteristics. Descriptive findings were expressed using histograms, continuous data plots, and pie charts to most clearly display the general trends of commercial vehicle crashes in the state of Montana. Findings are detailed in Chapter 4.

Model Development

Given the most recent findings from Blomquist and Carson (57) and to a lesser extent O'Donnel and Conner (26), crash severity for this investigation was modeled using ordered probit regression. Ordered probit models define an unobserved variable, z, such that:

$$z = \beta X + \varepsilon$$

where

- β is a vector of estimable regression parameters determined by maximum likelihood methods,
- **X** is a vector of measurable factors (e.g., driver age, vehicle configuration, truck fleet size, etc.) that define ranking and
- ε is a random error term assumed to be normally distributed.

The ordered probit equation allows the determination of various threshold values that reflect the discrete nature of the data:

$y = 1$ if $z \leq \mu_0$

$y = 2$ if $\mu_0 < z \leq \mu_1$

$y = 3$ if $z \geq \mu_1$

where

- y is the actual or observed severity level and

- μ is an estimable parameter that defines y.

For this effort:

y = 1 represents the severity level fatality,

y = 2 represents the severity level injury and

y = 3 represents the severity level property damage only.

Overall Goodness of Fit

The overall goodness of fit for the ordered probit model is measured by ρ^2 values, which indicate the amount of variability in the dependent variable (i.e., crash severity) that is described by the independent variables (i.e., driver, vehicle, cargo, carrier and operating environment characteristics) included in the model. ρ^2 values are calculated as follows:

$$\rho^2 = 1 - [\ln L_b / \ln L_0]$$

where $\ln L_b$ is the log-likelihood at model convergence and $\ln L_0$ is the initial log-likelihood. Values for ρ^2 range between zero and one, with one representing a perfect model. (68).

Significance of Model Variables

A two-sided t-test is used to verify the significance of each model variable. A model variable is considered significant if its estimated coefficient, β_i is proven not equal to zero at a sufficiently high level of confidence. The level of confidence used for this investigation is 95 percent, which corresponds to a t-statistic greater than or equal to $>|1.96|$. A two-sided t-test is required because model variables are significant if their estimated coefficients are either significantly less than zero or significantly greater than zero. This allows for analysis of model factors having both a significant positive relationship to crash severity and a significant negative relationship.

The two-sided t-test assumes a normal distribution for the variation in value of model coefficients resulting from unobserved effects. Application of the two-sided t-test to estimated coefficients from the ordered probit model is more easily justifiable due to the assumed normal distribution of its error terms than for the multinomial logit model with assumed generalized extreme value distributed error terms. (57)

Implications for this Investigation

The methodology described for this investigation will overcome many of the shortcomings noted in previous work. A large sample was obtained for this investigation avoiding any small sample issues. Also, data was obtained statewide to account for any geographic or locational biases. Further, the recommended methodology allows for investigation of multiple causative factors simultaneously and has been successfully applied for modeling crash severity previously.

Challenges still exist with respect to commercial vehicle safety data, however. Although the number of data elements available for this investigation showed promise, much of the data was missing from the data set. Further, inconsistencies between interstate and intrastate data may introduce some error to the model development process.

CHAPTER 4

RESULTS

This Chapter details the findings related to commercial vehicle safety in Montana. Specifically, this Chapter provides summary statistics related to crash and carrier characteristics and reveals statistically significant factors affecting commercial vehicle crash severity. This Chapter concludes with a discussion of the implications of these results for safety monitoring practices in Montana.

Descriptive Statistics

Descriptive statistics are categorized by driver, vehicle, cargo, carrier, operating environment and crash characteristics. The descriptive statistics consider the full data set comprising 6,524 crash records. Note that none of the findings below have been normalized to reflect prevalence of use, miles traveled, etc.

Driver Characteristics

Not surprisingly, the majority of the drivers in the data sample were from Montana, while the remainder were from neighboring states and Canada (see Figure 8). The majority of drivers (79 percent) were between the age of 25 and 55, prime working years, at the time of the crash. Another 14 percent were between the ages of 55 and 65 years

