LONGER COMBINATION VEHICLE SAFETY:

A COMPARATIVE CRASH RATE ANALYSIS

A Thesis

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Abstract

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Longer Combination Vehicles, a sub-class of commercial vehicles, are large trucks with two or more cargo spaces. The safety performance of LCVs is not yet fully understood since it is difficult to distinguish them from other truck types in both crash data files and count stations. Both of these data sources rely on the FHWA 13-vehicle classification that does not distinguish LCVs as particular truck types.

This thesis presents current regulations for LCVs in Western States and crash trends involving LCVs are presented for Montana, Oregon, Idaho, and Utah. A method for identification of LCVs using WIM data was used to determine VMT by road and truck type in Utah and Idaho. The relative crash rates are estimated using crash data and vehicle miles traveled (VMT) and are obtained by dividing the number of crashes by the number of miles traveled by each truck type. Relative crash rates of singles, doubles and triples were compared for Idaho; and relative crash rates of singles, LCV doubles, non- LCV doubles and triples were compared for Utah.

Finally, these estimated crash rates are then used to determine the relative safety of LCVs in Idaho and Utah. The estimated crash rates in Idaho are considerably lower on interstate routes in comparison to state routes. The single unit truck shows a consistently low crash rate in both state and interstate roads. Crash rates for doubles are higher than crash rates for triples on interstate routes. In contrast, triples show higher crash rates than doubles on state routes. Overall it is shown that crashes are more likely to occur on state routes than on interstate routes.

In Utah, turnpikes have the highest number of crashes per million VMT followed by Rocky Mountains and triples. Freeway doubles and singles have a substantially smaller number of

crashes per million VMT. The analysis per roadway segment shows that turnpikes have higher crash rates than triples, freeways, and singles but do not surpass the crash rates of Rocky Mountains.

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Dedication

This work is dedicated to my parents, Raul and Lydia, for all of their support and guidance throughout my life.

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List of Acronyms

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ANSI	American National Standards Institute
APM	Accidents Per Million Vehicles
ASL	Average Section Length
ATA	American Trucking Association
ATP	Average Truck Percentage
ATR	Automatic Traffic Recorder
CDL	Commercial Drivers License
CDOT	Colorado Department of Transportation
CMV	Commercial Motor Vehicle
DHSMV	Department of Highway Safety and Motor Vehicles
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
FBF	Federal Bridge Formula
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FWD	Freeway Double
GES	General Estimates System
GVWR	Gross Vehicle Weight Rating
HAZMAT	Hazardous Material
HPMS	Highway Performance Monitoring System
ICC	Interstate Commerce Commission
ISTEA	Intermodal Surface Transportation Efficiency Act
ITD	Idaho Transportation Department
ITS	Intelligent Transportation System
LCV	Longer Combination Vehicle
MCMIS	Motor Carrier Management Information System
MCSAP	Motor Carrier Safety Assistance Program
MDOT	Michigan Department of Transportation
MHP	Montana Highway Patrol
MMUCC	Model Minimum Uniform Crash Criteria
MTTIS	Michigan Truck Trip Information Survey
MVD	Motor Vehicle Division
NASS	National Automotive Sampling System
GES	General Estimates System
NGA	National Governors' Association

NHP	Nevada Highway Patrol
NHTSA	National Highway Traffic Safety Administration
NIATT	National Institute for Advanced Transportation Technology
NN	National Network
NTTIS	National Truck Trip Information Survey
OMCHS	Office of Motor Carriers and Highway Safety (now FMCSA)
OTHS	Office of Traffic and Highway Safety
PAR	Police Accident Report
PDO	Property Damage Only
RMD	Rocky Mountain Double
SAS	Statistical Analysis System
SQL	Structured Query Language
STAA	Surface Transportation Assistance Act
TIFA	Trucks Involved in Fatal Accidents
TIUS	Truck Inventory and Use Survey
TMG	Traffic Monitoring Guide
TPD	Turnpike Doubles
UDOT	Utah Department of Transportation
UHP	Utah Highway Patrol
UMTRI	University of Michigan's Transportation Research Institute
USDOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
WASHTO	Western Association of State Highway and Transportation Officials
WIM	Weigh-in-Motion
WSDOT	Washington State Department of Transportation

Chapter 1. INTRODUCTION

1.1 Background and Definitions

Longer Combination Vehicles (LCVs), a sub-class of commercial vehicles, are large trucks with two or more cargo spaces. Due to their high productivity and economic and fuel consumption efficiency, the use of LCVs has been increasing, both in terms of the number of vehicles on the road and the number of miles they are driven. LCVs usually exceed 75 feet in overall length and operate a gross vehicle weight rating (GVWR) greater than 80,000 pounds when they are fully loaded. The cargo spaces of these vehicles vary in configurations (i.e. box cars, hoppers, etc.) depending on the needs they serve.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 defined an LCV as "*any combination of a truck tractor with two or more trailers or semi-trailers which operates on the Interstate System at a gross vehicle weight greater than 80,000 pounds,*"(USDOT 1991). The legislation also provided that no state could permit multi-trailer trucks longer or heavier than those operating as of June 1, 1991, thus "freezing" state weight and length limits for trucks. Longer combination vehicles operate on 14 western and central states and six eastern states. Table 1.1 lists states allowing LCVs in the US.

For the analysis presented in this thesis, LCVs are defined as any combination vehicle with two or more cargo spaces in which at least one of the cargo spaces is longer than 28 feet. This definition of LCV is consistent with that used by the Federal Motor Carrier Safety Administration (FMCSA). Based on this definition, any truck-tractor with only one semi-trailer or any "truck and trailer" is not considered an LCV, irrespective of the number or axles of the combination or the gross weight at which it is registered. For truck-tractors with two trailers (a semi and a trailer), at least one of the trailers must be in excess of twenty-eight and a half feet long and the combination registered above 80,000 pounds gross in order to be an LCV. All triples are LCVs. This applies to both a truck-tractor with a semi-trailer and two trailers, and a truck having an integral freight bed or box with two trailers. Whether the power unit (tractor or truck) is a conventional or cab over is irrelevant to the determination of whether the combination is an LCV or not. The following truck combinations are considered LCVs:

1) Rocky Mountain Double – a truck-tractor, semi-trailer of 40 to 48 feet long and a trailer of 20 to 32 feet long. Usually a seven-axle combination, but may have as many as eleven axles
2) Intermediate Double – a truck-tractor, semi-trailer of 30 to 35 feet long and a trailer of the same length. Usually a seven-axle combination but may have as many as eleven axles
3) Turnpike Double – a truck-tractor, semi-trailer of 45 to 48 feet and a trailer of the same length. Usually a nine-axle combination
4) Tractor semi-semi (B-train) – similar to Turnpike doubles, except that a platform or stinger is used to connect the semi-trailers. Neither trailer can exceed 48 feet in length
5) Truck-tractor, semi-trailer and two trailers. Trailers are generally 28'6". Most commonly seen as a seven or eight axle combination in line-haul service
6) Truck and two trailers. Truck not to exceed 40 feet; trailers normally are not in excess of 28'6"; often has ten to eleven axles
7) Other. Other combinations not described above that have two or more trailers (or semi-trailer) and is registered in excess of 80,000 pounds. An example of equipment falling into this category would be an auto transporter where two stinger-steered trailers are used.

The general characteristic of these trucks are presented in Figure 1.1.

Table 1.1 States Allowing Different Types of Longer Combination Vehicles

State	Triples	Turnpike Doubles	Rocky Mountain Doubles	Intermediate Doubles
Alaska	Yes	Yes	Yes	Yes
Arizona	Yes	Yes	Yes	Yes
Colorado	Yes	Yes	Yes	Yes
Florida (toll roads)	No	Yes	No	No
Idaho	Yes	Yes	Yes	Yes
Indiana (toll roads)	Yes	Yes	Yes	Yes
Kansas (toll roads)	Yes	Yes	Yes	Yes
Massachusetts (toll roads)	No	Yes	No	No
Montana	Yes	Yes	Yes	Yes
Nebraska	Yes	Yes	Yes	Yes
Nevada	Yes	Yes	Yes	Yes
New York (toll roads)	No	Yes	No	No
North Dakota	Yes	Yes	Yes	Yes
Ohio (toll roads)	Yes	Yes	No	No
Oklahoma	Yes	Yes	Yes	Yes
Oregon	Yes	No	Yes	Yes
South Dakota	Yes	Yes	Yes	Yes
Utah	Yes	Yes	Yes	Yes
Washington	No	No	Yes	Yes
Wyoming	No	Yes	Yes	Yes

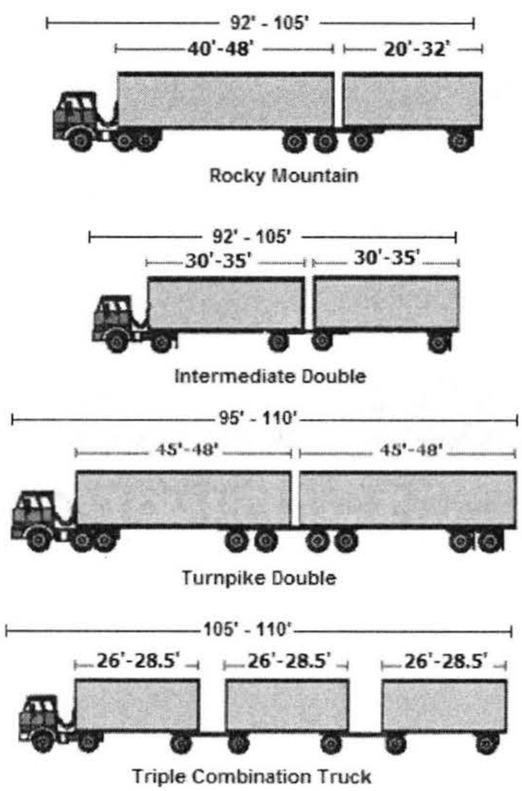

Figure 1.1 Characteristics of Longer Combination Vehicles (LCVs).

1.2 Laws and Regulations Governing LCV Operations

The regulations that govern the sizes and weights of trucks in general are some of the most crucial factors that go into road and bridge design and maintenance. This section presents a breakdown of regulations for LCV operation as a subset of heavy vehicles. Federal regulations, Western Association of State Highway and Transportation Officials (WASHTO) guidelines, and individual state laws are presented in this section.

1.2.1 Federal Regulations for LCVs

Federal regulations are applied to U.S. national highway networks and cover the limits of weight, dimensions and the number of trailers that can be towed for all types of heavy vehicles. There are two federal weight laws for highway motor vehicles. The first, known as the Federal Bridge Formula (FBF), requires vehicles to comply with specific axle spacing and weight, which prevents a vehicle from putting excessive load and stress on highway bridges. The second relevant federal law limits gross vehicle weight to 80,000 pounds for motor vehicles operating on the interstate system. While LCVs can match the FBF, they cannot operate economically under a total weight limit of 80,000 pounds. This prevents the use of LCVs on the nation's interstate highways.

Current laws that govern interstate truck operations and weight limit are:

1) Maximum of 20,000 pounds on any single axle and a maximum of 34,000 pounds on any tandem axle for vehicles on interstate highways.
2) The maximum weight of any group of two or more consecutive axles (W) is determined based on the Federal Bridge Formula (FBF). The formula includes two input parameters: 1) the distance in feet between the extreme of two or more consecutive axles (L) and 2) the total number of axles (N). W is determined according to the following equation:

$$W = 500\left[\frac{LN}{N-1} + 12N + 36\right]. \qquad (1)$$

3) Maximum vehicle weight cannot exceed 80,000 pounds on interstate highways.

4) States must allow vehicles 102 inches wide on the National Network (NN) for Large Trucks, a federally designed network that includes all interstates and 160,000 miles of state and US roads.
5) Grandfather exemptions apply to states that had vehicles exceeding the federal limit before the federal limit was enacted, and vehicles can continue to operate in these states indefinitely.
6) Statutory special exemptions apply to specified operations in certain states.
7) States that did not allow operation of LCVs on the NN before June 1991 may not legalize operation of these vehicles on the NN (LCV freeze).
8) States are required to verify that they have operational programs for enforcing weight limits on federal aid roads.

The Transportation Research Board Special Report 267 (Committee for the Study of the Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles 2002) has recommended a federally-supervised state-implemented permit program that allows the operation of certain trucks larger than those currently allowed under federal law. The permit program allows states to issue special permits for six-axle semi-trailers with a maximum weight of 90,000 pounds and for double trailer configurations with a maximum trailer length of 33 feet with weight limit governed by the current FBF.

Along with regulations pertaining to truck size and weight, the Federal Motor Carrier Safety Administration (FMCSA) mandates minimum training requirements for LCV operators as well as for the instructors who train the operators. These requirements include: a valid class A commercial driver license (CDL) with a double/triple endorsement; no more than one conviction for a serious traffic violation while operating a CMV; no convictions for a violation of state or local laws relating to motor vehicle traffic control arising in connection with any traffic accident while operating a CMV; and no accident in which the driver was found to be at fault while operating a CMV in the last three years.

1.2.2 Laws and Regulations Governing LCV Operations in Western States

The Western Association of State Highway and Transportation Officials (WASHTO) Committee on Highway Transport and the motor carrier industry established guidelines in an attempt to standardize truck size and weight for vehicles in the 17 WASHTO states (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington and Wyoming) (WASHTO 2001). These guidelines are recommendations of minimum standards and are intended to encourage consistency and easy movement of large vehicles from state to state. However, each state has the right to make exceptions to these recommendations based on local conditions and/or highway system configurations. The WASHTO guidelines recommend that the maximum gross vehicle weight should be between 105,500 and 129,000 lbs. and that the axle weight limit should be determined by the FBF. The WASHTO maximum length configurations for different LCVs are presented in Table 1.2.

Table 1.2 WASHTO LCV Maximum Length Specifications

	Triple Combination	Turnpike Doubles	Rocky Mountain Doubles
Combination length	not specified	110 feet	not specified
Trailer combination length	95 feet	95 feet	81 feet
Trailer length	28.5 feet	45 feet	48 feet

In addition to weight and length limitations, WASHTO guidelines include the followings LCV permit provisions and operation requirements:

1) LCVs must be able to maintain a speed of 20 mph in normal driving conditions on any up-grade that is in route. If the LCV drops below 20 mph the driver must use the emergency flashers to warn others drivers.
2) LCVs must stay in the right lane unless they are passing.
3) Except when LCVs are passing, a minimum distance of 100 ft per 10 mph between other vehicles is required.
4) The heaviest trailer must be placed at the front and the lightest at the back.

5) If the visibility is poor or the windshield wipers are being used, the driver must turn on the headlamps.
6) Travel is prohibited during adverse weather conditions under State regulations.

1.2.3 LCV State Regulations

A summary of state regulations and permitting for LCVs in eight western states is presented in Tables 1.3 and 1.4, respectively.

1.3 Safety Performance of Longer Combination Vehicles

The safety performance of LCVs is not yet fully understood. It has been the subject of much debate on the national and state levels. The relatively small number of LCVs in operation and the small number of crashes involving LCVs makes it difficult to study their safety performance and impacts using data sets and methodologies similar to those applied to commercial motor vehicle safety [such as the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System/ General Estimates System (NASS/GES)], (FHWA 2001). A study conducted by Woodrooffe, et al. (2001) focused on comparing the safety performance of LCVs with other vehicles in Alberta, Canada, found LCVs to have the lowest collision rate of all commercial vehicle classes. The study also found that adverse conditions, such as weather and road surface, were present in 42 percent of all LCV collisions. The study concludes that Alberta's infrastructure permit system, which includes selective routing; restrictions on vehicle speed; restricted time of day operation; enhanced driver qualifications; and operating restrictions during adverse road and weather condition, was a key factor in creating a safe operating environment for LCVs.

Table 1.3 State Regulations for LCVs

	Colorado	Idaho	Montana	Nevada	Oregon	Utah	Washington	Wyoming
Rocky Mountain doubles								
Combination length*	111	105	95	N/A	N/A	N/A	N/A	N/A
Trailer combination length*	N/A	95	N/A	105	68	95	68	81
Trailer length*	48 + 28.5	N/A	N/A	N/A	40 + 20	N/A	N/A	N/A
Turnpike doubles								
Combination length*	111	105	95	105		N/A		81
Trailer combination length*		95'	N/A	N/A	not allowed	95	not allowed	N/A
Trailer length*	48 + 48	N/A	N/A	48 + 42		N/A		N/A
Triple combination								
Combination length*	115.5	N/A	105		N/A	N/A		
Trailer combination length*	N/A	95	95 (max)	95 (max)	96	95	not allowed	not allowed
Trailer length*	28.5 each	28.5 each	28.5 each	28.5 each	28.5 each	28.5 each		
Maximum Weights								
Allowable axle group weights	FBF	FBF	FBF	FBF	FBF	FBF	FBF	FBF
Gross vehicle weight (lbs.)	110,000	105,500	137,800	129,000	105,500	129,000	105,500	117,000
Minimum Speed Limit	20 mph	15 mph	20 mph	20 mph	20 mph	20 mph	20 mph	not defined

* all lengths are in feet

Table 1.4 LCV Permit Regulations in Different States

	Idaho	Montana	Oregon	Utah
Types of permits available	Annual Trip	Annual Trip	Annual Trip	Annual Trip
Issue post for permits	Centralized Office in Boise Internet	MDOT Internet	ODOT	Utah DOT
Time required to have a permit issued	Immediately	2 - 30 days	Immediately	1 -15 days

A study of large trucks by the Montana Department of Transportation yields similar results. The study concludes that there was no indication that large trucks have a higher crash frequency compared to all other vehicles on the interstate and the primary systems (Montana DOT, 1997). Crash data for Idaho highways from 1990 through 1998 show that crash rates for triple trailers were less than those for single unit or double trailer trucks. Fatal crash rates were also lower for triple trailers (Idaho Transportation Department, 1999)

Lyles, et al. (1991) analyzed the differential truck accident rates for the state of Michigan. The study's objective was to calculate disaggregate truck accident rates by road class, day or night, and urban or rural operating conditions for bobtails, single, and double trailer configurations. Accident data used were obtained from the Michigan DOT accident database. The overall findings showed that 5 percent of all accidents in Michigan involved trucks larger than a pickup. Trucks were more likely to be involved in multiple-vehicle accidents than other vehicles. The proportion of truck accidents resulting in fatalities was almost twice as high as non-truck accidents. Truck accidents were more likely to occur on U.S. and state routes than on city streets and county roads. Vehicle miles traveled (VMT) was the vehicle exposure measure used in the study, and was obtained using a program to collect detailed travel information created by the University of Michigan's Transportation Research Institute (Blower, D., and Campbell, K., 1991). Based upon the surveys, it was estimated that Michigan-registered tractor trailers traveled an average of 25,000 miles annually. Single-unit trucks accounted for 59 percent of the total miles traveled on limited access roads. An analysis of gross vehicle weight showed that 39 percent of trucks were operating in a gross weight range between 20,000 and 40,000 pounds, 43 percent weighed between 40,000 and 80,000 pounds, and 14 percent weighed more than 80,000 pounds. Accident rate, expressed as accidents per million vehicle mile traveled (APM), was 30.35 APM for bobtails, 6.79 APM for single unit trucks, and 5.69 APM for double combination trucks. The results show that bobtails had a higher accident rate than single-unit and double combination trucks.

