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16. Abstract

The objective of this research is to characterize large truck safety levels in Texas on the basis of driver, vehicle, cargo, and carrier traits while controlling for the effects of crash and operating environment conditions. Data to support this investigation considered a three-year time span from January 1, 2004 to December 31, 2006. During this time, 44,012 total large truck crashes occurred in Texas. Historical large truck crash and carrier profile information was collected from three sources: the Motor Carrier Management Information System (MCMIS) Crash File, the MCMIS Census File, and the Texas Department of Transportation intrastate carrier database. Crash severity served as a surrogate measure for large truck safety and was modeled using ordered probit regression methods. The relationships between the significant (denoted through t-statistics values $\geq|1.645|$) explanatory variables and crash severity were for the most part intuitive and in agreement with previously reported findings. Despite their individual significance for contributing to large truck crash severity levels, these variables in combination achieved a poor overall goodness of fit ($\rho^2=0.0029$), likely attributable to missing data, timeline inconsistencies between crash and census data, and repeated measures (i.e., if a carrier was involved in more than one crash between 2004 and 2006, the same carrier characteristics were repeated). As indicated from the modeling exercise, roadside and carrier-based, on-site safety enforcement practices should be focused towards: (1) single-unit, three-axle and truck tractor (bobtail) vehicle configurations, (2) tank cargo body types, (3) grain/feed/hay cargo classifications, (4) carriers based in Illinois , and (5) private property carriers. Focusing safety efforts toward these factors, which have shown a significant influence on the severity of a potential crash, provides a more proactive approach to enhancing large truck safety.

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LARGE TRUCK CRASHES IN TEXAS:
A PREDICTIVE APPROACH FOR IDENTIFYING THOSE AT HIGHER RISK

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EXECUTIVE SUMMARY

In 2005, more than 423,500 traffic crashes involving large trucks occurred in the U.S. (FMCSA 2007). Truck-involved crash rates tend to be lower than that of non-trucks because trucks typically register more miles, truck drivers are generally more skilled, and truck maintenance is generally stricter. Conversely, truck-involved crash severities tend to be higher than that of non-trucks; accounting for nearly 12 percent of all traffic-related fatalities and more than 4 percent of all injuries (FMCSA 2007). Given these observations, the primary goal defined in the FMCSA's *Research and Technology 5-year Strategic Plan* (FMCSA 2003) relates to improving large truck crash severity; to reduce commercial motor vehicle (CMV)-related fatalities to 1.65 fatalities per 100 million commercial motor vehicle miles traveled (VMT) by 2008.

Current regulatory and enforcement efforts to enhance large truck safety - comprising on-site compliance reviews, roadside inspections, and traffic enforcement - are challenged to meet this goal for several reasons. In current practice, trucks are selected for roadside inspections or compliance reviews based largely on historical crash experience. In fact, probabilistic theory suggests a lower crash likelihood following the occurrence of a crash. Second, State and Federal resources cannot keep pace with the burgeoning truck volumes, particularly in Texas. At the national level, the number of registered large trucks increased 41 percent from 1985 to 2005. During the same time period, the miles traveled by these large trucks increased 80 percent (FMCSA 2007). Truck traffic moving to and from Texas currently accounts for approximately 20 percent of the average annual daily truck traffic (AADTT) in the U.S., with significant increases in international trade traffic from Mexico estimated over the next 20 years (Hong et al. 2007). Lastly, significant enforcement effort is expended on "satisfactory" carriers, vehicles, and drivers. In 2005, 65.90 percent of the 651 carriers reviewed by Texas officials were satisfactory. In the same year, Texas officials put only 5.2 percent of drivers and 26.7 percent of vehicles out-of-service (OOS) during 309,816 roadside inspections, finding a large majority of drivers and vehicles without significant fault (FMCSA 2006).

As an alternative approach, the objective of this research is to characterize large truck safety levels in Texas on the basis of driver, vehicle, cargo, and carrier traits while controlling for the effects of crash and operating environment conditions. Ultimately, an understanding of the driver, vehicle, cargo, and carrier characteristics that are most likely to result in a crash, particularly a severe crash, can assist regulatory and enforcement agencies in addressing safety problems in a *preventative* rather than reactionary manner. An additional benefit of this effort is the ability to make better use of existing resources. Having the ability to focus scarce regulatory and enforcement resources on large trucks highest at risk for safety-related problems, public agencies can perform their duties more effectively and efficiently without additional personnel.

Data to support this investigation considered a three-year time span from January 1, 2004 to December 31, 2006. During this time, 44,012 total large truck crashes occurred in Texas. Two types of data were required to perform this investigation: (1) historical crash information for large trucks in Texas and (2) carrier profile information describing size, operation, etc. (The historical crash information also contained information related to driver, vehicle, cargo, and operating environment characteristics.) These two types of data were collected from three sources: (1) historical crash information was obtained electronically from the Motor Carrier Management Information System (MCMIS) Crash File, (2) carrier profile information for *interstate* carriers (and select intrastate carriers) was obtained electronically from the MCMIS Census File and (3) *intrastate* carrier profile information was obtained electronically from the Texas Department of Transportation, Motor Carrier Division. The MCMIS Crash and Census Files were combined into a single data set using common data elements such as USDOT number. Supplemental intrastate carrier profile information was manually matched to the MCMIS Crash File using carrier name and address identifiers.