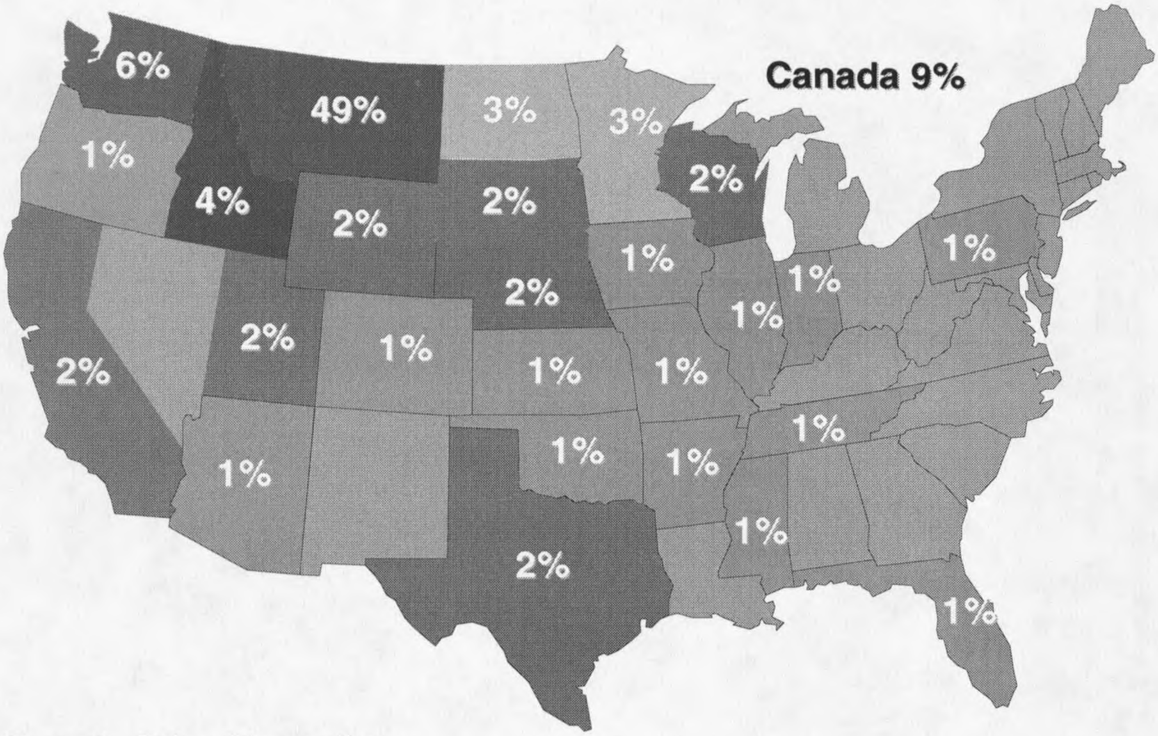

Figure 8. Driver License State.

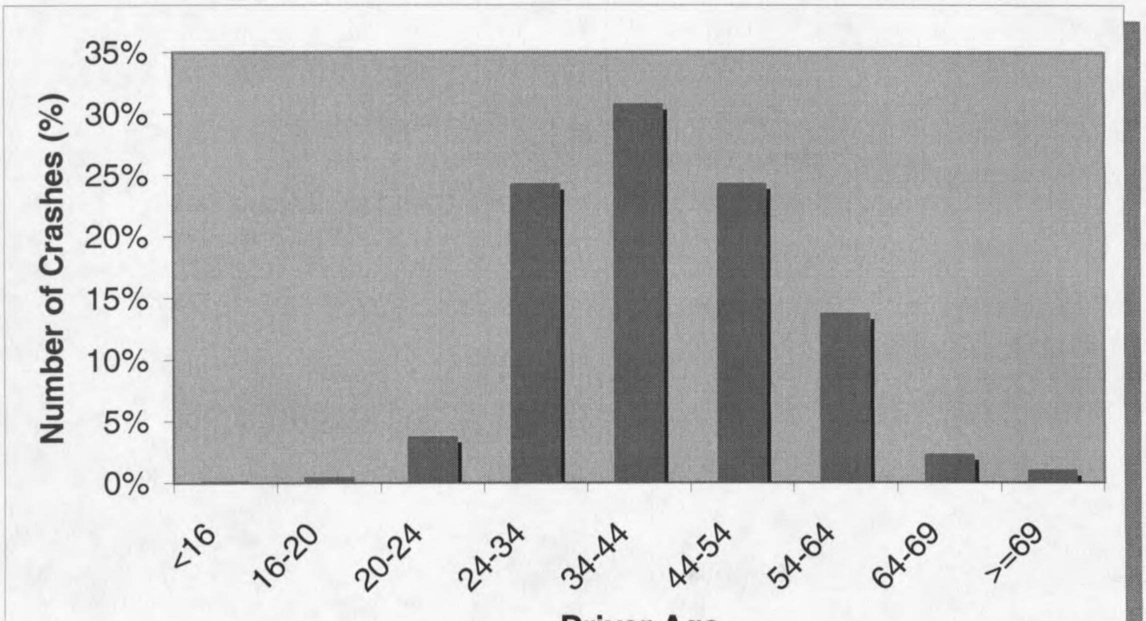

Figure 9. Driver Age.

old (see Figure 9). The majority (93 percent) of the drivers appeared normal at the time of the crash while only 1 percent were fatigued, 1 percent were asleep and 1 percent had been drinking (3 percent were unknown) (see Figure 10). This is somewhat surprising because of the high number of single vehicle crashes occurring in Montana; only 2 percent of the drivers were fatigued/asleep while 46 percent of the crashes involved a single vehicle.