Another research that examines accident rates of heavy-duty vehicles was conducted by Campbell, et al. (1996) using the TIFA and NTTIS data sets for accident and vehicle exposure data, respectively. The fatal accident involvement rates were calculated by dividing the number of trucks involved in fatal accidents by the truck VMT. Five basic truck configurations with gross vehicle weight rating (GVWR) greater than 10,000 pounds were analyzed. The accident data were obtained from TIFA for a five-year period (1980–1984), while VMT was obtained from NTTIS for only 1983. The authors believe that the percentage distributions of VMT were stable over time; thus the use of 1983 vehicle exposure data is justifiable. Accident rates (in APM) for different vehicle types reported in the study are presented in Table 1.5. The results of the study show that accident rates for bobtails are higher than other truck configurations. Straight trucks plus trailers and double trucks had relatively higher crash rate than straight truck and single-unit trucks.

Table 1.5 Fatal Accident Rates

Truck Configuration	Crash Rates (APM)
Straight trucks	0.89
Straight truck + trailer	1.16
Bobtail	2.28
Single truck	1.01
Double trucks	1.11

Source: Campbell, et al. 1996

Another study that examines the safety performance of LCVs was conducted in Alberta, Canada (Woodrooffe 2001). The purpose of the study was to determine the safety performance of vehicles on Alberta roads, including LCVs, based on data from 1995 to 1998. The study finds that LCVs in Alberta generally operate on four-lane highways, but Rocky Mountain doubles are allowed to travel on an expanded route system. Average annual daily traffic counts (AADT) were used to determine the volume of different types of Commercial Motor vehicle (CMV) classes. Additional vehicle surveys were used to obtain the total kilometers traveled by each type of LCV. Vehicle collision involvement rates were obtained by dividing the number of collisions involving a particular type of vehicle by the total kilometers traveled by that vehicle type. Different configurations of LCVs were analyzed, such as Rocky Mountain doubles, turnpike doubles, and triple combination trucks. The results showed that LCVs had the lowest collision rates of all vehicle classes. During the four-year period when the study was conducted, only 53 LCVs were involved in collisions, which was less than 14 LCVs per year. Out of the 53 collisions, 37 occurred in rural areas, while 17 occurred in urban areas. Weather was found to be the most frequently contributing factor. The best safety performance among LCVs was observed to be Rocky Mountain doubles. Turnpike doubles had a higher number of collisions than other LCV configurations. Table 1.6 summarizes the results of the study.

Table 1.6 Vehicle Collision Rates by Vehicle Type

Vehicle Type	Collision Rate Per 100 million km traveled			
	Total	Fatalities	Injury	PDO
Unit Truck	187.19	3.67	34.40	149.23
Tractor Semi	79.52	3.29	21.74	54.49
Multi Trailer	103.70	4.71	30.52	68.47
Rocky Mountain doubles*	10.31	0.00	1.87	8.43
Turnpike doubles*	20.00	2.00	5.00	13.00
Triple combination*	16.87	1.69	4.22	10.96
Personal vehicles	88.15	1.19	16.34	70.62

* LCVs *[Source Woodrooffe & Associates, page 16]*

In contrast, a report on LCVs and fatal crashes nationwide, prepared jointly by the Center for National Truck Statistics at the University of Michigan and the Federal Highway Administration (Blower, et al. 2001) was inconclusive, stating that:

> "*Based on the data presented, no conclusion can be made on the relative safety of LCVs compared to other truck combinations. First, data on mileage driven are based strictly on trailer number and length, while the definition of LCV used in the study is based partly on weight. Second, since LCV travel is rare, it is difficult to calculate the precise number of miles driven. Similarly, LCV fatal crashes are so infrequent that the number varies greatly from year to year. Based on the existing data, LCVs do not appear to be considerably more or less safe than other combination trucks. A more definitive conclusion could be reached only after further collection of data and additional analysis.*"

1.4 Research Objectives

The purpose of this research is to assess the LCV safety performance and identify their crash trends in a sample of western states. The objectives are to:

1. Examine the availability of crash and exposure measure data required to perform LCV safety analysis;
2. Collect LCV crash data and identify LCV crash characteristics in four western states (Utah, Idaho, Montana and Oregon);
3. Determine the total Vehicle Miles Traveled (VMT) by each type of commercial vehicles in two western states (Utah and Idaho); and
4. Conduct a comparative crash rate analysis to assess the relative safety performance of different commercial vehicle classes in two western states (Utah and Idaho).

1.5 Thesis Organization

The thesis is organized in five chapters. Following the Introduction, Chapter 2 presents crash and vehicle exposure data available in eight western states. Chapter 3 lists the crash data used for the analysis as well as the methodology to obtain VMT for each truck type. Chapter 4 summarizes the crash characteristics in four western states (Utah, Idaho, Montana, and Oregon) and provides a comparative crash rate analysis for two states (Utah and Idaho). Finally, Chapter 5 summarizes the finding and conclusions obtained from the analysis performed in Chapter 4, future research and recommendations are also included.

Chapter 2. AVAILABILITY OF CRASH AND VEHICLE EXPOSURE DATA

2.1 Background

A study conducted for the AAA Foundation for Traffic Safety (Scopatz, et al. 2000) examines crash and vehicle exposure data availability for large trucks in five states that allow LCVs operations: Florida, Idaho, Nevada, Oregon and Utah. The objectives of the study were to investigate crash and VMT data availability and collection practices and to determine if they are adequate to support a safety performance analysis for different truck types. The study also examined the accuracy of the collected data. The results of the study show that, among the five states, Utah was the only state that had detailed descriptions of the vehicle configurations in crash reports, possibly allowing for a differentiation between various truck configurations. Crash reports in other states do not have enough data on vehicle configurations to distinguish among different types of double combination trucks. Data quality problems were observed in all states due to missing data or incomplete data and the lack of accuracy on driver self-reports that rely on the drivers to obtain and provide specific crash information.

The study also examines the availability of trucks' vehicle exposure data focusing on VMT estimates for different truck types. While the aggregate VMT was available in the five states examined in the study; none of the states had measures of exposure specifically for each vehicle configuration. Oregon was observed to estimate measures of VMT specific for trailers based on specific segments of the LCV fleet. Utah could produce measures of exposure based on the number of permits issued to different configuration of LCVs.

The results show that none of the states in the study had adequate crash reporting system or VMT estimates suitable for safety analysis of LCVs. Lack of details in vehicle configuration characteristics and measures of exposure for different truck types were the main obstacles that prevent a safety analysis of LCVs.

In the Motor Carrier Safety Improvement Act of 1999 that established the Federal Motor Carrier Safety Administration (FMCSA), Congress required FMCSA to conduct a comprehensive study to determine the causes of, and contributing factors to, crashes that involve commercial motor vehicles. To fulfill this requirement, FMCSA joined with the National Highway Traffic Safety Administration (NHTSA) to design and operate the Large Truck Crash Causation Study (LTCCS). Hedlund (2003) discusses how the LTCCS database can be used to investigate crash causes and contributing factors for different truck types including LCVs. The report identifies critical truck safety questions, outlines the specific information needed to address each, assesses how well the LTCCS database fills these needs, and briefly discusses other data that could be used for questions where LTCCS data are not adequate. The principal conclusions of the report follow:

1. *The LTCCS is a general-purpose data file designed primarily for problem identification. It collects over 1000 data variables describing all aspects of crashes' drivers, vehicles, and environment.*
2. *The LTCCS database can be used to investigate crash risk using relative risk methods. With the LTCCS database, these methods apply to many vehicle features such as truck configuration and length, some driver features, and a few environmental features. Their usefulness depends on whether there is a suitable control group of crashes where the feature being examined has no effect.*
3. *The 1000-case sample size limits statistical conclusions from the data. Analyses and national estimates of relatively infrequent situations will have large uncertainties and will only be able to distinguish large differences.*
4. *Data accuracy and completeness may limit many conclusions from the data. Directly observable variables likely will be quite accurate and complete. Variables that depend on interviews may be less accurate and complete, even if investigators check all possible sources to confirm the interview reports.*
5. *While LTCCS is designed as a statistical data file, its individual case reports will be useful for investigative analyses based on in-depth crash reconstructions.*
6. *Additional data from experimental settings almost certainly will be needed to develop specific interventions.*

2.2 Availability of Crash Data in Eight Western States

In order to examine the safety performance of different truck types, crash and exposure measure data were collected and analyzed. A primary data analysis was conducted to assess the availability of detailed crash and exposure measure data and determine states to be included in the final analysis. Crash and WIM data were collected from state DOTs. This chapter describes the characteristics of the collected data, states selected for the final analysis, and the road segmentation used in the study.

2.2.1 Idaho

In the State of Idaho, crash data are compiled and maintained by the Idaho Transportation Department (ITD). Data are collected by different law enforcement agencies in the state (city police, county sheriffs, and the Idaho State Police) using a standard collision report form. Only crashes above the state threshold of $750 for any one vehicle involved in the crash are recorded. The crash data and reports are sent to ITD's Office of Traffic and Highway Safety (OTHS). Crash data obtained from ITD include all truck-related crashes (1999 and 2003). Information in the Idaho crash data files include the following variables: crash identification number, date, severity, location (county, city, street name and milepost), road classification, number of vehicles involved in the crash, weather and road conditions, land use, vehicle type and year, contributing circumstances, type of collision, driver information, cargo body type, and license plate and VIN numbers. The following data variables pertain to truck details and truck configuration and may be used for detailed truck type identification:

a) Vehicle type: includes two-axle and three-axle trucks, semi-trucks, truck-trailer combinations, double trailers, and triple trailers. Other vehicle types such as farm and construction equipment, motor homes, and buses are also identified,
b) Vehicle and cargo body type: includes truck, truck tractor, cargo tank and flat bed, and
c) Number of axles.

While the crash data clearly identifies single unit and triple combination trucks, it groups all double combination trucks, both LCVs and non-LCVs in one category, limiting the ability to conduct any analysis involving LCV doubles. Although the number of axles is provided, given the large range of vehicle axle configurations and small sample size, this variable was not useful for double LCV identification.

The next step in the preliminary data analysis for the state of Idaho focused on identifying other sources of information that might allow for a better identification of the type of double combination trucks (LCV or non-LCV). Two approaches were investigated. The first approach focused on the hard copy of the crash report while the second involved contacting the truck carriers to obtain details on the trucks involved in the crash. Hardcopies of the 2002 truck related crashes were obtained from the Idaho State Police. The crash reports were manually examined to determine if additional truck type information was available. While some of the crash reports included additional data, such as the total vehicle length, this author concluded that such data are not sufficient to provide a reliable determination of the truck type involved in the crash. Two primary factors led to that conclusion: 1) vehicle length information was not reported in all crash reports, and 2) the reliability of the vehicle length data reported could not be verified.

The second approach was to contact the carriers to obtain more detailed vehicle type information. A sample of 72 double combination truck crashes (5 percent of the total double-combination crashes) was randomly chosen from the data files. The truck carriers' names were obtained from the crash data and the carriers' contact information was obtained from the American Trucking Association (ATA) database. The contact information for 9 of the 72 carriers could not be found (either relocated or went out of business) and 17 of the carriers declined to provide any information. Out of the 46 carriers who participated in the survey, 21 carriers stated that they do not keep any additional crash information, other than those included in the crash report; thus they could not report any additional information regarding the type of vehicle involved in the crash. The other 25 carriers (34.72 percent of the sample) provided detailed information regarding the type of truck/trailer for the vehicle involved in the crash. Again, this author concluded that this approach can not provide the adequate data needed for the analysis, primarily due to the low percentage of identified truck type. In conclusion, crash data allow a triple combination truck safety analysis; however, there is no crash data available to conduct safety analysis for LCV doubles in the state of Idaho.

2.2.2 Colorado

Crash reports in Colorado are compiled and completed by officers investigating the crashes. Colorado law requires that all crashes resulting in a fatality, injury, or property damage in excess of $1000 must be investigated. The crash reports are submitted to the Colorado Department of Revenue, Motor Vehicle Division (MVD), which is the legal custodian of records for crash reports. The Office of Transportation Safety then acquires the data from the MVD. Crash data obtained from Colorado DOT includes the complete record of crashes for 2002 and 2003. Information included in the Colorado crash data files contains the following: crash identification number, date and time, crash location (partial information), driver information, number of vehicles involved in the crash, weather conditions, type of collision and vehicle configuration. The crash data includes the following truck types: tractor/double, tractor /triple, buses (with 9 and more than 15 seats), single unit trucks (with 2 axles and 3 or more axles), truck/trailers, truck tractors (bobtails), and tractor/semi trailers. Cargo body type, total length of the trucks, and number of axles are not included in the crash data files. Again, and similar to Idaho, the crash data clearly identify single unit and triple combination trucks but group all double combination trucks in one category, limiting the ability to conduct any analysis involving LCV doubles using the state of Colorado crash data..

2.2.3 Montana

Crash data in Montana is reported by law enforcement officers when a person is killed or injured or property damage is greater than $1000. These crash reports are submitted to the Montana Highway Patrol (MHP) within ten days of the accident. Most accident reports are entered onto the official Crash File at MHP within six to eight weeks of the end of the year. Crash data obtained from the Montana Department of Transportation includes all CMV crashes for 2002 and 2003. Information included in the Montana crash data files contains the following: crash identification number, crash date, crash location (county and city), crash severity, number of vehicles involved, weather and road conditions, contributing circumstances, type of collision, and vehicle type. The truck configuration data includes the following identification:

a) Vehicle body style, such as trucks, truck/tractors, and buses, and

b) Trailer style, such as semi cargo trailer, full cargo trailer, two trailer units, and three trailer units.

Single units and triple combination trucks are easily identified; however, all doubles (LCVs and non LCVs) are classified as a general category of two trailer unit trucks. Therefore, Montana crash data cannot be used to conduct a safety performance analysis of LCV doubles. Due to the fact that the crash reports do not include exact location of crashes involving triples, a safety performance study of triples cannot be performed.

2.2.4 Oregon

Crashes are legally reported when crashes result in death, bodily injury, or damage to the vehicle over the threshold of $1,500. Data collected on crashes comes from driver self-reports. Four different reports are used in Oregon: the police crash report, a CMV supplemental report completed by law enforcement, a CMV self-report form, and a driver self-report form. Crash data for Oregon was available for 2002 and 2003; the crash data provides the following information: crash identification number, date and time, vehicles involved, vehicle classification, cargo body type, location (street name and city), citation issued, vehicle GVWR, truck/bus identifier, and type of harmful event contributing to the crash. The following data variables pertain to truck details and truck configuration and may be used for detailed truck type identification:

a) Truck classification identifies vehicles such as buses, single unit trucks, truck/trailer, tractor/semi-trailer, tractor/double, and tractor/triple, and
b) Vehicle and cargo body type: includes bus, cargo tank, and flatbed along with other detailed cargo body type descriptions.

The truck variables for Oregon do not allow the identification of all LCVs. Triple trailer trucks can be easily identified since there is a direct classification for these vehicles. However, freeway doubles, Rocky Mountain doubles, and turnpike doubles are lumped into a single category that does not allow specific LCV doubles identification.

2.2.5 Washington

Washington State Department of Transportation (WSDOT) maintains records for collisions on all public roadways in the state. The Motor Vehicle Laws of Washington require a report from the operator of any vehicle in an accident resulting in injury or death to any person, or damage to the property of any person to an apparent extent of $500 or more. Washington does not allow triples or Turnpike doubles on their roads. Therefore, freeway doubles and Rocky Mountains are the only double trailer configurations allowed in Washington. Crash data were obtained from the WSDOT for years 2002 and 2003.

Information included in the Washington crash data files includes the following: crash identification number, crash date and time, number of vehicles involved in the crash, contributing circumstances, collision type, weather conditions, accident severity, direction of travel, and vehicle type and year. The truck configuration data includes identification of the following:

a) Vehicle type, such as truck, semi trailer, truck-tractor, and double trailer combinations, and
b) Vehicle style, such as van, tow truck, tanker truck, etc.

Since triples and turnpikes are not allowed on Washington roads, the sample of trucks consist of single unit trucks, non-LCV doubles, and Rocky Mountains, the only configuration of LCV allowed, and both are included in a single category. Similar to other states, crash data can not support LCV and non-LCV comparative crash analysis.