Crash severity served as a surrogate measure for large truck safety and was modeled using ordered probit regression methods. The relationship between the significant (denoted through t-statistics values $\geq|1.645|$) explanatory variables and crash severity was for the most part intuitive and in agreement with previously reported findings. Despite their individual significance for contributing to large truck crash severity levels, these variables in combination achieved a poor overall goodness of fit with a ρ^2 value of 0.0029. This low explanatory power is likely attributable to (1) missing data, particularly related to intrastate carrier operations; (2) timeline inconsistencies between the MCMIS Census File that reflects active carriers at the time of the data request and the MCMIS Crash File that includes crashes occurring between 2004 and 2006; and (3) the structure of the final combined dataset, resulting in a number of repeat measures related to carrier characteristics (i.e., if a carrier has been involved in more than one crash between 2004 and 2006, the same carrier characteristics are repeated for each crash).

As indicated from the modeling exercise, roadside and on-site, carrier-based safety regulatory and enforcement efforts should be focused towards the following vehicle, cargo, and carrier characteristics:

- Single-unit, three-axle and truck tractor (bobtail) vehicle configurations
- Tank cargo body type
- Grain/feed/hay cargo classification
- Carriers based in Illinois
- Private property carriers

Focusing safety efforts toward these factors, which have been predicted to increase the severity of large truck crashes, provides a more proactive approach to enhancing large truck safety; the use of historical safety ratings is reactive. Several other factors were identified as decreasing the predicted severity of large truck crashes; less attention can be put towards safety-related enforcement when these factors are present.

Informally, regulatory and enforcement personnel in the State of Texas can be made aware of these areas for focus simply through a chain-of-command informational memo. On a more formal basis, these results could ultimately be integrated into both the ASPEN/ISS system for targeting roadside safety inspections and the SAFESTAT system for targeting compliance reviews and educational contacts. Prior to this happening however, further evaluation is required to determine if targeting of these characteristics does in fact improve large truck safety levels in Texas and whether these results are transferable to other areas of the country.

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CHAPTER 1.
INTRODUCTION

In 2005, more than 423,500 traffic crashes involving large trucks occurred in the U.S. (FMCSA 2007). Truck-involved crash rates tend to be lower than that of non-trucks because trucks typically register more miles, truck drivers are generally more skilled, and truck maintenance is generally stricter. Conversely, truck-involved crash severities tend to be higher than that of non-trucks; accounting for nearly 12 percent of all traffic-related fatalities and more than 4 percent of all injuries (FMCSA 2007). Contributing to this elevated level of severity are the physical characteristics of large trucks: the difference in mass between large trucks and non-trucks results in a near instantaneous velocity change upon impact, the high rigidity of a large truck's structure results in energy dissipation through the collapse of the smaller vehicle, and the height of the truck results in damage to the upper and weaker parts of the smaller vehicle.

Given these observations, the primary goal defined in the FMCSA's *Research and Technology 5-year Strategic Plan* (FMCSA 2003) relates to improving large truck crash severity; to reduce commercial motor vehicle (CMV)-related fatalities to 1.65 fatalities per 100 million commercial motor vehicle miles traveled (VMT) by 2008. Methods for achieving this goal focus on: improved consistency and effectiveness of enforcement, identification and targeting of those at high-risk, and research efforts to enhance and promote large truck safety practices.

Current regulatory and enforcement efforts to enhance large truck safety - comprising on-site compliance reviews, roadside inspections, and traffic enforcement - are challenged to meet this goal for several reasons. First, the underlying premise of these efforts is contrary to probabilistic theory. In current practice, trucks are selected for roadside inspections or compliance reviews based largely on historical crash experience. In fact, probabilistic theory suggests a lower crash likelihood following the occurrence of a crash.

Second, State and Federal resources cannot keep pace with the burgeoning truck volumes, particularly in Texas. At the national level, the number of registered large trucks increased 41 percent from 1985 to 2005. During the same time period, the miles traveled by these large trucks increased 80 percent (FMCSA 2007). Truck traffic moving to and from Texas currently accounts for approximately 20 percent of the average annual daily truck traffic (AADTT) in the U.S., with significant increases in international trade traffic from Mexico estimated over the next 20 years (Hong et al. 2007). In a 2002 study, Middleton estimated an enforcement ratio of one Texas Department of Public Safety (DPS) trooper per every 45 million vehicle-miles traveled by truck in the state. Historically, enforcement resources at the Federal level have been similarly constrained. As a result, only a small percentage of trucks (<10 percent) and a smaller percentage of carriers (<5 percent) are inspected or reviewed each year.