Vehicle Characteristics

The percentage of vehicles licensed in Montana was 46 percent (see Figure 11). The predominant type of commercial vehicle involved in crashes in Montana, reflective of its prominence in operation, is five-axle, tractor semi-trailers (see Figures 12 and 13). The largest weight class (greater than or equal to 80,000 pounds), again, likely related to the commonality of this weight class had the highest percentage of commercial vehicle crashes (see Figure 14). The most frequent cargo body type was van/enclosed box (see Figure 15).

Carrier Characteristics

The carrier characteristics available from the crash reports were minimal; however, from this data source it was observed that 46 percent of the carriers were based in Montana (see Figure 16).

Additional information was obtained from the carrier profile information on specific carrier characteristics including type of carrier; 75 percent of the carriers are

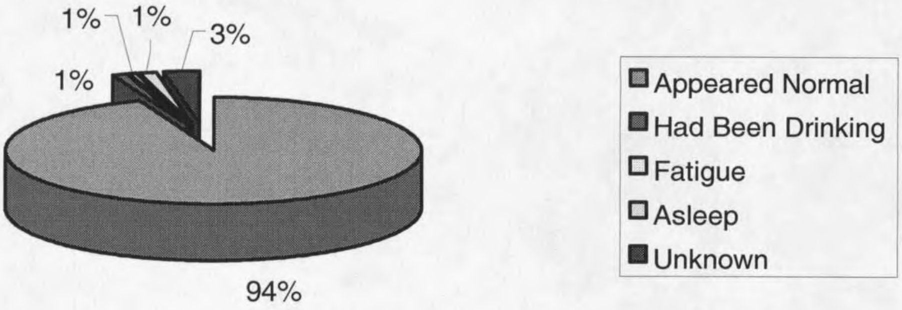

Figure 10. Apparent Driver Condition.