2.2.6 Wyoming

Crash data were obtained from the Wyoming DOT for years 2002 and 2003. Wyoming does not allow triples on their roads, but does allow Turnpikes doubles and Rocky Mountain doubles. Information included in the Wyoming crash data files is the following: crash identification number, crash date and time, crash location, number of vehicles and people involved in the crash, weather conditions, collision type, accident severity, contributing circumstances, and vehicle type and year. The truck configuration data includes the following identifications: a) vehicle type, such as semi tractor, truck, and tractor trailer; b) trailer style, such as single trailer and double trailer; and c) number of axles.

Since triples are not allowed in Wyoming roads and double combination truck data does not distinguish between LCVs and non-LCVs, a comparison study among LCVs and non-LCVs cannot be performed.

2.2.7 Utah

Crash data is reported on all crashes above the state threshold of $1000 for any damage, injury or fatality. A single basic crash report is used for all kinds of crashes. Trained law enforcement personnel collect and report the crash data to Utah Highway Patrol and local law enforcement agencies. The crash reports do not meet all MMUCC guidelines; however, the reports take into consideration most of the variables considered in the MMUCC guidelines. Crash data were available from 1999 to 2003. Information in the Utah crash data files includes accident code, date, route, collision type, direction of travel, speed (posted and actual), driver and vehicle details, and vehicle type. The vehicle type variable provides sufficient information to identify LCV trucks.

This is the only state among the eight states included in this study that allows the identification of all LCV trucks. Since the vehicle type variable in the crash data files is directly associated with a range of total vehicle length, number of trailers and a graphic depiction of each kind of truck, freeway doubles, turnpike doubles, Rocky Mountain doubles and triples, are easily identified. Figure 2.1 and Table 2.1 show the association of the vehicle type variable with a description, graphic representation and total length range for each vehicle. The characteristics of crash data for the eight states are summarized presented in Table 2.2.

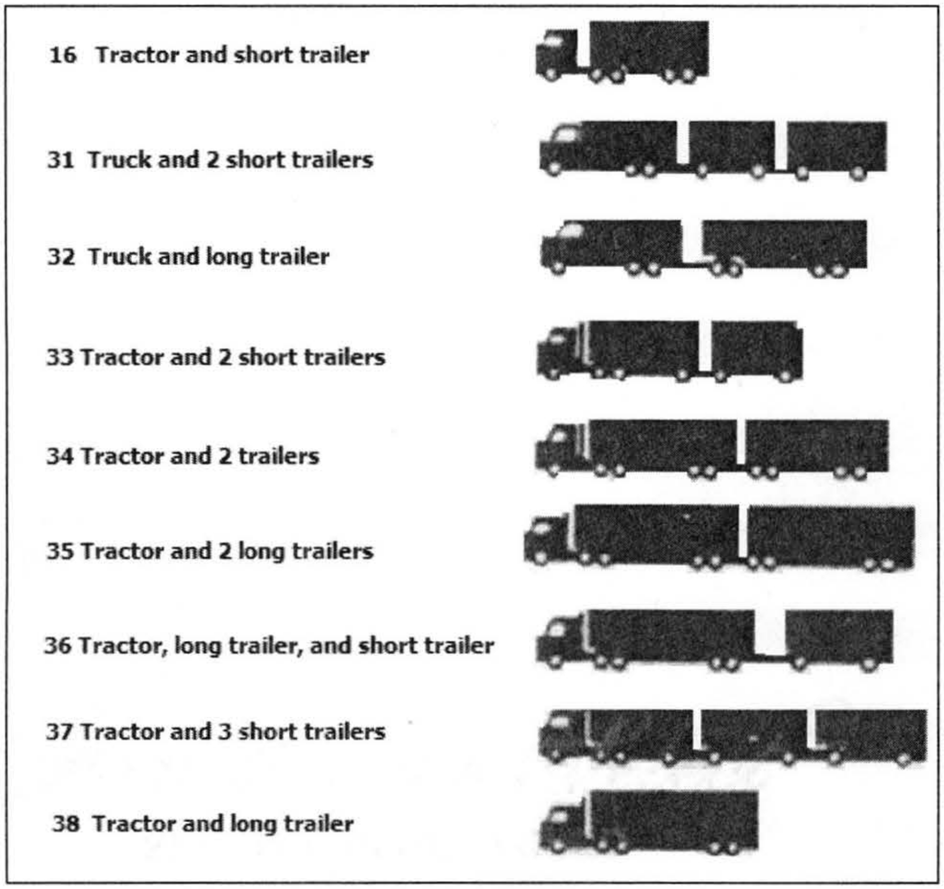

Figure 2.1 Description of trucks in Utah.

Table 2.1 Truck Types in Utah Crash Reports

Code	Truck type	Truck type
14	Truck - long trailer	Single unit trailer (Non LCV)
16	Tractor and short trailer	
38	Tractor & long trailer	
51	Other singles	
33	Tractor - two short trailers	Freeway double (Non LCV)
34	Tractor - 2 trailers (Intermediate double)	Rocky Mountain double (LCV)
35	Tractor - long -short trailer (Rocky mountain double)	
36	Tractor - 2 long trailers (Turnpike double)	Turnpike double (LCV)
37	Tractor - 3 short trailers (Triple)	Triple (LCV)
99	Others	Non LCV

Table 2.2 Characteristics of Crash Data Obtained by State

	Colorado	Idaho	Montana	Nevada	Oregon	Utah	Washington	Wyoming
Crashes reported by	Police officers	Police officers	Police officers	Police officers	Police officers, Drivers (self reports)	Police officers	Police officers	Police officers
State threshold ($)	1,000	750	1,000	N/A	1,500	1,000	500	n/a
Crashes submitted to	Colorado Department of Revenue, Motor Vehicle Division	ITD, Office of Traffic and Highway Safety	Montana Highway Patrol	Nevada DOT	Oregon DOT	Utah DOT	Washington DOT	Wyoming DOT
Truck types included in crash data	Singles, doubles, and triples	Singles, doubles, and triples	Singles, doubles, and triples	Doubles and triples	Singles, doubles, and triples	Singles, freeway doubles, Rocky Mountain doubles, turnpike doubles, and triples	Singles and doubles	Singles and doubles
LCVs discernable from crash data	no	no	no	no	no	yes	no	no
Years of crash data	2002/2003	1999-2003	2002/2003	2002/2003	2002/2003	1999-2004	2002/2003	2002/2003
Graphic depiction of truck in crash data	no	no	no	no	no	yes	no	no

2.3 Availability of Exposure Measure Data

This section assesses methods currently used for the estimation of Vehicle Miles of Travel (VMT). Three methods are currently used for truck VMT estimation: non-count-traffic methods, count-based methods that include direct and indirect estimation procedures, and survey-based methods.

2.3.1 Non-Count-Based Methods

These methods use non-traffic data, such as fuel sales, household size and population, among others to estimate VMT. These methods provide only approximations, since the accuracy of the data used and their representation cannot be verified. Examples of the non-count based methods include fuel consumption-based methods and odometer recording based methods

2.3.1.1 Fuel Sales Based Methods

The VMT estimation method using fuel sales is based on information on retail gasoline and diesel fuel sales, estimates of fleet fuel efficiencies, and price per gallon of fuel:

$$VMT = \frac{RetSales * MPG}{PPG} \qquad (2)$$

where

RetSales = total daily retail sales of fuel for the study area ($)

PPG = average unit price per gallon of fuel ($)

MPG = fleet fuel efficiency (MPG).

The accuracy of VMT estimates using this method depends on the quality of retail fuel sales data and on assumptions regarding fleet fuel efficiency, which in turn depends on several factors such as topography, weather, and driving patterns. The estimates of fuel sales can be biased as fuel purchased from one state can be used in another.

2.3.1.2 Odometer Recording Based Methods

In this method, VMT is estimated using odometer recordings for all vehicles registered in the state for different periods of time. The VMT estimates do not consider the possibility of errors associated with odometer reading and reporting, unreported vehicles, and vehicles registered in other states.

2.3.2 Count-Based Method to Estimate VMT

This method is the most commonly used in the United States. It estimates VMT based on the collection of data obtained from traffic count stations. The traffic data of interest include traffic counts, vehicle classification counts, and truck weight data. The data collection program adopts a sequential or nesting format, as shown in Fig 2.2. The illustration shows that truck weighing count programs are a subset of vehicle classification count programs, which are a subset of traffic volume count programs. This nesting procedure implies that sites selected for truck weighing automatically should collect all data types, and sites selected for vehicle classification should also collect volume count data. There are two different methods to estimate VMT using traffic-count-based methods:

1. Direct method: VMT for each truck type is estimated directly by multiplying truck volume by the section length. This method is used when detailed truck data are available for specific roadway segments.
2. Indirect method: VMT for each truck type is estimated based on average truck percentages, total truck VMT, and average section length. There are different indirect methods such as the Highway Performance Monitoring System (HPMS) Method, Average Truck Percentage (ATP) Method and Average Section Length (ASL) Method.

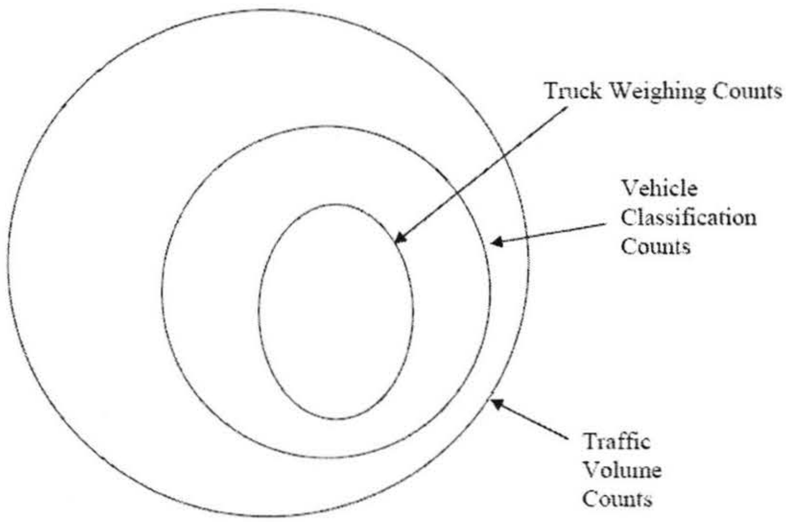

Figure 2. 2 Nested format of the traffic data collection process for truck VMT estimates.

2.3.2.1 HPMS Method

The HPMS is a federally recommended data collection and reporting process adopted by most DOTs for VMT estimation. The HPMS is a program developed by the Federal Highway Administration (FHWA) for monitoring the nation's highway infrastructure. The estimation of AADT is based on three types of count procedures (FHWA 2001): Continuous counts (year-round) using automatic traffic recorders (ATRs), HPMS coverage counts, which are short period counts performed on the HPMS-generated standard sample sections and adjusted by factors derived from the continuous counts, and special needs studies, which are dependent on state data requirements. The continuous count program is primarily, but not exclusively, for the establishment of seasonal adjustment factors. These adjustment factors facilitate the expansion of short-term standard sample counts to universal samples. Continuous ATR count data is also reported monthly to the FHWA for preparation of the Traffic Volume Trends report. The number of ATR locations usually depends on the predetermined precision level established for functional class.

The AADT estimation procedure for the standard samples is one half of a 48-hour count that has been adjusted for the terms of the year. A shorter duration traffic volume count will require some adjustments for the estimation of Annual Average Daily Traffic (AADT) to correct for temporal biases, equipment type, and a growth factor to account for a non-counting year (FHWA 2001). The HPMS uses the FHWA's 13 vehicle classifications (see Table 2.3).

Table 2.3 FHWA Vehicles Classification

	Type of Vehicle	Definition
1	Motorcycles	All two or three-wheeled motorized vehicles.
2	Passenger Cars	All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers.
3	Other Two-Axle, Four-Tire Single Unit Vehicles	All two-axle, four-tire, vehicles, other than passenger cars.
4	Buses	All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles.
5	Two-Axle, Six-Tire, Single-Unit Trucks	All vehicles on a single frame with two axles and dual rear wheels.
6	Three-Axle Single-Unit Trucks	All vehicles on a single frame with three axles.
7	Four or More Axle Single-Unit Trucks	All trucks on a single frame with four or more axles.
8	Four or Fewer Axle Single-Trailer Trucks	All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
9	Five-Axle Single-Trailer Trucks	All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
10	Six or More Axle Single-Trailer Trucks	All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
11	Five or fewer Axle Multi-Trailer Trucks	All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
12	Six-Axle Multi-Trailer Trucks	All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
13	Seven or More Axle Multi-Trailer Trucks	All vehicles with seven or more axles with of three or more units, one of which is a tractor or straight truck power unit.

The HPMS statewide VMT estimation is calculated using the following equation:

$$DVMT_s = \Sigma_i \Sigma_j \Sigma_k DMVT_{ijk} * EF_{ij}, \tag{3}$$

where

$DVMT_s$ is the statewide VMT estimate for functional class *j*,

$DMVT_{ijk}$ is the VMT for sample section *k* in group *i* of functional class *j*, and

EF_{ij} = expansion factor for group *i* in functional class *j*.

2.3.2.2 Average Truck Percentage (ATP) Method

The ATP follows the HPMS procedure (Benekohal 2003). The difference between the two methods is in the way VMT is estimated for different truck types and at different volume group levels. In the ATP method, the average percentage of different truck types in the traffic is estimated from field counts. These percentages are then used together with the total VMT for a specific truck type to estimate VMT for different truck types on a specific road segment.

2.3.2.3 Average Section Length (ASL) Methods

This method estimates VMT based on the average section length of roadway section. Three different estimates are considered to estimate this value. The first one is the ASL at each roadway functional class level. The average roadway section length for a roadway functional class is simply the ratio of total roadway length to the total number of roadway sections in that functional class. The second approach is the ASL at one sample level, which uses the average roadway section length that comes from the sampled section, and the last approach is the ASL at volume group level (Benekohal 2003).

2.3.3 Survey Methods to Estimate VMT

Surveys have been used to determine and modify national, regional, and local VMT based on licensed driver characteristics. Surveys can be based on demographic, socio-economic, or vehicle travel characteristics. Surveys based on vehicle travel characteristics provide the best information for the purposes of estimating VMT for trucks in particular. A good example of a survey-based method is the Michigan Truck Trip Information Survey (MTTIS), a program initiated and maintained by the University of Michigan's Transportation Research Institute. The survey is used to collect trucks' travel information, estimate VMT and calculate accident rates. The sample of the survey covers truck tractors with empty weight over 6,000 pounds, since this weight was considered to be the lower weight for truck tractors; the sample also covers "other" trucks licensed to operate at a weight of 80,000 pounds or more. By considering these weights, the survey covers all heavy-duty truck tractors registered and operating in the state of Michigan.

The data collection is done by telephone interviews. When the interview could not be completed, mail versions of the survey forms were used. The first part of the survey was designed to establish an initial contact with the owner of the truck. This initial contact was also used to confirm the vehicle identification number, obtain information about the truck (number of units, cargo body style, cargo type, weight, length, number of axles, etc), and information about the company. This first interview also served to make agreements for obtaining detailed mileage information for random days on later interviews.

In the second phase of the survey, truck travel information over the course of one year was collected and divided into four quarters. Each quarter covered the activities of a truck during 24 hours of a random day; in case the truck was not used the day selected, travel information from the last day the truck was used was recorded. The start date for each trip quarter was determined in such a way that a survey day did not fall on a weekend more than twice per survey year. Data collected includes details such as driver's age, years of experience, cargo weight, number and type of trailers; route followed the day of the truck's survey and road classification. In order to obtain the aggregation of miles for a specific configuration of trucks, "trips" were recorded; a new "trip" was considered whenever there was any change in driver, vehicle configuration or cargo type. Then travel was estimated based on company type, power unit type, number of trailers, trailer type, trailer body and time of day.

2.3.4 Current VMT Estimation Practices in Western States

A study that examined different technologies used for truck classification and methodologies for estimating truck VMT (Benekohal and Girianna 1998) found that the FHWA's 13 vehicle classes classification method is the most common classification method used in most states. Tube counters were found to be the most common tool used for short term truck counts. Additionally, the study found that truck data from short counts was adjusted using continuous general traffic count data and not necessarily continuous truck data. A handful of states did use factors for trucks that varied from those used for general traffic.

This study categorized current truck classification technologies into three groups: axle-based, vehicle-length-based, and machine-vision-based. Axle-based classifications are usually done by applying tube counters along with a vehicle classification algorithm. The disadvantages of tube sensors include the difficulty of installation in segments with high traffic volumes, the large number of unclassified vehicles, and the low durability of tube counters. Vehicle-length-based systems measure the vehicle length based on the vehicle speed and occupancy time. These systems may not provide sufficient details on the vehicle or trailer configuration to classify trucks into single and multiple trailer trucks. Visual based systems use cameras to record vehicles and feed the data to digitizers which distinguish vehicle characteristics based on the recorded frames. Drawbacks to this system are the difficulty in distinguishing vehicles closely spaced together as well as distinguishing vehicles when the line of sight is blocked by other vehicles.

Other classification technologies mentioned in this document include inductive loops, pressure sensitive devices placed under the pavement, and non intrusive technologies that use light beams to detect the presence of a vehicle. Some of these technologies are currently still under development and have shown to have different levels of accuracy at varying vehicle speeds.

Brown, et al. (2003) described a methodology to estimate VMT for commercial vehicles at the state level using the following five steps:

1. Individual State truck and bus VMT is estimated by multiplying the rural and urban annual VMT by the rural and urban annual percent trucks.
2. The national total of truck and bus VMT is estimated by adding truck and bus VMT obtained in the previous step.
3. The percentage of truck and bus VMT is calculated from the national total VMT for each state by dividing the results of Step1 by results in Step 2.
4. A truck and bus adjustment factor is determined by summing the total rural and urban VMT.
5. An adjusted VMT for commercial motor vehicles for each state is estimated by multiplying results of Step 3 by the results of Step 4.

The results obtained were later used to estimate crash involvement rates per state. Table 2.4 shows how this methodology was conducted to estimate CMV VMT and crash involvement rates for the two states in the study.