Lastly, significant enforcement effort is expended on "satisfactory" carriers, vehicles, and drivers. In 2005, 65.90 percent of the 651 carriers reviewed by Texas officials were satisfactory. In the same year, Texas officials put only 5.2 percent of drivers and 26.7 percent of vehicles out-of-service (OOS) during 309,816 roadside inspections, finding a large majority of drivers and vehicles without significant fault (FMCSA 2006). Enforcement support tools, such as the Inspection Selection System (ISS), result in only modest improvements over traditional random or Commercial vehicle Safety Alliance (CVSA) decal status based methods of selection. Lantz et al. (1997) determined the vehicle OOS rate as 33.7 percent for ISS-targeted carriers versus 20 percent for non-targeted carriers and the driver OOS rate as 13.5 percent for ISS-targeted carriers versus 9.9 percent for non-targeted carriers.

An alternative approach is to identify broader driver, vehicle, cargo, carrier and operating environment characteristics using advanced statistical modeling methods that, singularly or in combination, compromise large truck safety. This approach was applied previously with success by Burke et al. (2002) with a focus on large truck safety in a rural environment and is consistent with recommendations by the *Committee on Future Truck and Bus Safety Research Opportunities* (Transportation Research Board (TRB) 2006) to better "link crashes to carrier and driver information" and "quantify specific driver, vehicle, and environmental crash risk factors."

The objective of this research is to characterize large truck safety levels in Texas on the basis of driver, vehicle, cargo, and carrier traits while controlling for the effects of crash and operating environment conditions using advanced statistical modeling methods. As an example, if the large truck safety-related data were to indicate low safety levels for out-of-state drivers, carriers with small vehicle fleets, and haulers of flatbed trailers, both roadside inspections and on-site, carrier-based safety reviews could be performed with these characteristics in mind. On the roadside, regulatory and enforcement personnel could adjust their selection of large trucks for roadside safety inspections; currently vehicles are selected for safety inspections randomly or on the basis of historical crash or safety records. As part of a more detailed carrier-based safety program, regulatory and enforcement personnel could increase the frequency of safety reviews or educational contacts for carriers possessing the characteristics that show a lower safety level.

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

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

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

CHAPTER 2.
LITERATURE REVIEW

When conducting a review of related literature, researchers considered both large truck crash frequency (most often expressed as a rate or risk of occurrence) and large truck crash severity, with a focus on identifying characteristics previously reported as contributing - either positively or negatively - to large truck safety levels. This review does not wholly consider specific actions leading to the occurrence of a crash (i.e., crash causation), or the investigatory characteristics of a crash that has occurred (i.e., point of impact, number of vehicles involved, etc.). Instead, this review is focused on prior studies that have attempted to establish more general statistical associations between various characteristics and large truck safety levels.

In reviewing previous efforts, numerous studies were uncovered that investigated large truck crash safety levels based on various driver, vehicle, cargo, carrier, and operating environment characteristics. However, few studies were found that addressed the effect of these characteristics comprehensively or in combination. Further, a disproportionate amount of the previous work focused on driver and, to a lesser extent, vehicle characteristics effecting large truck safety rather than cargo, carrier, and operating environment effects.

A synopsis of key characteristics contributing to large truck safety levels, as previously reported in the literature, is provided below. For additional detail regarding individual study data sources, analysis methods, or findings, the reader is referred to the referenced citations.

DRIVER CHARACTERISTICS

A recent study conducted under the *Commercial Truck and Bus Safety Synthesis Program* (Knipling et al. 2004) identified a number of driver characteristics potentially correlated with large truck and bus safety including:

- driver age and gender;
- driving history (i.e., commercial driving experience; longevity with company; crashes, violations, and incidents; and defensive driving);
- non-driving criminal history;
- medical conditions and health (i.e., sleep apnea, narcolepsy, diabetes, etc.);
- alcohol and drug abuse;
- driver fatigue;
- personality (i.e., impulsivity and risk-taking, social maladjustment and aggressive/angry personalities, introversion/extroversion, locus of control, extreme dichotomous thinking);
- sensory-motor performance; and
- other risk factors (i.e., stress, recent involvement in other crashes, safety belt use).

In reviewing the literature specific to large truck safety, a significant body of work focused on the effects of fatigue and the factors contributing to fatigue (i.e., sleep patterns, operating environment) was identified. A more limited body of work was uncovered that focused on the effects of other driver conditions (i.e., under the influence of alcohol or drugs, medical conditions), driver age and experience, and safety belt use on large truck safety. Of primary interest to this investigation are prior studies directly linking these characteristics to the occurrence or severity of large truck crashes. However, select studies focused exclusively on contributory factors (with no direct link to crash outcome) have additionally been included. Other suspected factors, including driver gender, driving and non-driving criminal history, or personality, were not substantively addressed in the literature. With few exceptions, prior studies related to driver characteristics considered the effect of these factors on crash occurrence rather than severity.

Driver Fatigue

The role of truck driver fatigue in truck crashes is difficult to quantify. Estimates of fatigue-related fatal crashes range from a low of 0.36 percent from police-reported data on truck crashes (Knipling and Shelton 1999) to 31 percent for in-depth studies of fatal-to-the-driver large truck crashes (NTSB 1990). Considering large truck crashes resulting in either serious injury or fatality, a study conducted by the American Automobile Association Foundation for Traffic Safety (AAA 1985) found that fatigue was the primary cause in 40 percent and a contributing cause in 60 percent of crashes. More recent studies have confirmed that driver fatigue increases crash severity levels (Burke et al. 2002, Bunn et al. 2005).