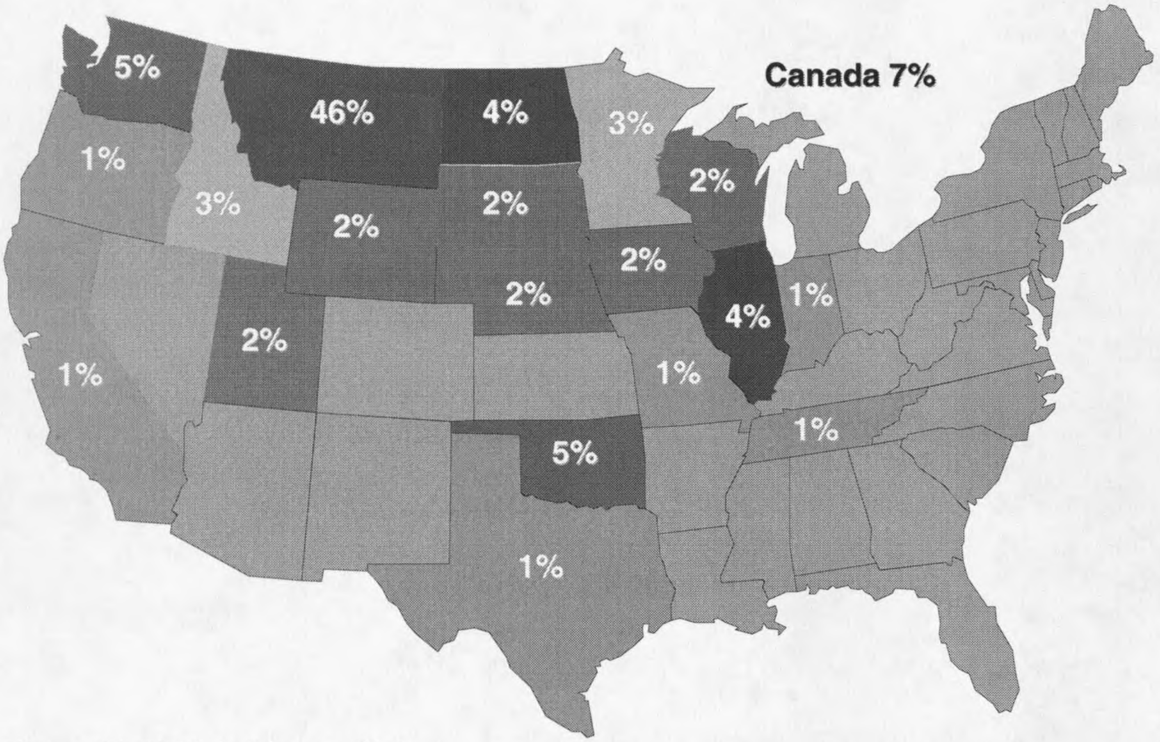

Figure 11. Vehicle License State.

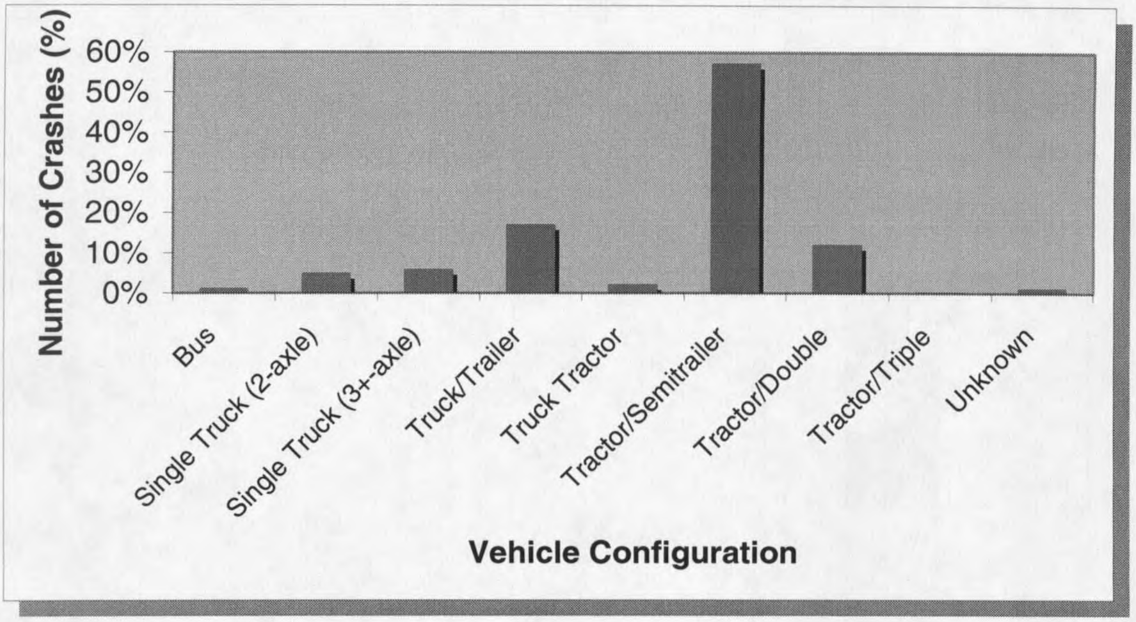

Figure 12. Vehicle Configuration.