Table 2.4 Crash Involvement Rates for CMV's

State	Fatal Crashes	Adjusted VMT (million)	Crash Rate
Idaho	26	1,639	1.59
Utah	42	1,580	2.66

Source: Brown,et al. (2003)

The current practices used by state DOTs to estimate VMT for trucks vary from state to state and are not well documented. As part of this study, the VMT estimation procedures for a sample of western states were investigated and documented.

2.3.4.1 Colorado

Colorado uses two methods to calculate truck VMT; both methods are count-based methods. The first method estimates VMT by multiplying truck average daily traffic (ADT) by the length of a roadway section. Truck ADT on a highway segment is calculated by taking an average of the estimated truck ADT in two consecutive classification count stations and then multiplying it by the distance between the two stations. The second method used is the HPMS method which calculates VMT by multiplying total VMT (by functional class) by the average truck percentages (by truck types). The Colorado DOT calculates the total VMT and the statewide average truck percentage for a specific roadway group, by functional class and vehicle types. The total VMT is obtained from the HPMS database which records average annual daily traffic (AADT) for HPMS highway segments. The average truck percentages by roadway functional class and vehicle types are obtained from truck data collected at permanent classification count stations.

2.3.4.2 Idaho

Idaho's statewide VMT is based on fuel consumption. ITD uses information from the state fuel tax records to identify the number of gallons of gasoline and the number of gallons of special fuel taxed in Idaho. Idaho's statewide VMT is based on gasoline and diesel fuel consumption in the state multiplied by truck fleet fuel efficiency estimated using Eq. 4. Additionally, count-based VMT is calculated for the State Highway System, and for each functional classification above local roads. VMT for functionally classified routes is subtracted from the statewide VMT to get VMT for local roads.

$$AVMT = TNG(FMPG), \tag{4}$$

where

$AVMT$ = annual vehicle miles traveled

TNG = total number of gallons of fuel sold (gasoline and diesel)

$FMPG$ = total fleet miles per gallon

2.3.4.3 Montana

The State of Montana estimates the VMT following the HPMS procedures. The estimation of AADT is done through ATR stations on a given roadway segment over a 24- or 48-hour period. There are 83 continuous automatic traffic recorders located on Montana highways.

2.3.4.4 Oregon

Since the majority of heavy trucks operating in Oregon are not subjected to the state fuel tax, Oregon considers the fuel consumption method of little use to estimate VMT. Instead, VMT is estimated from the weight-mile-tax reported and from the available traffic-count-classification data. The traffic classification data are obtained through permanent ATR stations located throughout the state and on a limited number of special classification counts performed on an as-needed basis. The primary source of VMT data for trucks is the number of miles reported by truck operators in the weight-mile tax report. These miles are collected and summarized by the Motor Carrier Transportation Division in an annual Highway Use Statistics (HUS) Report. The weight-mile tax miles and revenues are reported by declared gross weight or by gross weight and number of axles, but not by specific vehicle configuration. The weight-mile-tax data, however, can be combined with the traffic classification data from the states' special truck weigh database to obtain additional detail on VMT by specific truck configuration.

Other states such as Nevada, Utah, Washington and Wyoming follow the count-based HPMS procedures using data from permanent ATR count station as well as 48-hour count stations in different location throughout the state's highway system.

2.4 Conclusions

The availability of data required to perform LCV crash analysis in eight western states: Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming was examined. The following conclusions can be made:

1) Crash reports in six of the eight states can identify crashes involving triples (Washington and Wyoming do not allow triples)
2) Among the eight states surveyed, Utah's crash report is the only report that distinguishes between different combinations of doubles.
3) None of the crash reports in the eight states follow crash data collection forms that match the Model Minimum Uniform Crash Criteria (MMUCC) guidelines, although Utah's crash reports take into consideration most of the variables considered in the MMUCC guidelines.
4) While the crash reports in all eight states include some truck characteristics that could distinguish between LCVs and non-LCVs, such as the number of axles, GVWR, distance between axles, length of the trailers and overall length, not all characteristics are always included in the crash reports.
5) A pilot study to examine the validity of obtaining additional crash data through the carriers of the truck involved in the crash shows that a considerable percentage of the

carriers either did not maintain records of crash data or were not willing to share such information with the project team

6) None of the eight states maintain VMT per truck type. Most states use count-based methods using the FHWA 13-vehicle classification system.

Chapter 3. DATA ANALYSIS

3.1 Introduction

The purpose of this analysis is to assess LCV safety performance and identify LCV crash trends in a sample of western states. To conduct a comparative crash rate analysis that assesses the relative safety performance of different commercial vehicle classes, exposure measure data that are specific to each of the vehicle classes should be obtained. For this reason, it is important to determine the total VMT by each type of commercial vehicle. Based on the extensive review of the availability of exposure measure data presented in Chapter 2, this author concluded that none of the eight states included in the review maintain VMT per truck type. All vehicle classification algorithms classify vehicles according to the 13 FHWA vehicle classes that are based on the number of axles rather than the configuration of the truck. These classifications are not detailed enough to differentiate between LCVs and non-LCVs.

A new algorithm developed at the University of Idaho to identify LCVs using data obtained from WIM stations is used to obtain VMT estimates for different truck types (Candia 2006). This algorithm uses vehicle-by-vehicle Weigh-In-Motion (WIM) data to classify vehicles into subcategories based on axle weight and spacing, gross vehicle weight (GVW), vehicle length, and cargo length. The algorithm classifies vehicles into: 1) single unit trucks, 2) non-LCV double combination trucks, 3) LCV double combination trucks, and 4) LCV triple combination trucks. Moreover, the algorithm attempts to identify different types of LCV double combination trucks such as Rocky Mountain doubles and turnpike doubles.

3.2 WIM Data Analysis

Weigh-in-Motion (WIM) scales are dynamic weighing systems that determine weights while vehicles are in motion. They enable vehicles to be weighed with little or no interruption in travel. WIM scales have been designed to sense the weights of the axles passing over the instrument using piezo sensors, strain gauges or hydraulic or pneumatic pressure transducers.

The readings are transmitted to a receiving unit where they are converted to weights. WIM data is used in different fields such as pavement studies, highway monitoring and capacity studies, accident rate calculation, analysis of truck transport practices and others to measure vehicle counts, axle and gross weight and vehicle classification.

WIM data records are divided into four types: 1) station description data; 2) traffic volume data; 3) vehicle classification data; and 4) truck weight data. Several fields in the station description record were replaced with fields that are needed to tie traffic data to geographic information systems (GIS), which allow traffic data to be overlaid on the National Highway Planning Network (NHPN) and similar systems. Algorithms for vehicle classification identified in the FHWA Traffic Monitoring Guide (FHWA 2002) include: 1) human observation either on site (manual) or video image; 2) vehicle length classification; 3) axle spacing classification; 4) axle spacing and vehicle length classification; 5) axle spacing, weight; and 6) vehicle length classification. Examples of axle spacing classification algorithms include American Society for Testing and Materials (ASTM) Standard E1572 (ASTM 2000), Scheme F algorithm, and Scheme F modified algorithm (Elliot, et al. 1998). Scheme F assumptions regarding axle spacing for each of the 13 vehicles classes included in the FHWA vehicle classification system were presented in Chapter 2 as Table 2.2.

3.2.1 Algorithm Description

The length and weight criteria for different classes of heavy vehicles used for the development of this algorithm were obtained from several sources including the Western Association of State Highway and Transportation Officials' Western Uniformity Scenario report (WASHTO 2004), the Comprehensive Truck Size and Weight Study (USDOT 2000), and the American Trucking Association carriers database (ATA 2004). Field observations were made and measurements of different truck types were also conducted. A sample of 250 trucks, representing different truck types, was used to obtain the configuration characteristics of the truck types used in the algorithm.

The classification algorithm is based on the number of "major spacings" between axle groups in each vehicle based on the criteria shown in Figure 3.1. Vehicles are initially classified into one of six groups based on the number of major spacing. Some groups have more than one vehicle class, Table 3.1. The characteristics of major spacing configuration for different truck types are presented in Fig. 3.2 and 3.3.

Trucks with one or two major spacing are classified as either single-unit trucks or single trailer trucks. Similarly, trucks with five or six major spacing are classified as triple combination trucks (a truck pulling two trailers or triple trailer truck). Trucks with three or four major spacing are classified as double combination trucks. These trucks are classified based on the estimated length of trailer 1, trailer 2, and the total cargo length according to the criteria presented in Table 3.2. The classification algorithm procedures are presented in the flow chart shown in Fig. 3.4.

Table 3.1 Preliminary Truck Classifications Groups

Major Spacing	Possible Truck Classification
1	Single-unit truck
2	Single trailer truck
3	B-train truck, or full truck with 1 trailer
4	Double trailer truck
5	Full truck with 2 trailers
6	Triple

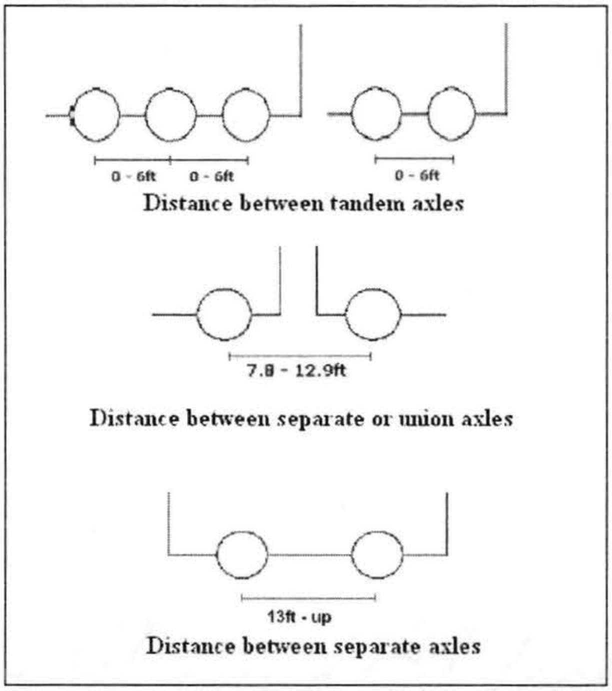

Figure 3.1 Criteria for Defining the Type of Axle Based on Axle Spacing.

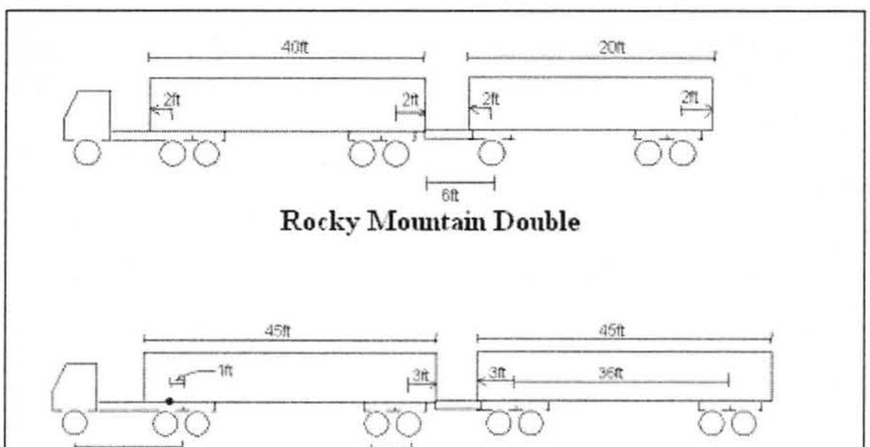

Figure 3.2 Typical Axle Spacing for LCV Doubles.

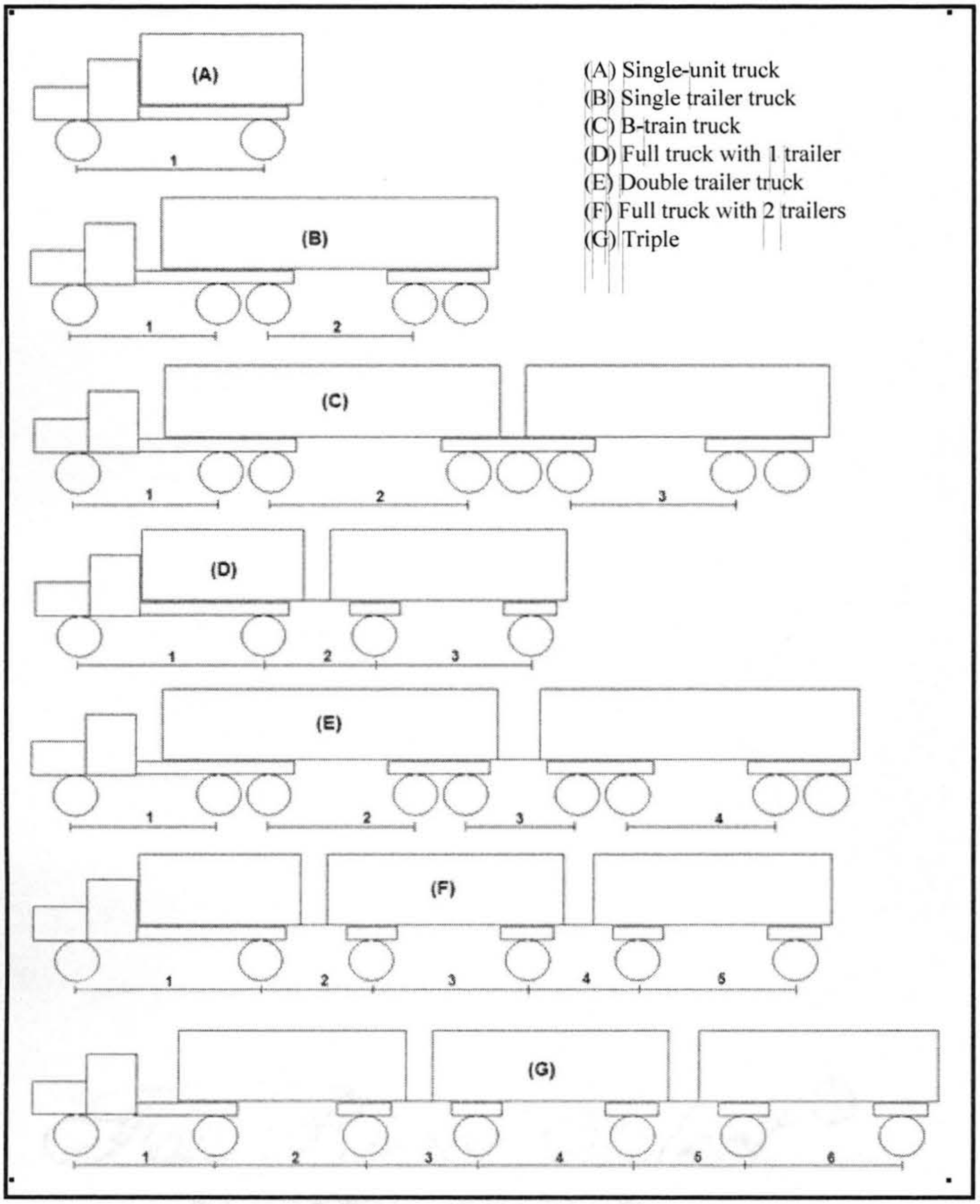

Figure 3.3 Characteristics of Major Spacing Configuration for Different Truck Types.

Table 3.2 Length Criteria for Classifying Double Trailer Trucks

Trailer 1		Trailer 2		Total length	Preliminary Truck Classification
26-28 ft		26-28 ft		< 57 ft	Freeway Double
40-48 ft	**and**	20-28 ft	**and**	60 – 76 ft	Rocky Mountain Double
30-40 ft		30-40 ft		60 – 80 ft	Intermediate Double
40-48 ft		40-48 ft		> 75 ft	Turnpike Double

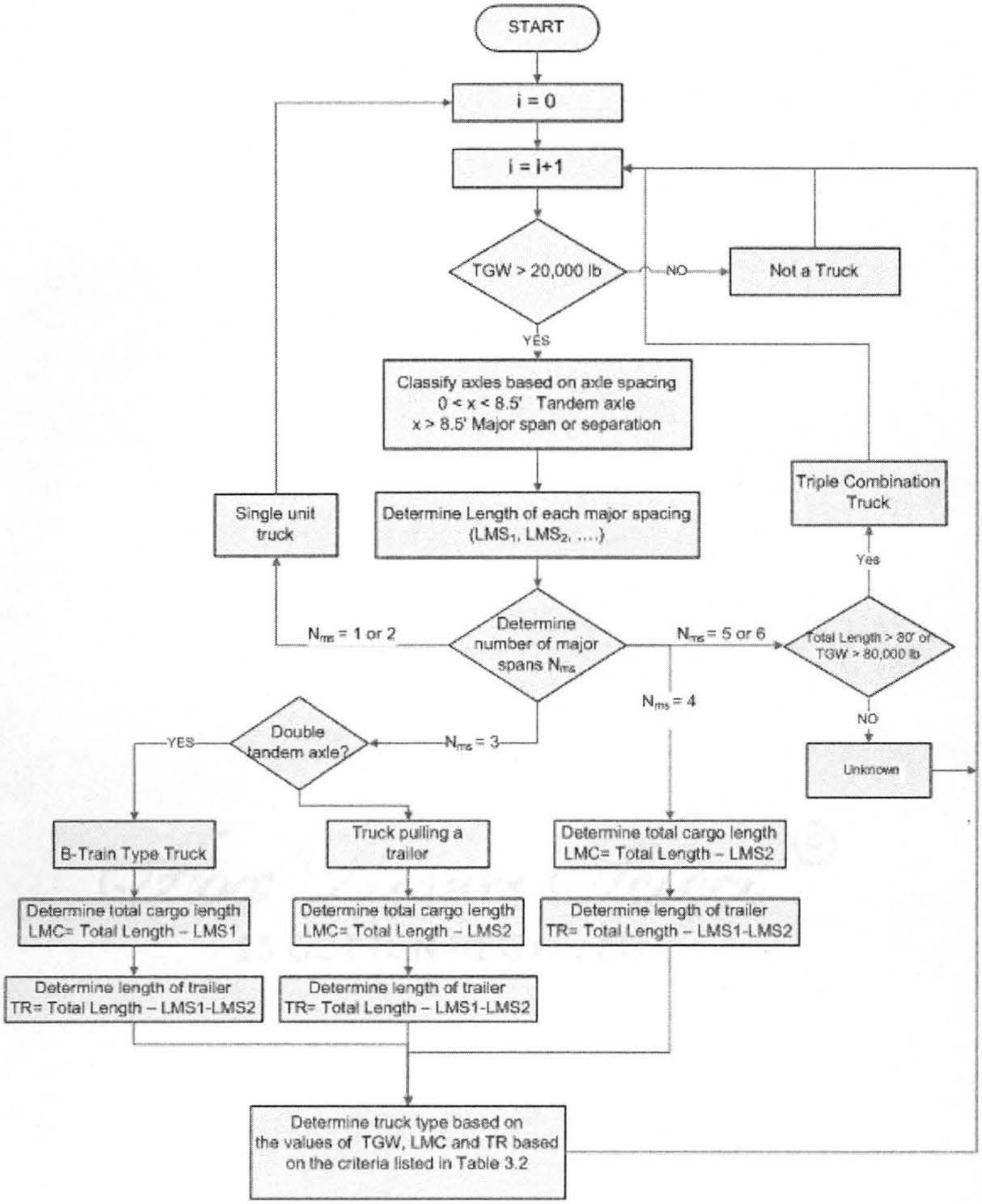

Figure 3.4 Flow Chart for WIM Data Truck Classification Algorithm.