Few studies have adequately accounted for the contributing role that fatigue may play in “awake” driver errors. In an instrumented vehicle study of local and short-haul driving, 20 percent of the driving errors committed by drivers were associated with elevated levels of PERCLOS, an eyelid droop measure of drowsiness (Hanowski et al. 2000). In a more recent naturalistic driving analysis of 661 long-haul truck driver at-fault traffic incidents, nearly 13 percent of incidents occurred during periods of moderate-to-high driver fatigue, although fatigue was identified as the critical reason in fewer than 2 percent of the incidents (Olson et al. 2005).

The trucking industry ranks “drowsiness” as the foremost driving-related problem currently faced. Expected involvement in fatigue-related crashes, particularly for long-haul, combination-unit trucks, is 4.5 times greater than for passenger vehicles because of increased exposure (60,000 versus 11,000 miles traveled per year), vehicle operational life (15 versus 13 years) and night driving (TRB 2007).

Large truck drivers are susceptible to three types of fatigue: (1) industrial fatigue, arising from working continuously over an extended period of time without proper rest, (2) cumulative fatigue, arising from working too many days on any protracted, repetitive task without a prolonged break, and (3) circadian fatigue, caused by a deviation from the natural 24-hour rhythm of work that favors daytime over nighttime schedules (Saccomanno 1995).

Industrial Fatigue/Hours of Driving. A number of historic studies have confirmed the effects of industrial fatigue on large truck safety levels. Harris and Mackie (1972) found that 62 percent of the observed crashes occurred in the second half of the trip, irrespective of trip duration.

Mackie and Miller (1978) again confirmed that significantly more crashes occurred during the second half of the trip but also found trip duration to be a significant determinant; trips of five or more hours in duration were found to have more crashes than expected. Jones and Stein (1990) found that drivers driving in excess of eight hours had an increased risk of crash involvement (almost twice that of drivers who had driven fewer hours), as well as drivers who violate logbook regulations, are age 30 and younger, and engage in interstate carrier operations. Lin et al. (1993) found driving time to have the strongest direct effect on crash risk; crash risk increases significantly after the fourth hour by approximately 65 percent until the seventh hour and approximately 80 percent and 150 percent in the eighth and ninth hours, respectively. Rest breaks, particularly those taken before the 6th or 7th hour of driving, appear to lower crash risk significantly for many times of day (Lin et al. (1994). Saccomanno et al. (1995) confirmed higher fatigue-related large truck crash rates attributable to longer driving distances, with an appreciable increase in crash rates for more than 9.5 hours of driving without proper rest. Haekkaenen and Summala (2001) noted that, regardless of the commercial driver type, fatigue-related problems were strongly related to prolonged driving. Echoing the findings of earlier works, Park et al. (2005) observed a significant increase in crash risk during the 2nd to 4th driving hour, and a further, greater increase during the 5th to 10th driving hour when compared with the first hour of driving. The crash risk difference between the 10th hour of driving and the first hour of driving was more than 80 percent.

In a related study with implications for industrial fatigue extent, Hertz (1991) investigated hours-of-service violations in the U.S. and found that fully half of the drivers were in violation of work hour regulations.

Cumulative Fatigue/Days of Driving. Turning attention to the effects of cumulative fatigue on large truck safety, Jovanis et al. (1991) found higher risk generally, but not exclusively, associated with extensive driving in the two to three days before the day of interest. Driving patterns with the highest risk of a crash were those that contained heavy driving the preceding three days (i.e., cumulative fatigue) and consisted of driving from 3 PM to 3 AM and from 10 PM to 10 AM suggesting the effects of circadian fatigue. The lowest risk was associated with driving from 8 PM to 6 AM but with limited driving in the preceding three days. In later work with Lin and Yang, Jovanis determined multi-day driving patterns to have only a marginal effect on the subsequent crash risk although daytime driving, particularly in the three days before the trip of interest, resulted in the lowest crash risk (Lin et al. 1993). McCartt et al. (2000) found more arduous schedules, with more hours of work and fewer hours off-duty to be predictive of self-reported falling asleep at the wheel.

Considering the amount of “rest and recovery” needed, O’Neil et al. (1999) concluded that drivers recovered baseline performance and were fit to resume driving duty within 24 and 36 hours of the end of a driving week, respectively. Further, a schedule of 14 hours on duty/10 hours off duty for a 5-day week did not appear to produce significant cumulative driver fatigue. Following a sleep dose/response (SDR) laboratory study, Balkin et al. (2000) observed differences in driving performance even with small differences in average nighttime sleep duration and noted that these performance decrements were maintained across the entire 7 consecutive days of sleep restriction, suggesting no compensatory or adaptive response to even mild sleep loss. Following more severe sleep restriction (e.g., the 3-hour TIB group), performance was not fully recovered even after three consecutive nights of 8-hour sleep, suggesting that full recovery from substantial sleep debt may require several days of extended sleep.