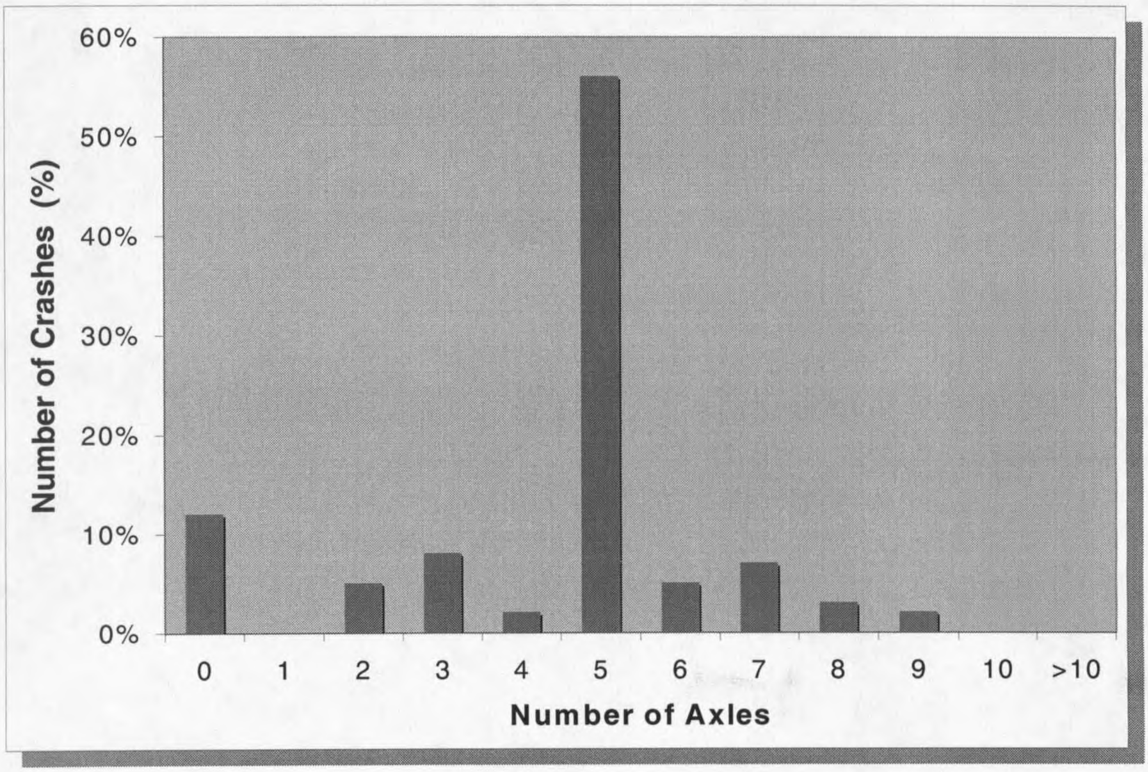

Figure 13. Number of Axles Including Trailers.

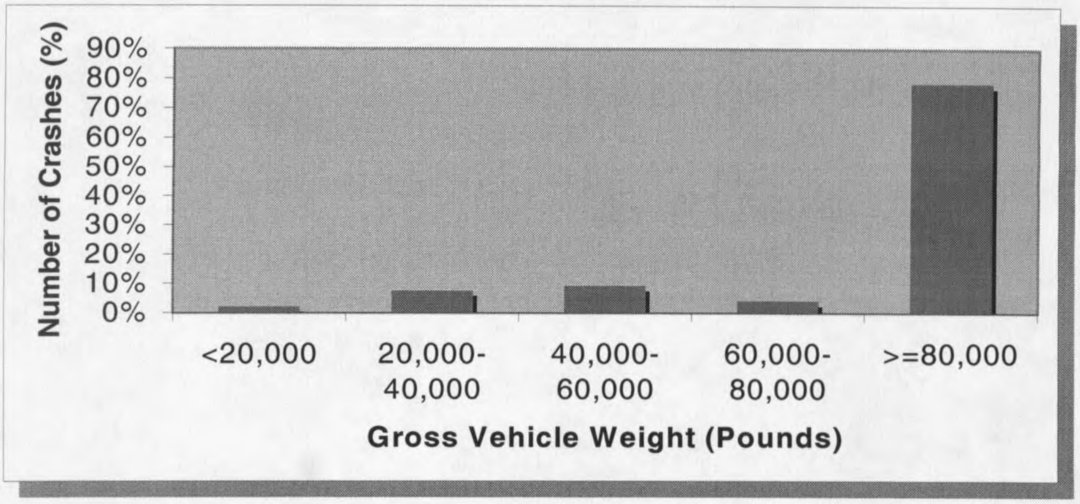

Figure 14. Gross Vehicle Weight.

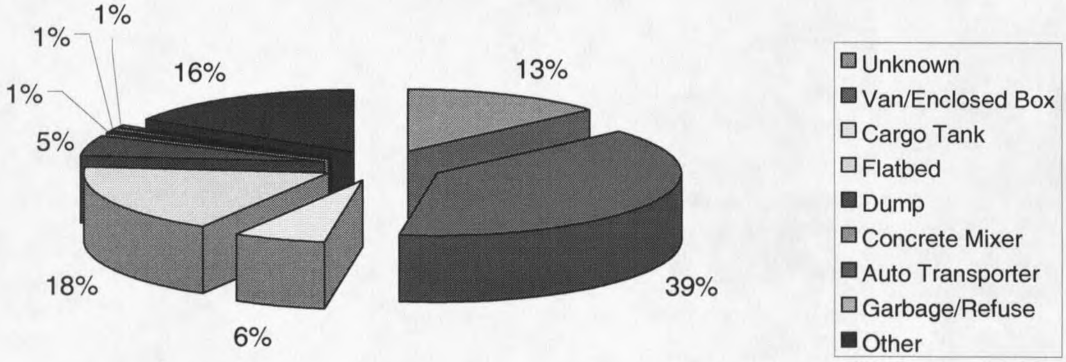

Figure 15. Cargo Body Type.