3.2.2 Algorithm Validation

To validate the algorithm, vehicle-by-vehicle data were obtained from a WIM station located on I-84 west of Boise, Idaho. Data were collected for a sample of 495 trucks during a four-hour data collection period [3:00 PM to 7:00 PM]. Data were obtained for each truck using manual observations and included truck type, number of axles, and truck weight as reported by the WIM station. To verify the manual observations in the lab, the operations of the WIM station during the data collection period were also recorded by video. The WIM data in TMG format were obtained from the station for the same time periods.

The WIM data were analyzed using the WIM data truck classification algorithm. The algorithm outputs were compared against the manually collected data. The results of this comparison are presented in Table 3.3. The algorithm successfully identified all 34 triple combination vehicles; all 23 non-LCV double combination vehicles; and all 35 LCV double combination vehicles that passed the WIM station during the data collection period. Out of the 503 single trucks, the algorithm correctly identified 501 and reported 2 as unknowns.

To further verify the output; the algorithm was tested using a set of WIM data from a station on a road segment where LCVs are not permitted. Data from 7 WIM stations were used in this verification analysis. The results are presented in Table 3.4. The results show a very minimal error with only two trucks incorrectly classified as LCV doubles out of a total of 275,000 truck data analyzed. The results help reinforce the classification capacity of the developed algorithm.

Output from the algorithm was used as a basis to estimate relative truck exposure measures (such as VMT) for different truck types. This will allow for a comparative crash rate analysis for different classes of heavy vehicles, including different types of LCVs. The output of the algorithm can be further improved with more extensive calibration using a larger sample of field data.

In the analysis presented in this thesis, outputs from the algorithm are used to obtain relative crash rates for different vehicles classes. They are also used to estimate annual VMT for each vehicle class using the count-based direct method described in Chapter 2 of this thesis.

Table 3.3 Results of the Field Data Validation of the Algorithm Output

Hour 1	Single	FWD	RMD	TPD	Triple	Percent Error
Observed	135	4	3	1	6	0%
From algorithm	135	4	3	1	6	
Hour 2						
Observed	118	6	9	0	7	0%
From algorithm	118	6	9	0	7	
Hour 3						
Observed	155	5	11	2	9	Less than 1
From algorithm	156	5	11	2	9	
Hour 4						
Observed	95	8	5	4	12	Less than 2
From algorithm	97	8	5	4	12	

Table 3.4 Results of the Algorithm Verification using Data from Seven WIM Stations

	Non-LCV		LCV		
Station #	**Single**	**FWD**	**RMD**	**TPD**	**Triple**
30001	56886	1926	0	2	0
30005	50572	1199	0	0	0
430007	56610	788	0	0	0
450003	21399	444	0	0	0
450007	15493	499	0	0	0
530001	39064	853	0	0	0
530005	27921	1314	0	0	0

3.3 Roadway Segmentation for Crash Rate Analysis

Based on the availability of crash data and VMT data, a comparative crash rate analyses are conducted for two states: Utah, using 1999-2004 crash data, and Idaho, using 1999-2003 crash data. VMT estimates used in the comparative crash rate analyses are obtained using the classification algorithm and WIM data from different WIM stations throughout the two states. A total of 14 WIM stations were used in Utah, all of them located on the interstate, 12 of them located on Interstate I-15, one on Interstate I-70, and one on Interstate I-84. For Idaho, 11 WIM stations were used in the analysis, four of them located on the interstate and the other seven located on different segments of state routes. Locations of the WIM stations in Utah and Idaho are listed in Tables 3.5 and 3.6, respectively.

Table 3.5 WIM Station Locations in Utah

Station #	Location	Road Class
310	I 15 North Bound Outside Lane near Plymouth MP 393	Freeway
502	I 15 North Bound Outside Lane near Nephi MP 221	Freeway
210065	I 15 North Bound Outside Lane MP 82.39	Freeway
290070	I 84 East Bound Outside Lane MP 69.05	Freeway
350041	I 15 North Bound Outside Lane 4th North MP 312	Freeway
350131	I 15 North Bound Outside Lane 13 South MP 309	Freeway
350531	I 15 North Bound Outside Lane 53 South MP 303	Freeway
350535	I 15 South Bound Outside Lane 53 South MP 303	Freeway
351061	I 15 North Bound inside Lane 106 South MP 297	Freeway
351065	I 15 South Bound Outside Lane 106 South MP 297	Freeway
410078	I 70 East Bound Outside Lane MP 38.5	Freeway
530055	I 15 North Bound Outside Lane MP 0.00	Freeway

Table 3.6 WIM Station Locations in Idaho

Station #	Location	Road Class
79	I-15 - 2.89 miles S of IC 131	Freeway
93	I-86- 3.8 miles E of IC 21	Freeway
96	US 20 - 1.9 miles S of Rigby C/L	State Route
115	I-90 - 1 mile. E of Harrison Exit 22	Freeway
118	US 95 - 0.5 mile. N of Kidd Creek Rd	State Route
119	US 95 - 1 miles N of Pack River Bridge	State Route
128	I-84 - 2.0 miles W of IC 17	Freeway
129	US 93 - 1.1 miles N of Jct. of SH25	State Route
133	US 30 - 2.0 miles W of C/L	State Route
134	US 30 - 0.7 miles SE of Nounan Road	State Route
135	US 95 - 0.8 miles N of Indian Valley	State Route

In addition to the state-wide relative crash rate analysis, the crash rate characteristics on different segments of the roadway are analyzed and examined. Roadway segments are determined based upon the location of WIM stations with truck data available. Ten roadway segments were defined in Utah and 11 roadway segments were defined for Idaho. Details of the road segments are presented in Table 3.7 and Fig. 3.5 for Utah and Table 3.8 and Fig. 3-6 for Idaho.

Table 3.7 Roadway Segments in Utah

Segment	Route	Travel Direction	Length (mile)	WIM stations		Route Class	Urban/Rural
1	I-15	north	132	530055	210065	Interstate	Rural
2	I-15	north	168	502	351061	Interstate	Rural
3	I-15	south	168	502	351065	Interstate	Rural
4	I-70	east	227	410078	---	Interstate	Rural
5	I-15	north	6	350531	---	Interstate	Urban
6	I-15	north	3	350131	350041	Interstate	Urban
7	I-15	south	6	350535	---	Interstate	Urban
8	I-15	north	11	310	---	Interstate	Urban
9	I-15	south	11	310	---	Interstate	Urban
10	I-84	south	43	290070	---	Interstate	Rural

Table 3.8 Roadway Segments in Idaho

Segment	Route	Length	WIM stations	Route Class	Urban/Rural
1	US 95	108	119	State	Rural
2	US 95	154	118	State	Rural
3	US 95	180	135	State	Rural
4	US 20	96	96	State	Rural
5	US 30	92	133	State	Rural
6	US 95	83	134	State	Rural
7	US 93	73	129	State	Rural
8	I-90	75	115	Interstate	Rural
9	I-84	146	128	Interstate	Rural
10	I-15	73	79	Interstate	Rural
11	I-86	63	93	Interstate	Rural

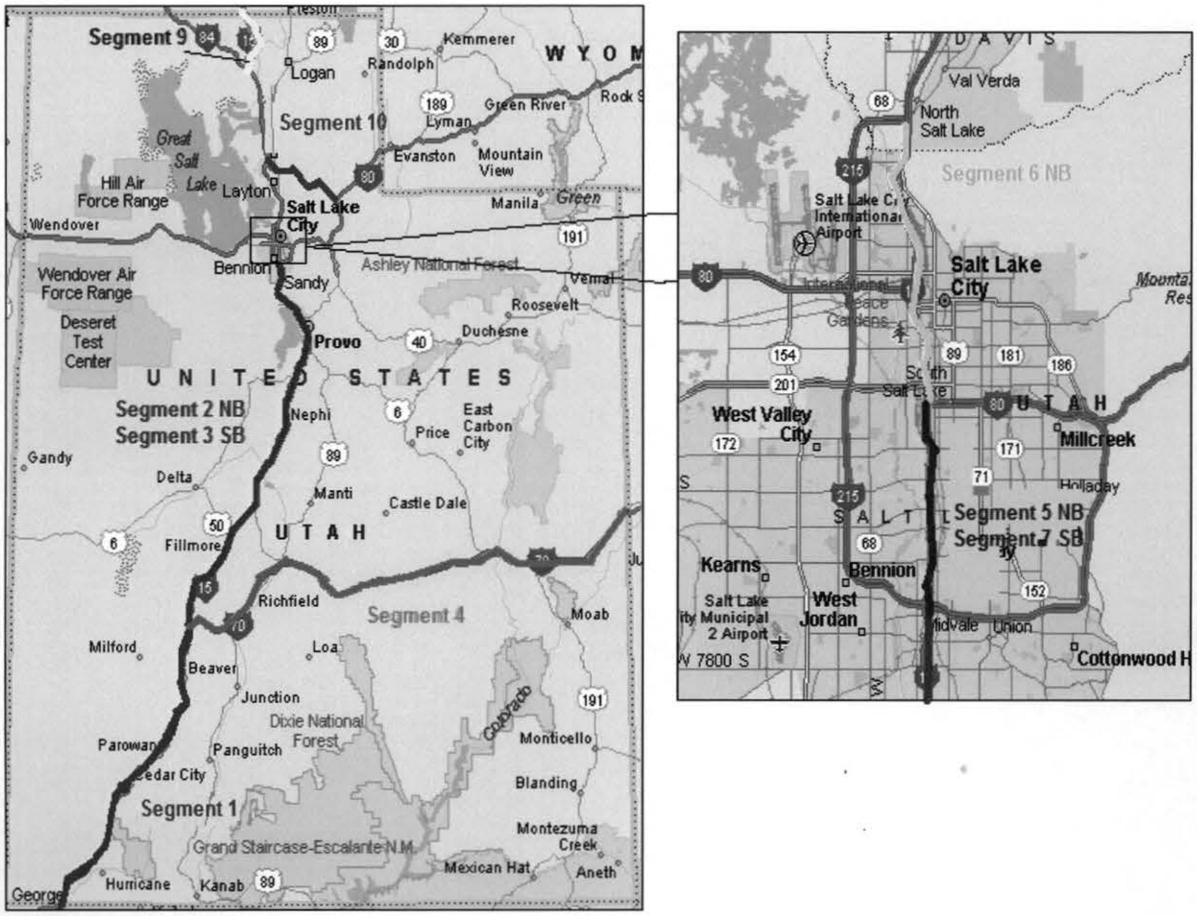

Figure 3.5 Roadway Segmentation in Utah.

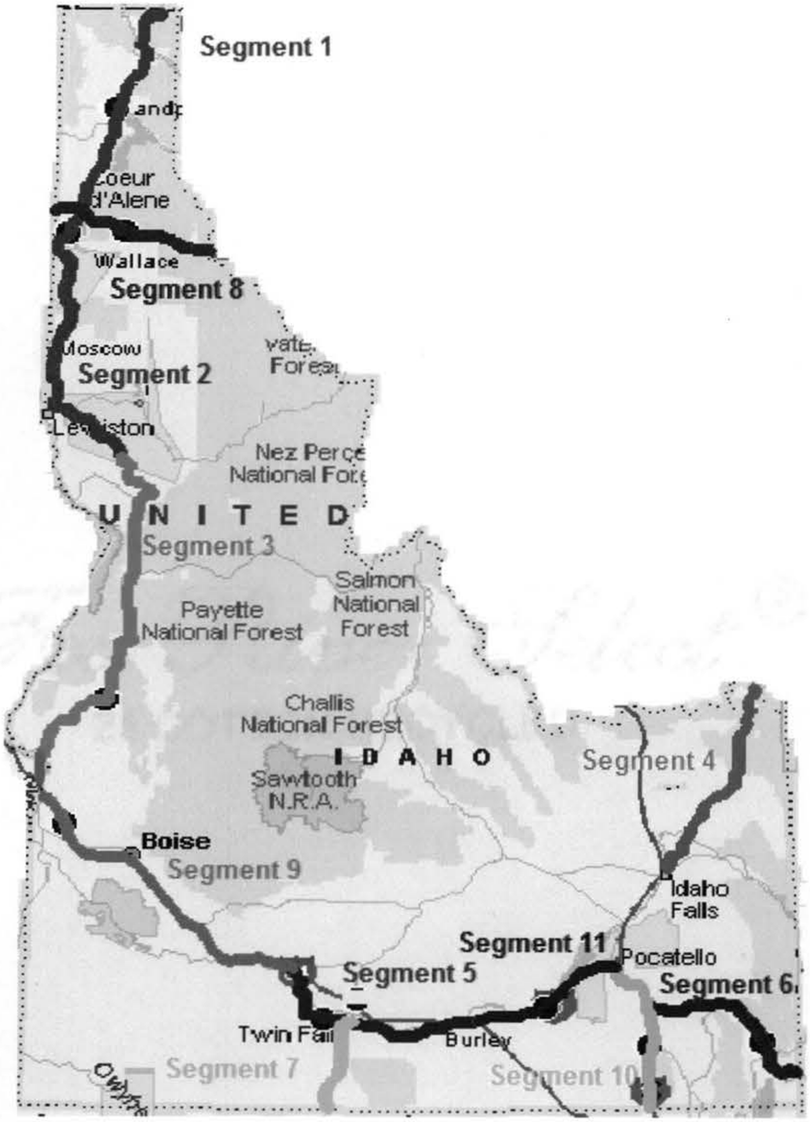

Figure 3.6 Roadway Segmentation in Idaho.

Chapter 4. RESULTS AND DISCUSSION

4.1 Introduction

This chapter summarizes the crash characteristics for different types of truck combinations in four states: Idaho, Utah, Montana and Oregon. It also presents a comparative crash rate analysis for different truck types in Idaho and Utah. Crash characteristics for Idaho are based on crash data from 1999 to 2003; the analysis for Utah was conducted using crash data from 1999 to 2004. For Montana and Oregon, the analysis was done based on two years of crash data (2002 and 2003). The second section of this chapter presents relative crash ratios for different truck configurations in Utah and Idaho for different road segments and years. The section also includes the results of statistical tests conducted to examine the significance of the difference in crash rate among different truck types.

4.2 Crash Characteristics in a Sample of Western States

4.2.1 Idaho

Crash data were available for the five years from 1999 to 2003. Because the state of Idaho crash reports do not include truck characteristics data that allows for the distinction between different type of double combination trucks, the analysis was conducted for only three types of truck configurations: single unit trailers; double combination trailers (combining both non-LCV doubles and LCV doubles); and triple combination trailers. Table 4.1 presents the five year crash trends for the three truck types. Figures 4.1 through 4.4 present pie graphs illustrating the percentages of each type of truck involved in crashes categorized by crash severity, collision, weather conditions, and light conditions.