Circadian Fatigue/Nighttime Driving. With few exceptions, historical studies generally suggest compromised large truck safety levels at night as a result of circadian fatigue. Mackie and Miller (1978) reported that "dozing driver" crashes were seven times more likely to occur between midnight and 8 AM than in other hours of the day, with the highest risk occurring between 4 AM and 6 AM. Similarly, Seiff (1989) reported that daytime travel is 3 times safer than nighttime travel for trucks. Jovanis et al. (1991) identified two driving patterns with the highest risk of a crash as those that contained heavy driving the preceding three days (i.e., cumulative fatigue) and consisted of driving from 3 PM to 3 AM and from 10 PM to 10 AM. The lowest risk was associated with driving from 8 PM to 6 AM but with limited driving in the preceding three days. Lin et al. (1993) confirmed that driving patterns involving some type of nighttime driving had an elevated crash risk. Continuing work in this area, Lin et al. (1994) found daytime driving, particularly between 10 AM and noon, to result in a significantly lower crash risk. Conversely, driving during times of day involving night or dawn results in a 40 percent higher crash risk. Saccomanno et al. (1995) similarly noted higher fatigue-related crash rates at nighttime as compared to daytime. In addition, researchers suggest the additive effect of circadian and industrial fatigue; the nighttime single-vehicle crash rate is 2.3 and 3.3 times higher than the daytime rate in southern and northern Ontario, respectively. The higher magnitude in northern Ontario, where travel distances are substantially longer, suggests a combined industrial/circadian fatigue effect. The National Transportation Safety Board (NTSB 1995) estimated that 58 percent of the large truck, single-vehicle crashes occurring at night had circadian fatigue as a probable cause. Chang and Mannering (1998) found that possible injury and injury/fatality crashes are more likely to occur at nighttime. Supporting this finding, Burke et al. (2002) observed a reduced crash severity between the hours of 9:00AM and 10:00AM. Most recently, Park et al. (2005) found that night and early morning driving was associated with a 20 percent to 70 percent increase in crash risk compared with daytime driving. Coupled with irregular schedules, night-early morning driving was associated with a 30 percent to 80 percent increase.

Contrary to prior studies, Hendrix (2002) compared fatal crash rates for tractor-trailer trucks on freeways, Interstates, and expressways for overnight travel (Midnight to 6 AM) to that of the rest of the 24-hour day and found no substantial increase in crash rate during overnight travel. Similarly, Drissel and Spiegel (2003) determined Midnight to 5 AM to be one of the safest periods of the day for the retail distribution segment of the trucking industry. Researchers note that unlike the long-haul industry, retail distribution drivers do not spend rest periods away from home, suggesting the importance of sleep patterns and operating environment on fatigue and large truck safety. Also considering local, short-haul operations, Barr et al. (2005) reported a strong and consistent relationship between drowsiness and time of day, however, drowsiness for this segment of the industry was twice as likely to occur between 6:00 AM and 9:00 AM, with approximately 30 percent of all observed fatigue occurring within the first hour of the work shift.

Sleep Patterns. Two previous studies focused specifically on the effects of sleeper berth use on fatigue-related crashes. Hertz (1988) found that the use of a sleeper berth in two shifts increased the risk of a fatal crash by a factor of three and that the risk of a crash was as high for drivers driving alone as for drivers driving in a team. In other words, the risk due to sleeper berth use does not appear to arise because of sleep disturbance due to the motion of the truck but rather because of the splitting of sleep into two periods. A study conducted by the FMCSA (1999) considered similar factors, concluding that use of a sleeper berth (versus sleep in a bed) contributed to an increased probability of drowsy driving and that solo drivers exhibited significantly more drowsiness than the team drivers. In a related study, McCartt et al. (2000) reported shorter, poorer sleep on road to be predictive of self-reported falling asleep at the wheel.

Operating Environment. As noted by Dolyniuk (1995), fatigue is greatly affected by external factors including shipper demands, travel speed, management and driver attitude, physical work involved, rates of pay, shift start times, etc. Few studies, however, have substantively considered the effects of these external factors on driver fatigue.

Taylor and Sung (1999) evaluated the effects of rest area availability on fatigue-related large truck crashes. They found that the probability of a nighttime single-vehicle crash occurring on a rural freeway segment increases when the distance to the last rest area exceeded 30 miles. This phenomenon continues for a distance of at least up to 50 miles. In a second study sponsored by the National Association of Truck Stop Operators (NATSO), Egan and Corsi (1999) found no association between truck parking capacity and large truck crash frequency or fatal crash rate. The study did find an association between the number of fatal crashes and the number of truck miles traveled.

The FMCSA (2000) considered the effects of vehicle configuration, including longer-combination vehicles (LCVs), on driver fatigue. Results of the study indicated that both triple trailer combinations resulted in higher levels of workload and fatigue for the driver, with the A-dolly configuration resulting in the highest workload and fatigue. Contrary to these findings, earlier work by TRB's Turner Proposal study committee concluded that the ratio of double- to single-trailer fatal and non-fatal crash involvement rates would improve (from 1.1 to 1.09) if doubles were equipped with standard A-frame dollies (Morris 2003).