Table 4.1 Crash Frequency and Percentage for Different Truck Types (Idaho)

STATE ROADS PERMITTING LCVS										
Year	Crash Frequency					Crash Percentage				
	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
Single	178	176	175	134	153	86.41	83.81	81.40	83.75	84.53
Doubles	26	32	38	24	26	12.62	15.24	17.67	15.00	14.36
Triple	2	2	2	2	2	0.97	0.95	0.93	1.25	1.10
Total	206	210	215	160	181	100.00	100.00	100.00	100.00	100.00
STATE ROADS NOT PERMITTING LCVS										
Year	Crash Frequency					Crash Percentage				
	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
Single	59	89	135	103	43	84.29	74.17	95.07	85.83	84.31
Doubles	11	31	7	17	8	15.71	25.83	4.93	14.17	15.69
Triple	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
Total	70	120	142	120	51	100.00	100.00	100.00	100.00	100.00
INTERSTATE ROADS										
Year	Crash Frequency					Crash Percentage				
	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
Single	248	320	277	298	291	82.12	83.55	82.44	85.63	86.61
Doubles	46	50	47	42	35	15.23	13.05	13.99	12.07	10.42
Triple	8	13	12	8	10	2.65	3.39	3.57	2.30	2.98
Total	302	383	336	348	336	100.00	100.00	100.00	100.00	100.00
OTHER ROADS										
Year	Crash Frequency					Crash Percentage				
	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
Single	288	391	407	428	464	87.80	87.87	89.06	85.77	87.55
Doubles	38	53	49	69	64	11.59	11.91	10.72	13.83	12.08
Triple	2	1	1	2	2	0.61	0.22	0.22	0.40	0.38
Total	328	445	457	499	530	100.00	100.00	100.00	100.00	100.00

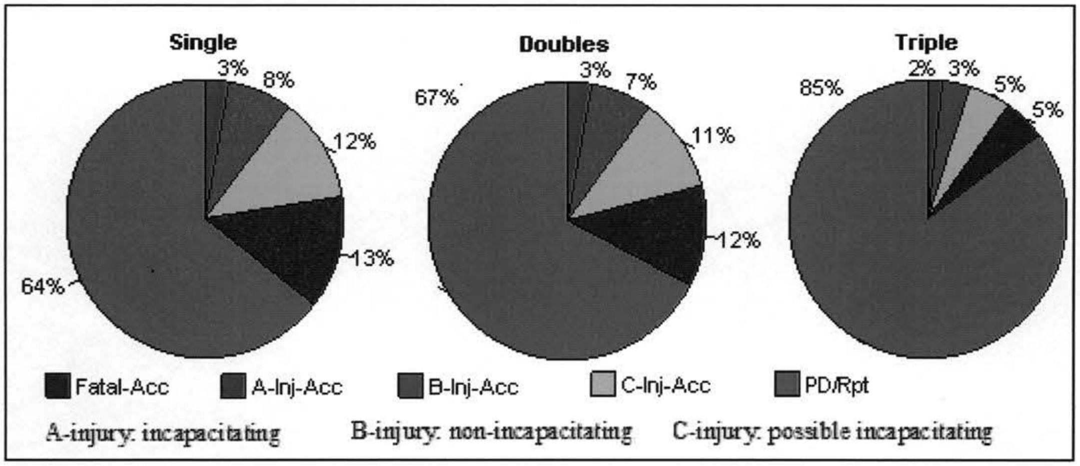

Figure 4.1 Crash Severity for Different Truck Types in Idaho.

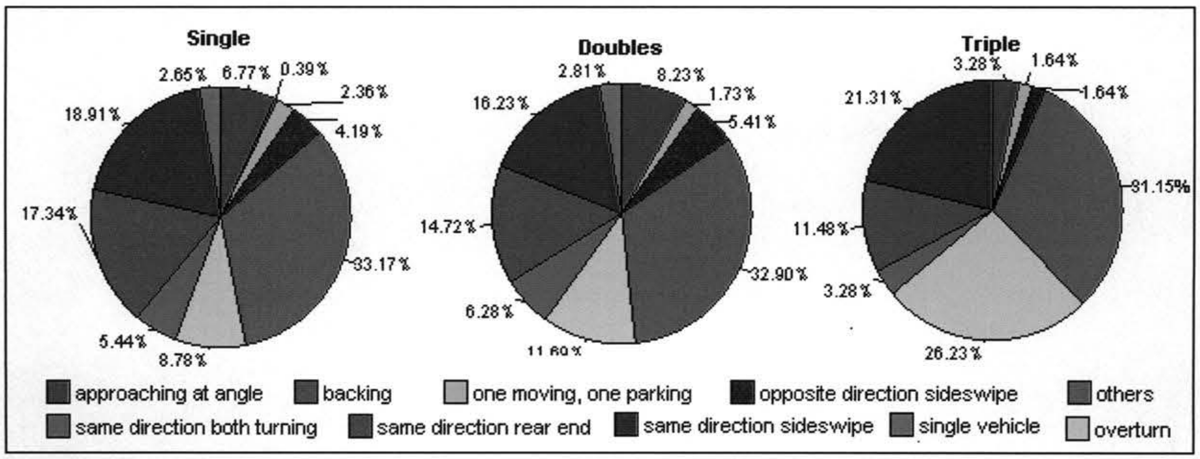

Figure 4.2 Collision Types for Crashes Involving Trucks in Idaho.

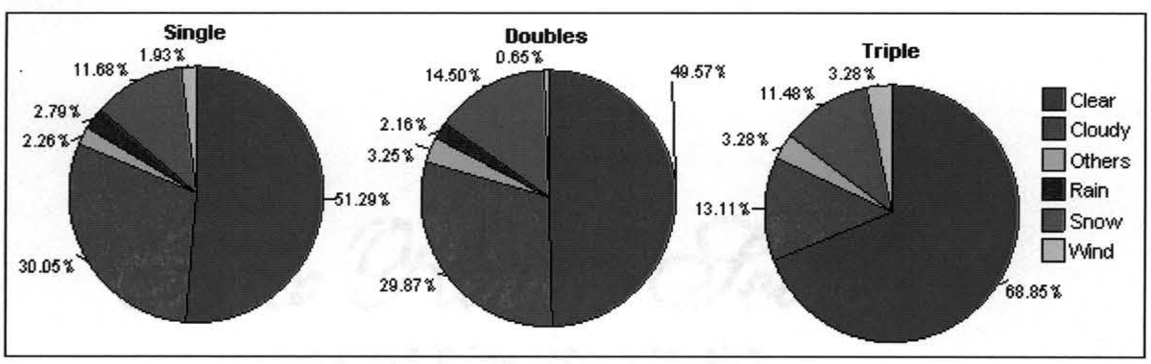

Figure 4.3 Weather Conditions for Crashes Involving Trucks in Idaho.

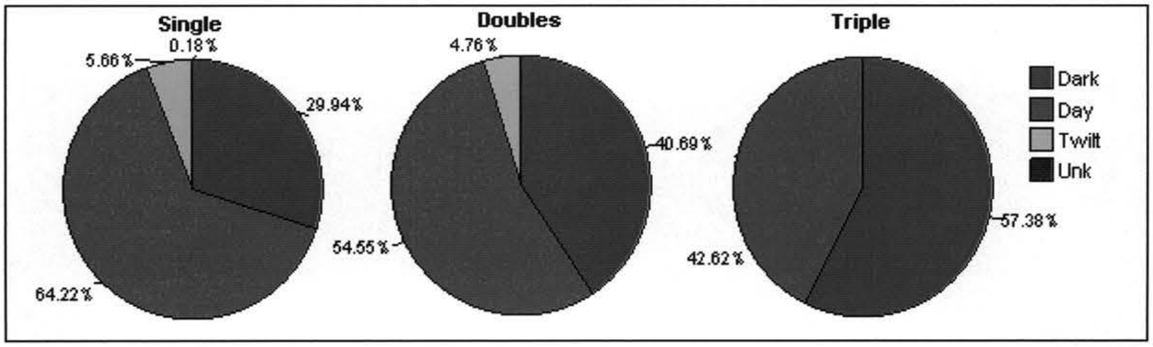

Figure 4.4 Light Conditions for Crashes Involving Trucks in Idaho.

Single unit crashes represent, on average, 85 percent of truck crashes in Idaho. This ratio was consistent throughout the five years analyzed in this study. Double combination trucks were involved in an average of 10 to 15 percent of total truck crashes. Triple combination trucks were involved in 0 to 2.9 percent of the truck crashes.

The crash severity data (Fig. 4.1) show that, among the three truck types examined in this analysis, triple combination trucks had the highest percentage of property damage-only (PDO) crashes--85 percent compared to 64 percent and 67 percent for single and double combination trucks, respectively. The crash severity index for triple combination trucks, computed using the percentage of crashes for each severity type and a severity value ranging from 1 for PDO crashes to 5 for fatal crashes, is1.37 compared to 1.89 and 1.82 for single and double combination trucks, respectively. Double combination trucks have a fatal crash rate that is slightly lower than single unit trucks and their severity index was also lower than that for single unit trucks. The percentage of trucks involved in a fatal or incapacitating injury crash are 25 percent for single unit trucks and 23 percent for double combination trucks. Both are significantly higher than triple combination trucks with only 10 percent fatal or incapacitating injury crashes.

Collision types for Idaho are presented in Figure 4.2. The percentage of same direction side swipe collisions is higher in crashes involving triples(21.31 percent) than in crashes involving doubles(16.23), and singles (18.91). Same direction rear end collisions are more frequent in singles (17.34 percent) than doubles (14.72 percent) or triples (11.48 percent). The percentage of collisions approaching at angle is higher in doubles (8.23 percent) than in singles (6.77 percent) and triples (3.28 percent).

The percentage of crashes during snowy weather conditions are 11.48 percent, 14.50 percent, and 11.68 percent for triple, double, and single-unit trucks, respectively. Again, this confirms that triple and double combination trucks have a higher proportion of adverse weather conditions crashes than single-unit trucks. The percentage of triple combination truck crashes that occurred during windy weather condition is 3.28 percent higher than that for double combination trucks (0.65 percent) or that for single unit trucks (1.93 percent). This may be attributable to the length configuration of triple combination trucks. The percentage of triple combination truck crashes that occurred during clear or cloudy weather conditions are 79.96 percent. This percentage is comparable to that for single-unit trucks (80.34 percent) and for double combination trucks (79.44 percent).

Figure 4.4 shows crashes according to light conditions data. The percentages of crashes during dark light conditions are 57.38 percent, 40.69 percent, and 29.94 percent for triple, double, and single-unit trucks, respectively. The higher proportion of night crashes for triple combination trucks might be attributable to the fact that their operation is restricted during peak traffic conditions (primarily during the day), forcing them to operate more during night. Without detailed day/night VMT, any conclusions from this data are unreliable.

4.2.2 Montana

Crash data was available from 2002 and 2003. Vehicle configurations presented in the study covered only single unit trailers, double combination trailers and triple combination trailers. The following tables and figures describe the crash trends in Montana based on the two years of crash data available.

Table 4.2 Crash Frequency and Percentage for Different Truck Types (Montana)

Year	Crash Frequency		Crash Percentage	
	2002	2003	2002	2003
Single	409	391	89.50	85.37
Doubles	45	64	9.85	13.97
Triples	3	3	0.66	0.66
Total	457	458	100.00	100.00

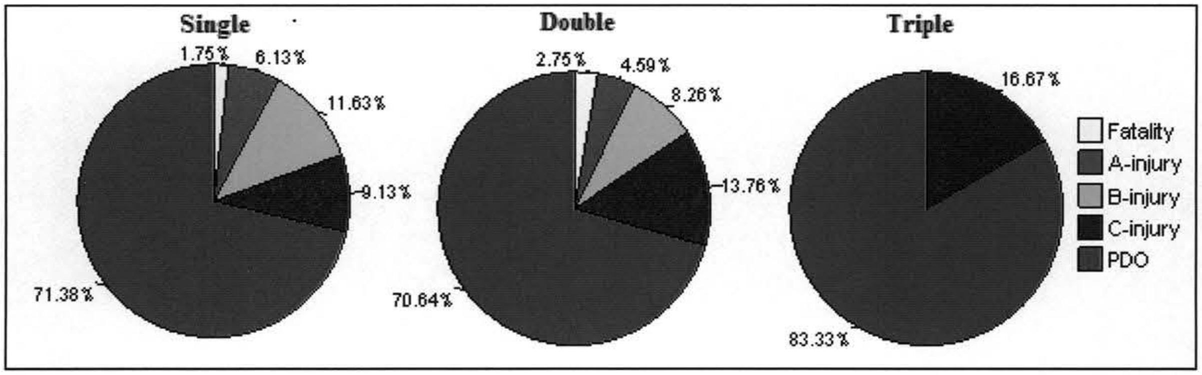

Figure 4.5 Crash Severity for Different Truck Types in Montana.

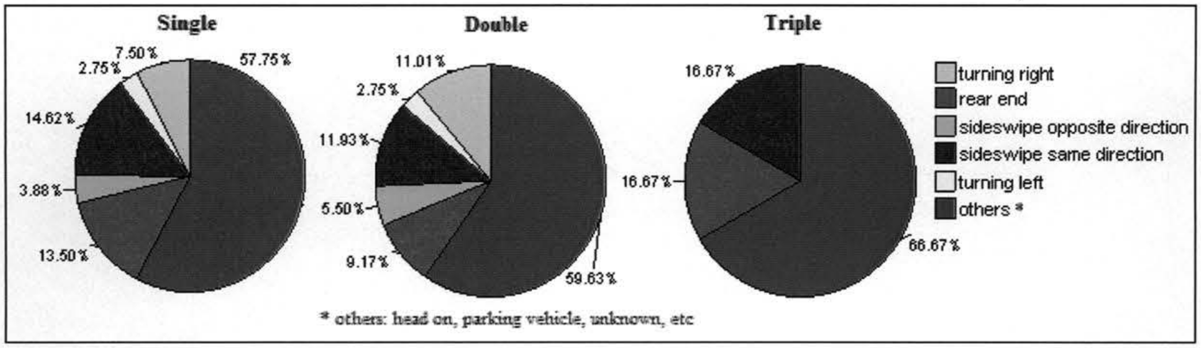

Figure 4.6 Collision Types for Crashes Involving Trucks in Montana.

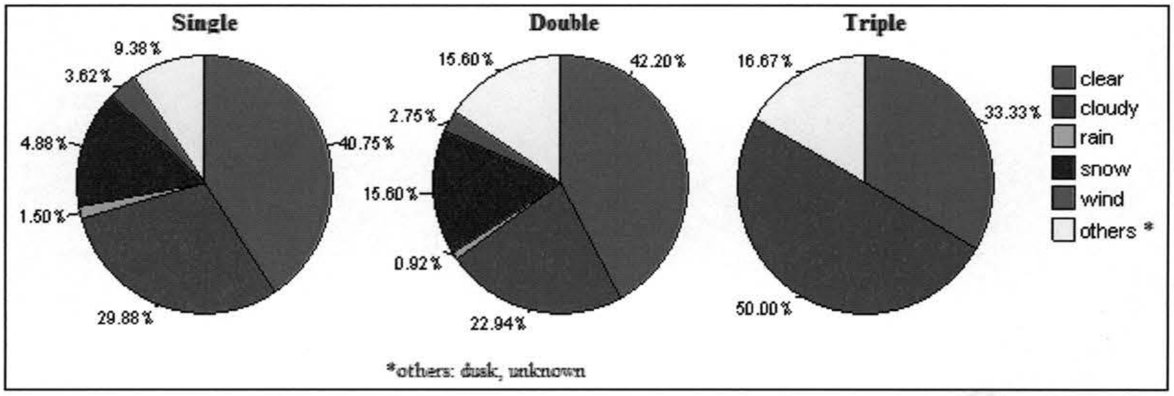

Figure 4.7 Weather Conditions for Crashes Involving Trucks in Montana.

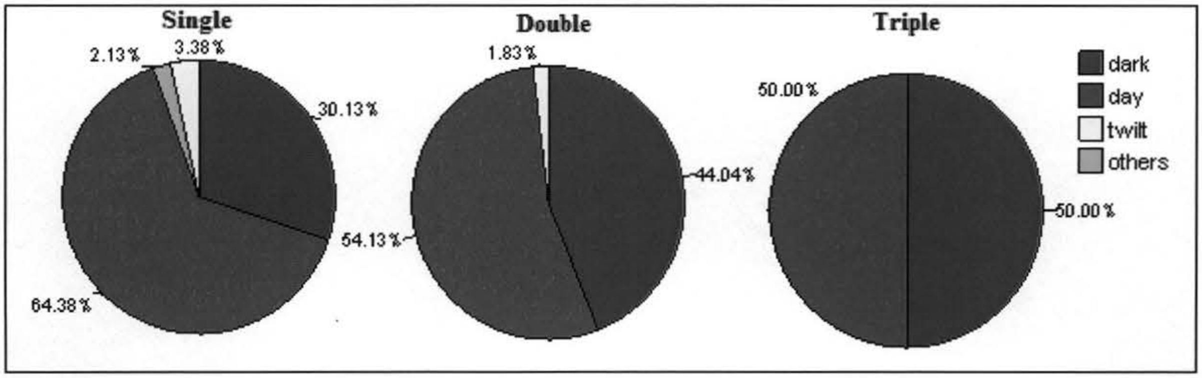

Figure 4.8 Light Conditions for Crashes Involving Trucks in Montana.

Single unit crashes represent, on average, 87 percent of truck crashes in Montana. This ratio was consistent in both years analyzed in this study. Double combination trucks were involved in an average of 10 to 14 percent of total truck crashes. Triple combination trucks were involved in 0.6 percent of the truck crashes.

The crash severity data, presented in Fig. 4.5, show that, among the three truck types examined in this analysis, triple combination trucks had the highest percentage of property damage-only (PDO) crashes (83 percent compared to 70 percent and 71 percent for single and double combination trucks, respectively). The crash severity index for triple combination trucks, computed using the percentage of crashes for each severity type and a severity value ranging from 1 for PDO crashes to 5 for fatal crashes, is1.17 compared to 1.58 and 1.54 for single and double combination trucks, respectively. Even though double combination trucks have a fatal crash rate that is higher than single unit trucks, their severity index was lower than that for single unit trucks. The percentage of fatal crashes involving triples was zero, in comparison to 1.75 for singles, and 2.75 for doubles.

Collision types are presented in Figure 4.6. The percentage of same direction side swipe collisions is higher in crashes involving triples (16.67 percent) than in crashes involving doubles (11.93 percent), and singles (14.62 percent). Rear end collisions are more frequent in triples (16.67 percent) than doubles (9.17 percent) or singles (13.5 percent).

Weather conditions data (Fig. 4.7) shows that triple combination trucks have a higher proportion of adverse weather conditions crashes than single and double unit trucks. The percentage of triple combination truck crashes that occurred during cloudy weather conditions is 50 percent in comparison to 22.94 percent for double-unit trucks, and 29.28 percent for single–unit trucks.

Light conditions data are presented in Fig. 4.8. The percentages of crashes during dark conditions are 50 percent, 44.04 percent, and 30.13 percent for triple, double, and single-unit trucks, respectively.

4.2.3 Oregon

Crash data was available for the years 2002 and 2003. Vehicle configurations presented in the study covered only single unit trailers, double combination trailers and triple combination trailers. The following tables and figures describe the crash trends in Oregon based on the two years of crash data available.