To more comprehensively identify operating environment effects on driver fatigue, Crum et al. (2001) developed a Truck Driver Fatigue Model that considers two measures of fatigue: (1) frequency of close calls due to fatigue and (2) driver perceptions of fatigue as a problem. Statistically significant factors found to increase both measures of driver fatigue included starting the work week tired and longer than expected loading and unloading time. Regularity of time, regularity of route, and hours of uninterrupted sleep were each statistically significant factors for at least one fatigue measure. Building upon the work completed in 2001, Crum et al. (2002) tested the previously developed Truck Driver Fatigue Model on a random sample of 279 drivers at 116 trucking companies and 122 drivers at 66 motor coach companies, which was then stratified on the basis of safety performance (i.e., SAFESTAT ratings). In the truck company study, starting the workweek tired was the single most significant factor related to fatigue. Other significant fatigue-influencing factors were difficulty in finding a place to rest and shippers' and receivers' scheduling requirements (including loading and unloading).

An earlier study conducted by O'Neil et al. (1999b) found mixed results when considering the effects of loading and unloading tasks on truck driver fatigue. An initial improvement in alertness was observed but this effect waned as the day progressed and may have contributed to a decrease in overall performance after 12 to 14 hours of duty.

Spanning more than three decades, historical research related to fatigue effects on large truck safety levels have formed the basis for recent changes in the *Part 395: Hours-of-service of Drivers, Title 49,* Code of Federal Regulations (General Accounting Office (GAO) 2007). Under this rule, long-distance (>150 air-mile radius of their work reporting location) drivers:

- may drive a maximum of 11 hours after 10 consecutive hours off duty;
- may not drive beyond the 14th hour after coming on duty, following 10 consecutive hours off duty;
- may not drive after 60/70 hours on duty in 7/8 consecutive days (a driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty); and
- using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.

Drivers who operate within a 150 air-mile radius of their normal work reporting location:

- may drive a maximum of 11 hours after coming on duty following 10 or more consecutive hours off duty;
- are not required to keep records-of-duty status (RODS); and
- may not drive after the 14th hour after coming on duty 5 days a week or after the 16th hour after coming on duty 2 days a week.

Dick et al. (2006) considered the effects of these revised hours-of-service regulations on large truck safety. Following the rule change, statistically significant decreases in rates of collision (-3.7 percent) and preventable collision (-4.7 percent) were observed. Even greater reductions in rates of driver injury (-12.6 percent) and driver collision-related injury (-7.6 percent) were observed.

Other Driver Conditions

Outside of fatigue, surprisingly few studies were uncovered that focused on driver condition for large truck involved crashes. Those identified focused on: (1) medical conditions and health status or (2) alcohol and drug abuse.

Medical Conditions and Health Status. Medical conditions and health status can have a significant impact on drivers' performance if their cognitive, perceptual, and psychomotor skills are affected. Staplin et al. (2003) pinpointed a small number of physical and cognitive abilities (i.e., vision and visual attention, divided attention, reaction time, flexibility and range of motion of extremities, etc.) that, if impaired due to disease, trauma, or simply the effects of normal aging, result in a 2- to 5-times increase in the risk of causing a crash. Commercial drivers must pass a medical examination to qualify for a commercial driver's license (CDL); specific disqualifying medical conditions include vision and hearing impairment, diabetes, and epilepsy.

Under the *Federal Vision and Diabetes Waiver Programs*, select commercial motor vehicle operators who do not meet Federal standards for specified medical conditions are permitted to participate in Interstate operations. In 1999, the FHWA conducted a study to determine if the "waivered" drivers under these programs posed a higher safety risk. The crash rate for non-waivered drivers (drivers who did meet the current medical standards) was determined to be 2.605 crashes per million vehicle-miles traveled (VMT). By comparison, crash rates for the vision and diabetes waiver groups were 1.706 and 2.309, respectively, suggesting that neither waiver group presents a threat to public safety. Contrary to the FHWA (1999) findings, Laberge-Nadeau et al. (1998 and 2000) observed an increased risk of crash for straight truck drivers with diabetes with complications and 46 to 55 year old articulated and straight truck drivers with diabetes without complications. Drivers of single-unit trucks who are diabetic without complications and not using insulin had an increased crash risk of 1.68 to 1.76 when compared with healthy drivers of the same vehicle class. These findings are consistent with earlier work. In a study conducted cooperatively with Dionne et al. (1995), Laberge-Nadeau reported that diabetic straight truck drivers have more crashes than drivers in good health. In an earlier study, Laberge-Nadeau et al. (1996) also observed that truck drivers with binocular vision problems had more severe crashes than healthy drivers.

Turning attention to sleep-related disorders, Stoohs et al. (1993, 1994 and 1995) found that truck drivers identified with sleep-disordered breathing had a two-fold higher crash rate per mile than drivers without sleep-disordered breathing. No additional studies were uncovered that directly linked the incidence of sleep-related disorders with more frequent of severe large truck crashes however McCartt et al. (2000) reported that symptoms of sleep disorder were predictive of self-reported falling asleep at the wheel.

Quantifying the extent of possible sleep-related disorders, Young et al. (1993) estimated that 4 percent of middle-aged male commercial drivers have some form of sleep apnea. In a more extensive study, Pack et al. (2002) found that mild, moderate, and severe sleep apnea occurs in 17.6 percent, 5.8 percent, and 4.7 percent of commercial drivers, respectively.