Table 4.3 Crash Frequency and Percentage for Different Truck Types (Oregon)

Year	Crash Frequency		Crash Percentage	
	2002	2003	2002	2003
Single	409	391	89.50	85.37
Doubles	45	64	9.85	13.97
Triples	3	3	0.66	0.66
Total	457	458	100.00	100.00

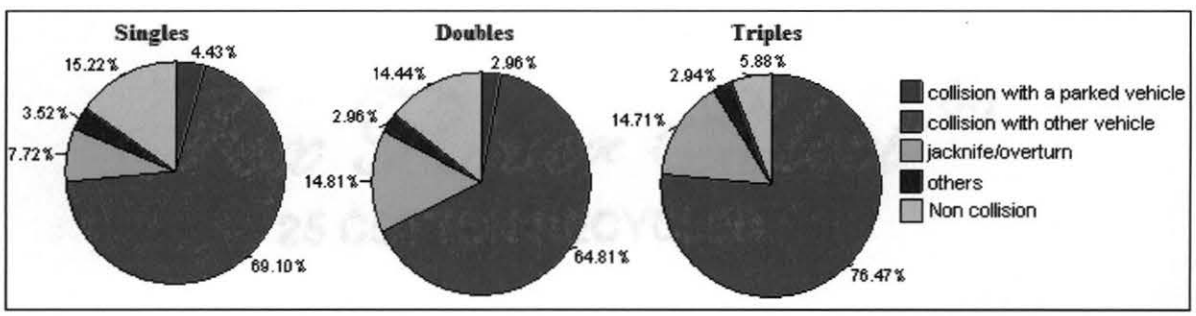

Figure 4.9 Collision Types for Crashes Involving Trucks in Oregon.

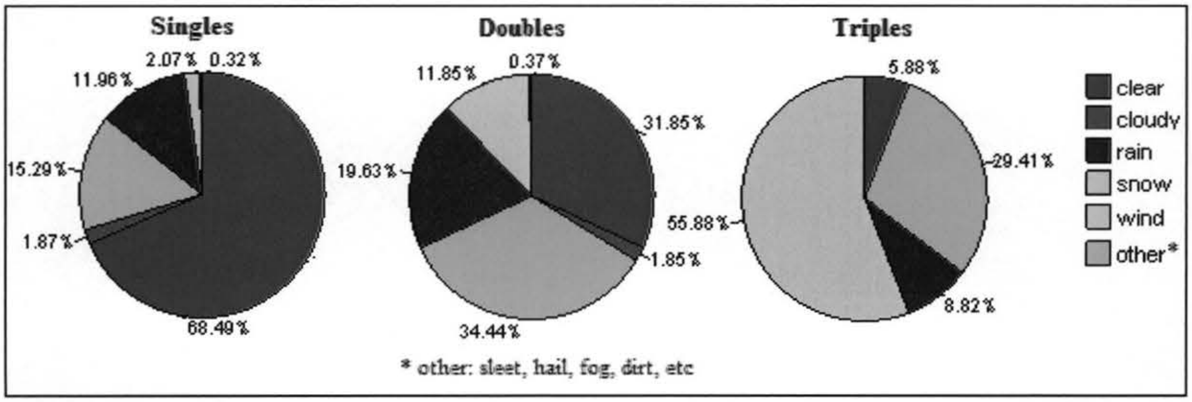

Figure 4.10 Weather Conditions for Crashes Involving Trucks in Oregon.

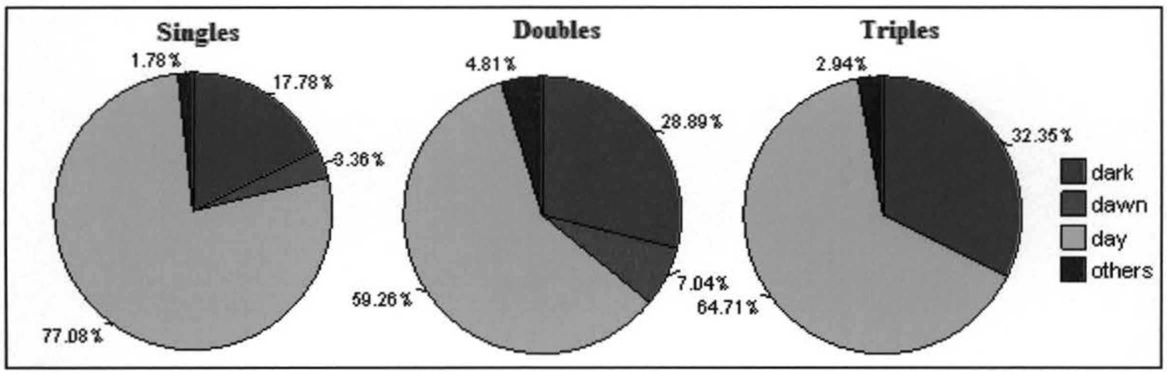

Figure 4.11 Light Conditions for Crashes Involving Trucks in Oregon.

Single unit crashes represent, on average, 90 percent of truck crashes in Oregon. Double combination trucks were involved in an average of 6 to 10 percent of total truck crashes. Triple combination trucks were involved in 1 percent of the truck crashes.

Collision types are presented in Figure 4.9. The percentages of collision with other vehicle is higher in crashes involving triples (76.47 percent) than in crashes involving doubles(64.81 percent), and singles (69.10 percent). Non collision crashes are the next most frequent type of collision; they are greater in singles (15.22 percent) than doubles (14.44percent) and triples (5.88percent).

Weather conditions data (Fig. 4.10) show that triple and double combination trucks have a higher proportion of adverse weather conditions crashes than single unit trucks. The percentage of triple combination truck crashes that occurred during snow weather conditions is 55.88 percent in comparison to 11.85 percent for double-unit trucks, and 2.07 percent for single–unit trucks.

Light conditions data are presented in Fig. 4.11. The percentages of crashes during dark conditions are 32.35 percent, 28.89 percent, and 17.78 percent for triple, double, and single-unit trucks, respectively. The majority of crashes occur during daylight conditions.

4.2.4 Utah

Crash data for the state of Utah were available for the six-year period from1999 to 2004. Vehicles configurations examined in the study include single unit trailers, non-LCV double combination trailers, LCVs double combination trailers, and triple combination trailers. Table 4.4 presents the five year crash trends for the three truck types. Figures 4.12 and 4.13 illustrate the percentages of each type of truck involved in crashes categorized by crash severity and collision type.

The crash tables shows that single unit truck crashes represent on average 81 percent of truck crashes. Rocky Mountain doubles were involved in an average of 10 percent of truck crashes. All other truck types were involved in the remaining 9 percent of the crashes.

Table 4.4 Crash Frequency for Different Truck Types (Utah)

INTERSTATE ROADS												
Year	Crash Frequency						Crash Percentage					
	1999	2000	2001	2002	2003	2004	1999	2000	2001	2002	2003	2004
Single	764	883	782	795	567	588	79.34	83.07	81.20	78.48	81.94	77.06
FWD	55	60	41	39	29	32	5.71	5.64	4.26	3.85	4.19	4.19
RMD	86	71	90	123	58	93	8.93	6.68	9.35	12.14	8.38	12.19
TPD	19	25	25	29	20	24	1.97	2.35	2.60	2.86	2.89	3.15
Triples	39	24	25	27	18	26	4.05	2.26	2.60	2.67	2.60	3.41
Total	963	1063	963	1013	692	763	100	100	100	100	100	100
OTHER ROADS												
Year	Crash Frequency						Crash Percentage					
	1999	2000	2001	2002	2003	2004	1999	2000	2001	2002	2003	2004
Single	908	916	813	902	685	779	80.28	81.79	82.87	79.19	80.68	81.49
FWD	69	76	53	58	72	43	6.10	6.79	5.40	5.09	8.48	4.50
RMD	118	94	83	129	69	109	10.43	8.39	8.46	11.33	8.13	11.40
TPD	27	27	25	32	10	14	2.39	2.41	2.55	2.81	1.18	1.46
Triples	9	7	7	18	13	11	0.80	0.63	0.71	1.58	1.53	1.15
Total	1131	1120	981	1139	849	956	100	100	100	100	100	100

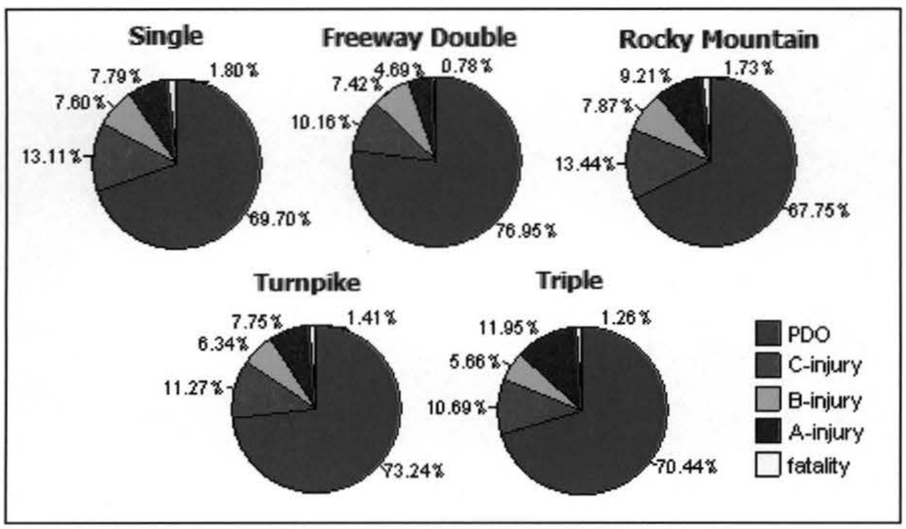

Figure 4.12 Severity Types for Crashes Involving Trucks in Utah.

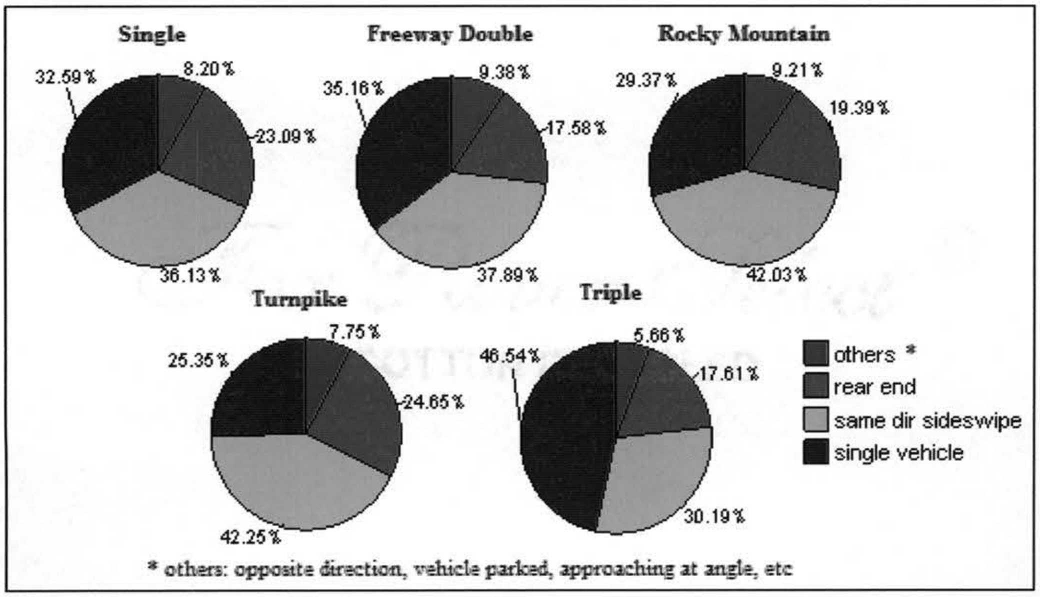

Figure 4.13 Collision Types for Crashes Involving Trucks in Utah.

The crash severity data for the State of Utah are presented in Fig. 4.12. The percentage of incapacitating injuries is greater in crashes involving triples (11.95 percent) and Rocky Mountains (9.21 percent) than other truck types. The percentage of fatalities is constant for all truck types and varies from 0.78 percent to 1.80 percent. The crash severity index for freeway double trucks, computed using the percentage of crashes for each severity type and a severity value ranging from 1 for PDO crashes to 5 for fatal crashes, is 1.42 compared to 1.53 for turnpikes and triples, 1.59 for singles, and 1.64 for Rocky Mountains. Even though the fatal crash rate was higher for singles, Rocky Mountains had the highest severity index among all truck types.

Figure 4.13 shows that the proportion of single vehicle crashes is higher for triples, 46.54 percent, and freeway doubles, 35.16 percent, than other truck types.

4.2 Crash Frequency per VMT and Comparative Analysis Results

In order to determine the safety performance of LCVs, crash ratios obtained from each vehicle type were obtained. The relative crash rate for each truck type was determined by dividing the truck crash frequency by the VMT. The following section describes the procedure used to determine crash rates for Idaho and Utah.

4.2.1 Crash Rate Analysis for Idaho

The crash rates were estimated based on crash frequencies and VMT estimates. The procedure used to determine the crash rates is described below.

1. Crashes were separated according to the road where the crash occurred: state roads (US 95, US 20, US 30 and US 93) and interstate roads (I-90, I-84, I-15 and I-86). Crash frequency tables by year and vehicle type on state and interstate roads are presented in Table 4.5.
2. Each road where crash data were available was divided in segments. The segments were determined based upon the location of the permanent count stations that were used to determine the VMT. (More details regarding road segmentation are presented in Chapter 3).
3. VMT was obtained by multiplying the average number of trucks between two consecutive stations (obtained from permanent count stations along interstate roads) by the distance between them. The VMT results for state and interstate roads are presented in Table 4.6.
4. Crash rates were obtained per year and truck type on all state and interstate roads by dividing the frequency of crashes by the VMT (millions). The results are presented in Table 4.7
5. The same procedure was used to determine crash rates by segment using the average of the five years of study. Table 4.8 shows the Crash frequencies by segment, VMT by segment is presented in Table 4.9 , and the crash rates by segment is presented in Table 4.10.

Table 4.5 Crash Frequency in Idaho

STATE ROADS			
Year	Single	Double	Triple
1999	178	26	2
2000	176	32	2
2001	175	38	2
2002	134	24	2
2003	153	26	2
INTERSTATE ROADS			
year	Single	Double	Triple
1999	248	46	8
2000	320	50	13
2001	277	47	12
2002	298	42	8
2003	291	35	10

Table 4.6 VMT in Idaho

STATE ROADS			
year	Single	Double	Triple
1999	1,012,229,232	87,086,300	3,433,486
2000	954,699,657	82,136,791	3,238,346
2001	995,439,658	85,641,823	3,376,536
2002	1,014,656,640	87,295,140	3,441,720
2003	1,013,503,621	87,195,941	3,437,809
INTERSTATE ROADS			
year	Single	Double	Triple
1999	1,962,052,778	160,182,320	48,340,406
2000	1,850,540,425	151,078,433	45,593,001
2001	1,929,508,737	157,525,419	47,538,597
2002	1,966,757,940	160,566,450	48,456,330
2003	1,964,522,988	160,383,988	48,401,266

Table 4.7 Crashes per Million VMT

STATE ROADS			
Year	**Single**	**Double**	**Triple**
1999	0.18	0.30	0.58
2000	0.18	0.39	0.62
2001	0.18	0.44	0.59
2002	0.13	0.27	0.58
2003	0.15	0.30	0.58
INTERSTATE ROADS			
Year	**Single**	**Double**	**Triple**
1999	0.13	0.29	0.17
2000	0.17	0.33	0.29
2001	0.14	0.30	0.25
2002	0.15	0.26	0.17
2003	0.15	0.22	0.21

Table 4.8 Total Crash Frequency by Segment and Truck Type

Roadway	Segment	Single	Double	Triples	Total
US 95	1	225	33	0	258
US 95	2	133	31	0	164
US 95	3	110	24	1	135
US 20	4	112	19	6	137
US 30	5	60	16	1	77
US 30	6	81	7	0	88
US 93	7	87	15	2	104
I-90	8	209	28	0	237
I-84	9	910	133	40	1083
I-15	10	194	34	7	235
I-86	11	107	21	4	132

Table 4.9 VMT by Segment and Truck Type

Roadway	Segment	Segment Length (mi)	Average Annual VMT*1000			
			Single	Double	Triple	Total
US 95	1	108	49,416	4,863	100	54,380
US 95	2	155	277,131	30,448	646	308,225
US 95	3	180	27,815	7,495	146	35,456
US 20	4	96	358,341	22,415	1,751	382,507
US 30	5	92	34,718	3,834	98	38,650
US 30	6	83	235,484	6,738	505	242,728
US 93	7	73	31,751	11,502	194	43,447
I-90	8	75	424,319	24,867	3,305	452,491
I-84	9	146	923,435	68,162	26,595	1,018,192
I-15	10	73	279,610	33,619	13,289	326,518
I-86	11	63	339,394	33,919	5,267	378,580

Table 4.10 Crash Rates by Segment and Vehicle Type

Route	Segment	Singles	Doubles	Triples
US 95	1	0.91	1.36	0.00
US 95	2	0.10	0.20	0.00
US 95	3	0.79	0.64	1.37
US 20	4	0.06	0.17	0.69
US 30	5	0.35	0.83	2.03
US 30	6	0.07	0.21	0.00
US 93	7	0.55	0.26	2.06
I 90	8	0.10	0.23	0.00
I 84	9	0.20	0.39	0.30
I 15	10	0.14	0.20	0.11
I 86	11	0.06	0.12	0.15

4.2.2 Crash Rate Analysis for Utah

Table 4.11 Crash Frequency (Utah)

Year	Singles	Non-LCV doubles	LCVs		
		Freeway Doubles	Rocky Mountains	Turnpikes	Triples
1999	764	55	86	19	39
2000	883	60	71	25	24
2001	782	41	90	25	25
2002	795	39	123	29	27
2003	567	29	58	20	18
2004	588	32	93	24	26

Table 4.12 VMT (Millions) by Year and Truck Type (Utah)

Year	Singles	Non-LCV doubles	LCVs		
		Freeway Doubles	Rocky Mountains	Turnpikes	Triples
1999	1,072.21	55.39	79.83	16.67	28.27
2000	1,095.78	56.61	81.58	17.04	28.89
2001	1,154.69	59.66	85.97	17.95	30.44
2002	1,213.60	62.70	90.36	18.87	32.00
2003	1,178.25	60.87	87.72	18.32	31.06
2004	1,013.30	52.35	75.44	15.75	26.72

Table 4.13 Crashes per Million VMT (Utah)

Year	Singles	Non-LCV doubles	LCVs		
		Freeway Doubles	Rocky Mountains	Turnpikes	Triples
1999	0.71	0.99	1.08	1.14	1.38
2000	0.81	1.06	0.87	1.47	0.83
2001	0.68	0.69	1.05	1.39	0.82
2002	0.66	0.62	1.36	1.54	0.84
2003	0.48	0.48	0.66	1.09	0.58
2004	0.58	0.61	1.23	1.52	0.97

Table 4.14 Total Crash Frequency by Segment and Truck Type (Utah)

Route	Segment	Single Unit	Non-LCV Doubles	LCVs		
			FWD	RMD	TPD	Triples
I-15	1	279	15	27	3	19
I-15	2	500	23	69	18	23
I-15	3	454	28	78	28	20
I-70	4	224	9	15	8	5
I-15	5	71	5	5	2	0
I-15	6	34	5	4	1	0
I-15	7	62	3	11	3	1
I-15	8	26	1	2	0	1
I-15	9	23	2	8	0	1
I-84	10	123	9	10	2	1

Table 4.15 VMT by Segment and Truck Type

Road	Seg.	Length (mi)	Average Annual VMT*1000					
			Single Unit	FWD	RMD	TPD	Triples	Total
I-15	11	132	104729.9	5824.656	5689.364	2246.551	3720.517	122211
I-15	22	168	412518	23874.82	37206.89	5679.987	8173.491	487453.1
I-15	33	168	415050.7	18824.77	31667.24	7903.474	14006.93	487453.1
I-70	44	227	54523.66	2571.206	2465.54	880.55	845.328	61286.28
I-15	55	7	56779.4	1679.486	1117.401	692.206	1017.796	61286.28
I-15	66	4	12658.38	392.482	273.462	92.502	138.215	13555.04
I-15	77	7	12219.85	368.134	519.402	216.762	230.896	13555.04
I-15	89	11	5040.017	186.274	301.153	33.618	122.973	5684.036
I-15	910	11	89073.96	5569.165	6715.246	360.601	2808.55	104527.5
I-84	1011	43	15660.22	1581.82	1768.275	211.424	0	19221.74

Table 4.16 VMT Crash Rates by Segment and Vehicle Type

Route	Segment	Single Unit	FWD	RMD	TPD	Triples
I-15	1	0.44	0.43	0.79	0.22	0.85
I-15	2	0.20	0.16	0.31	0.53	0.47
I-15	3	0.18	0.25	0.41	0.59	0.24
I-70	4	0.68	0.58	1.01	1.51	0.99
I-15	5	0.21	0.50	0.75	0.48	0.00
I-15	6	0.45	2.12	2.44	1.80	0.00
I-15	7	0.85	1.36	3.53	2.31	0.72
I-15	8	0.86	0.89	1.11	0.00	1.36
I-15	10	0.04	0.06	0.20	0.00	0.06
I-84	11	1.31	0.95	0.94	1.58	0.00

4.3 Testing the Significance of Crash Rate Differences

Because the samples are relatively small, five years and three truck types in Idaho, and six years and five truck types in Utah--the Student's t-test analysis was chosen as the statistical method to determine the difference in mean crash rates for the following conditions:

4.3.1 Idaho

- State Roads: Singles vs. doubles, singles vs. triples, and doubles vs. triples
- Interstate Roads: Singles vs. doubles, singles vs. triples, and doubles vs. triples
- Roadway Segments: Singles vs. doubles, singles vs. triples, and doubles vs. triples
- Singles: State vs. interstate roads.
- Doubles: State vs. interstate roads.
- Triples: State vs. interstate roads.

4.3.2 Utah

- Yearly and segment based
    - Singles vs. freeway doubles (non LCV)
    - Singles vs. rocky mountains (LCV)
    - Singles vs. turnpikes (LCV)
    - Singles vs. triples
    - Freeway doubles (non LCV) vs. rocky mountains (LCV)
    - Freeway doubles (non LCV) vs. turnpikes (LCV)
    - Freeway doubles (non LCV) vs. triples
    - Rocky mountains (LCV) vs. turnpikes (LCV)
    - Rocky mountains (LCV) vs. triples
    - Turnpikes (LCV) vs. triples

The null hypothesis is:

$$H0\text{: } \mu 1 - \mu 2 = 0 \qquad (5)$$

A summary of the results is provided in Table 4.17 for Idaho and Table 4.18 for Utah.

Table 4.17 T-Test Analysis Results in Idaho

	Single vs. Doubles	**Single vs. Triples**	**Doubles vs. Triples**
State Roads	YES	YES	NO
Interstate Roads	YES	YES	NO
Segments	NO	NO	NO
	State vs. Rural Roads		
Singles	NO		
Doubles	NO		
Triples	NO		

Table 4.18 T-Test Analysis Results in Utah

Vehicle Types	**Reject hypothesis**
Singles vs. freeway doubles	YES
Singles vs. rocky mountains	YES
Singles vs. turnpikes	YES
Singles vs. triples	YES
Freeway doubles vs. Rocky Mountains	NO
Freeway doubles vs. turnpikes	NO
Freeway doubles vs. triples	NO
Rocky Mountains vs. turnpikes	NO
Rocky Mountains vs. triples	NO
Turnpikes vs. triples	NO

Chapter 5. RESULTS AND DISCUSSION

5.1 Conclusions

This thesis presents a procedure to determine the LCV safety performance in Idaho and Utah and identify crash characteristics for the two additional states of Montana and Oregon. Estimation of the total Vehicle Mile Traveled (VMT) by each type of commercial vehicles in two western states (Utah and Idaho) was obtained and a comparative crash rate analysis was conducted to assess the relative safety performance of different commercial vehicle classes in two western states (Utah and Idaho).

The literature research was conducted to determine the current level of available information to conduct a safety performance analysis of LCVs. Three areas were observed, crash availability, measures of exposure, and safety performance of trucks in the U.S. In addition, federal, western, and state rules and regulation governing LCVs were described to compile up-to-date information on LCV operations. Most previous studies regarding LCVs have compared crash rates of singles and multi trailer combinations without focusing particularly on LCVs. It is difficult to compare results from studies conducted outside the U.S. because the environment, rules and scenarios are different. There is still a considerable debate about the safety performance of LCVs based on crash rates analysis in the United States.

Crash data availability and collection vary from state to state. Usually, descriptions of CMV configurations do not have enough details to distinguish LCVs from other truck types. The availability of data required to perform LCV crash analysis in the eight western states of Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming was examined; however, only four states (Idaho, Montana, Oregon, and Utah) have adequate data to conduct the study. Among the eight states surveyed, Utah's crash report is the only report that distinguishes between different combinations of doubles. None of the crash reports in the eight states follow crash data collection forms that match the Model Minimum Uniform Crash Criteria (MMUCC) guidelines, although Utah's crash reports take into consideration most of the variables considered in the MMUCC guidelines. Crash reports in all eight states did not always include all the characteristics required to distinguish between LCVs and non-LCVs. None of the eight states maintain VMT per truck type. Most states use count-based methods using the FHWA 13-vehicle classification system.

VMT is the most common measure of exposure used in the U.S and is estimated, most of the time, using traffic-count-based methods that use traffic count stations to obtain volume and category of trucks passing through a specific segment of the road. The traffic count stations classify trucks based on the 13-vehicle classification given by the FHWA that do not distinguish LCVs from other configuration of trucks. Current practices in western states show that the HPMS is the most used method to estimate VMT; however some states use additional information such as fuel consumption and mile-tax reports. None of the eight states included in the review maintain VMT per truck type.

A new algorithm developed at the University of Idaho was used to identify LCVs using data obtained from WIM stations to obtain VMT estimates for different truck types. This algorithm uses vehicle-by-vehicle WIM data to classify vehicles into subcategories based on axle weight and spacing, GVW, vehicle length, and cargo length. The algorithm classifies vehicles into single unit trucks, non-LCV double combination trucks, LCV double combination trucks (Rocky Mountains and Turnpikes), and LCV triple combination trucks. In the analysis presented in this thesis, outputs for the algorithm are used to obtain relative crash rates for different vehicle classes. They are also used to estimate annual VMT for each vehicle class using the count-based direct method.

Roadway segments were determined based upon the location of WIM stations with truck data available to conduct the crash rate analysis per roadway segment. Eight roadway segments were defined in Utah and 11 roadway segments were defined for Idaho.

Crash characteristics for different types of truck combinations in four states: Idaho, Utah, Montana and Oregon are presented. Crash characteristics for Idaho are based on five years of crash data; the analysis for Utah was conducted using six years of crash data. For Montana and Oregon, the analysis was done based on two years of crash data. Crash data allowed the distinction of all truck types only in Utah; the remaining states differentiated only between singles, doubles, and triples.

Single unit crashes represent more than 80 percent of the crashes in all the states, doubles were involved from approximately 10 to 15 percent in Idaho and Montana, 10 percent in Oregon, and 14 percent (LCV doubles) and 4 percent (non-LCV doubles) in Utah. The percentage of triples involved in crashes varies from 0 to 3 percent in all the states.

Triple combination trucks had the highest percentage of property damage-only (PDO) crashes in all states. The percentage of fatal crashes for singles and doubles is higher than the percentage for triples in Idaho. Montana shows overall lower fatality crash percentages for all trucks (zero fatal crashes recorded for triples and less than 3 percent of crashes were fatal for singles and doubles). Oregon crash reports observed for this study did not provide a severity measure. In Utah the percentage of incapacitating crashes is highest for triples. Fatal crash percentages are fairly equal for all truck types ranging from 0.78 percent to 1.8 percent. The crash severity index (presented in Fig.5.1) for triple combination trucks, in Idaho and Montana, was lower compared to single and double combination trucks, respectively. Double combination trucks have a fatal crash rate lower than single unit trucks; their severity index was also lower than that for single unit trucks in Idaho. Double combination trucks have a fatal crash rate higher than single unit trucks; however their severity index was lower than for single unit trucks in Montana. The crash severity index for freeway double trucks, was lower than turnpikes and triples, (same severity index) followed by singles and rocky mountains that have the highest severity index for all truck types in Utah.

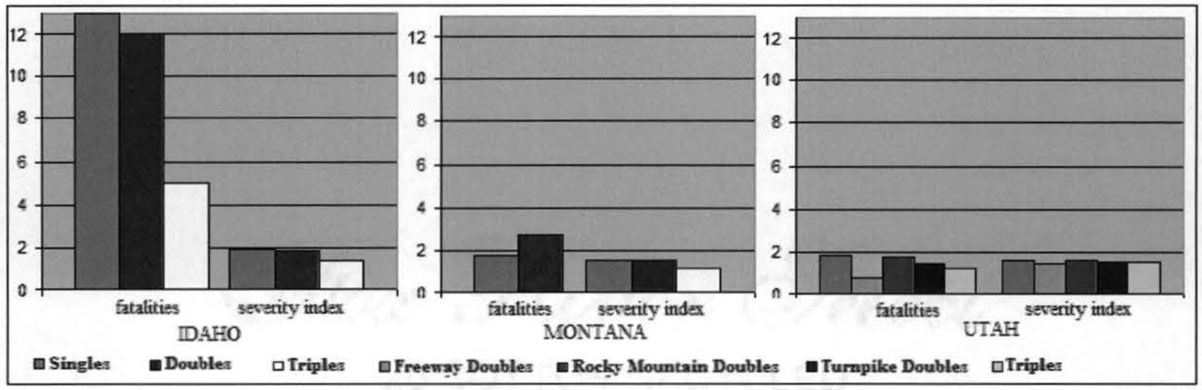

Figure 5.1 Fatalities and Severity Index for Crashes Involving Trucks (Idaho, Montana and Utah).

In Idaho, triples show the highest crash percentage of same direction side swipe collisions, singles show the highest percentage of rear end collisions, and doubles show the highest percentage of collisions approaching at an angle. In Montana, triples show the highest percentage of rear end and same direction side swipe collisions. In Oregon, singles have the highest percentage of non collision crashes and triples have the highest percentage of crashes with other vehicles. Utah crash reports observed for this study did not provide the type of collision.

In Idaho, the percentages of crashes during snowy weather conditions is higher for doubles in comparison to singles and triples. During windy condition crashes involving triples are higher than crashes involving doubles and singles. The percentage of crashes occurring during clear condition is greater than 79 percent for all truck types.

In Montana, triples and doubles crashes are more likely to occur than singles in crashes in adverse weather conditions. During cloudy weather triples experienced a higher crash percentage than singles or doubles. In Oregon, weather conditions data, show that triple combination trucks have higher proportion of adverse weather conditions crashes than single and unit trucks. Under snowy weather conditions again triples showed the highest percentage of crashes followed by singles and doubles. Utah crash reports observed for this study did not provide weather conditions.

In Idaho, the percentage of triple crashes was higher at night in comparison to singles and doubles. More than 50percent of triple crashes occurred during dark conditions, this may be attributable to the prohibition on triple truck circulation during peak traffic hours. Montana shows a similar trend to Idaho with nearly 50percent of triple trailer crashes occurring during dark conditions. Oregon also shows a higher percentage of crashes attributed to triples in comparison to doubles and singles. The percentage of crashes for all truck types in Oregon is below 33 percent. Utah crash reports observed for this study did not provide weather conditions.

The safety performance of LCVs was determined based on crash ratios obtained from each vehicle type. The relative crash rate for each truck type was determined by dividing the truck crash frequency by the VMT. This analysis was conducted per year and roadway segment. State and interstate roads were taken into consideration in Idaho, since both of them allow LCVs on these roads. Only interstate roads were taken into consideration in Utah.

The number of crashes per million VMT in Idaho for state and interstate roads is less than one for all years and all truck types. On average, on state roads, triples have the highest number of crashes per million VMT (0.59) followed by doubles (0.34) and singles (0.16). On interstate roads, doubles have the highest number of crashes per million VMT (0.28), followed by triples (0.21), and singles (0.15). Segments 1, 3, 5, and 7 (US 95, US 95, US 30, and US 93 respectively) show values greater than one for doubles on US 95 and triples for the remaining two roadway segments.

In Utah, turnpikes have the highest number of crashes per million VMT (considering the average for all the years) followed by Rocky Mountains and triples. Freeway doubles and singles have substantially smaller crashes per million VMT.

The analysis per roadway segment shows in general higher results than the results obtained in the previous analysis (yearly analysis). Rocky Mountains have highest number of crashes per million VMT (1.15) in comparison to turnpike doubles (0.90); freeway doubles (0.73), singles (0.52), and triples (0.47).

The difference in the number of crashes per million VMT using the yearly analysis and the roadway segment analysis varies due to the fact the yearly analysis uses all crashes occurring on state and interstate roads (Idaho), and interstate roads (Utah), while the roadway segment analysis uses only crashes where the exact location was available.

Since the samples (years of analysis) were relatively small, five years in Idaho and six years in Utah, the Student's t-test analysis was conducted to determine the difference in mean crash rates for different conditions depending on road classification and truck type. Since Idaho does not allow a differentiation between LCV doubles and non-LCV doubles, the t-test analysis was conducted to determine if there is a significant difference among the mean crash ratio of singles, doubles and triples, without breaking down doubles into more detailed categories.

In Idaho, there is a significant difference in the mean crash ratio for singles versus doubles on state and interstate roads, and singles versus triples on interstate roads. There is not a significant difference between doubles and triples on state and interstate roads. There is not a significant difference between different truck types when the student t-test analysis was conducted on the crash rates obtained by segments. Also there was not a significant difference in the mean crash ratio between different truck types operating on state and interstate roads.

The t-test analysis was conducted in Utah for Singles, LCV doubles (Rocky Mountains and turnpikes), non-LCV doubles, and triples. The results show that there is a significant difference in the mean crash ratio between singles and freeway doubles, Rocky Mountains, turnpikes and triples when the student's t-test was conducted. There was not a significant difference between the mean crash ratio for the other truck types.

5.2 Recommendations for Future Research

This study was limited in scope to just four states (Idaho, Montana, Oregon, and Utah) to determine crash trends, with only two of those (Idaho and Montana) used in the crash rate analysis. From a national perspective, the results can be used to state general advantages and disadvantages related to LCVs; however, it is not possible to develop a state-by-state valid set of recommendations. It would be useful to conduct a study in other states where LCVs are permitted to assess the safety performance of LCVs in the entire country, and in particular, to compare safety performance of LCVs versus other truck types. There is a need for a focused study of crash data availability for trucks in different western states. The lack of information which would allow the classification of trucks makes it difficult to conduct an analysis focused on LCVs only. There is a need to improve crash data collection to include particular characteristics of trucks involved in crashes to make it possible to classify them as LCVs and non-LCV trucks.

The lack of complete crash data information involving trucks in general in some states limited the ability to identify the factors that may have contributed to the accidents. The exact location of the crashes, priority information to determine safety performance crash rates by roadway segment, was not available for the majority of the states.

Although two years of crash data is useful in identifying general trends in crash characteristics, more years of analysis is recommended to obtain greater insight into crash characteristics by state. It is recommended that crash rate analysis results be verified before using the data.

An additional method to estimate more reliable crash data is recommended; surveys can be used and implemented to address this issue. The output of the algorithm can be further improved with more extensive calibration using a large sample of field data.

Once the crash data forms and measure of exposure data are implemented to provide enough information to distinguish all different truck types, improved data will be available to support truck safety and operation performance. The collection of crash and exposure data must be collected at the same level of detail to calculate crash involvement rates for LCVs.

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