Contrary to findings reported by Stoohs (1993, 1994, and 1995) and McCartt (2000), Barr et al. (2004) found that commercial drivers diagnosed with sleep apnea had no greater likelihood of having a crash, or multiple crashes, than drivers without sleep apnea. A limitation of this study, however, was that it did not control for mileage exposure, which can vary widely among CDL holders.

Several studies have considered the incidence of obesity – a prime risk factor for sleep apnea – among commercial drivers. Korelitz (1993) observed 73 percent of truck drivers to be either overweight (Body Mass Index (BMI) between 25 and 30) or were obese (BMI >30). Similarly, Stoohs et al. (1993) reported that 71 percent of the truck drivers diagnosed with sleep apnea were also classified as obese (i.e., BMI >28). Stoohs (1993, 1994, and 1995) additionally reported that obese drivers presented a two-fold higher crash rate than non-obese drivers. In a related study, Roberts and York (2000) found the incidence of obesity among commercial drivers to be approximately twice that of the general population.

Though not a definitive in affecting large truck safety levels, FMCSA's report to Congress on the *Large Truck Crash Causation Study* (FMCSA 2006b) stated that among truck drivers, prescription drug use was an “associated factor” (may not have contributed to a crash, but was present at the time of the crash) in 28.7 percent of all crashes sampled, and over-the-counter drugs were an associated factor 19.4 percent of the time.

Alcohol and Drug Abuse. Federal law requires all motor carriers employing commercial drivers to have drug and alcohol testing programs. The random testing rates are 10 percent for alcohol and 50 percent for controlled substances (i.e., illegal drugs). In 1999, 0.2 percent of CDL holders tested positive for alcohol use and 1.3 percent tested positive for controlled substances (FMCSA 2001b). In 2002 only 2 percent of large truck drivers in fatal crashes had tested Blood Alcohol Content (BAC) levels above 0.08 percent, versus about 25 percent of drivers of passenger vehicles (NHTSA 2003). These statistics suggest that commercial driver alcohol and illegal drug use are not major factors in the crashes although few additional studies have been conducted to confirm or refute these findings. In a study conducted by Shao (1987), researchers found both passenger car and single-unit truck driver condition to be among the top three explanatory variables for crash occurrence, however, the proportion of truck drivers reported to be in an unsafe condition was small (1.4 percent, compared to 10 percent of car drivers).

Despite the reported infrequency of occurrence, Golob et al. (1987) noted that large truck-involved crashes involving alcohol are most severe in terms of both injuries and fatalities.

Driver Age and Experience

Substantially more studies were uncovered related to driver age and experience and the subsequent effects on large truck safety levels as part of this investigation. In general, large truck safety levels were observed to improve with increasing age and experience.

Age. Driver age was a common factor considered in the previously described fatigue-related studies. With a focus on local, short-haul operations, Hanowski et al. (2000) found that driver age was the strongest predictor of “critical incident” involvement - when a measured variable exhibited a pre-determined "signature" or exceeded a trigger criterion possibly indicating fatigue, lapses in performance, a safety-related external event, or potentially even hazardous driving behavior. Barr et al. (2005) noted higher levels of fatigue associated with younger and less experienced drivers. Conversely, McCartt et al. (2000) older, more experienced drivers showed a higher likelihood of falling asleep at the wheel, based on self-reported data.

With driver age as a primary focus, Eicher et al. (1982) found that young drivers are involved in a disproportionately high number of large truck crashes. Drivers under age 30 comprise less than 15 percent of all large-truck drivers but account for 30 percent of the drivers of large-trucks involved crashes. Similarly, Lyles et al. (1991) found that drivers under the age of 26 are anywhere from one to six times as likely to be involved in a crash as a driver over the age of 26. The 19 to 20 age group had the greatest risk of being involved in a crash. In a related study, Blower (1996) found that young truck drivers, aged 18 to 21, had moving violation rates almost twice those of the middle-aged drivers (30 to 49 years old) and were about 50 percent more likely to be charged with a violation in a crash. Consistently, Chang and Mannering (1998) observed a higher likelihood of a possible injury crash if the driver is age 25 or younger.

Shifting focus from young drivers to aging drivers, Llaneras et al. (1995) found that older commercial drivers demonstrated the expected performance deficiencies on traditional ability measures (e.g., reaction time, range of motion, simple problem solving) but actually drove a truck simulator better than younger truck drivers in a control group. Reporting similar findings, the Trucking Research Institute and InterScience America (1998) found that:

- Age alone is not a reliable predictor of job performance.
- Age is not a good predictor of sensory-motor abilities. While many perceptual, sensory-motor, and cognitive abilities do generally decline with advancing age, there are huge individual differences within age groups.
- Drivers past the age of 50 do begin to have slower reaction times, stiffer joints, and other physical signs of age. Nevertheless, these drivers are often among the safest and most reliable commercial drivers.

Burke et al (2002) reported a decreased crash severity with increased driver age, however, Bunn et al. (2005) found that truck drivers over 51 years of age were at increased risk for a fatality, should a crash occur. The physiological changes described above likely explain the inconsistent findings related to crash severity for drivers older than 51.

In practice, fleet managers consider age to be an important factor when hiring employees. Corsi and Barnard (2003) found that 59 percent of high-safety fleets and nearly 66 percent of large fleets considered age 25+ to be an important or very important selection factor in driver employee hiring decisions. The percentage was even higher (69 percent) for hiring owner-operators. In a more recent survey conducted by FMCSA (Knipling et al. 2004), experts and carrier safety managers rated "young driver" (younger than 25 years old) as having the 5th and 6th strongest association with crash risk of 16 factors considered. In contrast, both groups rated "older driver" (60 years old or older) as having the 12th strongest association with crash risk among the 16 factors.

Experience. Chirachavala and Cleveland (1986) observed driver experience to have a greater effect on truck crash involvement rates than driver age. Specifically, drivers with less than one year of experience had higher crash involvement rates than drivers with two or more years of experience. Lin et al. (1993) found that the most experienced drivers - those driving more than ten years - had the lowest crash risk.

Staplin and Lococo (2003) considered the extent to which large truck crashes can be linked to "churning" (high rates of turnover in the industry) among commercial drivers. Researchers found that drivers with frequent job changes (i.e., three or more different carriers per year for 2 years or more) were more than twice as likely to be involved in a crash as the at-fault driver than drivers with less frequent job changes. It is uncertain whether job changes increase a driver's risk, or whether poor driving results in dismissal or other management actions resulting in job changes.

In practice, commercial driving experience is generally recognized by fleet managers as an important factor in driver safety. Corsi and Barnard (2003) found that 85 percent of carrier safety managers consider driving experience with other carriers to be an important or very important hiring criterion. Similarly, Knipling et al. (2003) reported that 86 percent of carrier safety managers required a minimum number of years of commercial driving experience and that managers rated this hiring criterion as the 4th most effective safety management technique of 28 presented. In a more recent survey (Knipling et al. 2004), experts and carrier safety managers rated "inexperienced" as having the 4th strongest association with crash risk of 16 factors considered. "New to company" was not rated by either safety managers or other experts as a strong correlate of crash risk.

Moving beyond years of driving experience, Murray et al. (2005) developed an overall truck driver performance-based model for predicting future crash involvement based on prior driving history. The model considers a range of statistically significant driving behaviors and events - including violations, convictions, and past crashes - with associated future crash likelihood increases ranging from 18 to 325 percent (e.g., drivers who had a previous crash were 87 percent more likely to have a future crash). Earlier studies support these general relationships. Gou et al. (1993) found that nearly 50 percent of heavy vehicle drivers involved in crashes already had at least one demerit point in their personal files. In addition, 2 percent of the drivers did not have an appropriate driver's license, and just under 2 percent had suspended licenses.

With a focus on speed-related violations, FHWA (1999b) reported that roughly 22 percent of large truck fatal crashes involving more than one vehicle are speed-related. Approximately 7 percent of multi-vehicle large truck fatal crashes involve speeding on the part of the truck driver and approximately 15 percent involve speeding on the part of another driver. Despite their frequency of occurrence, Hauer et al. (1991) found that speeding offenses, by either car or truck drivers, are among the least important convictions in terms of crash prediction. However, Chang and Mannering (1998) observed a higher likelihood of injury/fatality crashes if the driver was speeding.

Turning attention to driver training, Cleaves (1997) reported a reduction of almost 50 percent in the number of crashes after the implementation of a driver training program. Similarly, Horn and Tardif (1999) reported a 14 percent reduction in crashes attributable to a newly instituted training program and a >50 percent reduction in driver crash rates attributable to a retraining program.

Driver Safety Belt Use

Section 392.16 of the Federal Motor Carrier Safety Regulations (FMCSRs, FMCSA 2007b) requires commercial drivers to wear safety belts while driving. Despite this ruling, 311 of 588 (53 percent) fatally-injured large truck drivers in 2002 were not wearing safety belts (FMCSA 2003b). One hundred thirty-four (23 percent) of these drivers were ejected from the vehicle (FMCSA 2003b). In 2003, FMCSA completed a study of safety belt use by truck drivers. Of the nearly 4,000 commercial vehicle occupants observed, the safety belt usage rate was 48 percent. This compares unfavorably with a current passenger vehicle occupant usage rate of 79 percent (FMCSA 2003b). During an ergonomics assessment of Class 8 truck safety belts, Bergoffen et al., 2005 reported that numerous obese, "large-bellied" commercial truck drivers do not wear their safety belts.

There is essentially unanimous agreement among truck safety studies about the qualitative benefits of using safety belts. Horii (1987) estimated that the number of fatalities and serious injuries during heavy truck crashes could be reduced by roughly 25-percent had occupants been wearing seat belts. Chang and Mannering (1998) observed higher injury/fatality crash rates if the driver was not using restraint system. Simon (2001) used statistical models and formulae which suggest a lesser risk of injury in all cases for a belted driver. Similarly, Bunn et al. (2005) found that truck drivers who were not wearing a safety belt were at increased risk for a fatality, should a crash occur.

VEHICLE CHARACTERISTICS

When considering the effects of vehicle characteristics on large truck safety, the vehicle's configuration, number of axles, cargo body type, gross vehicle weight rating, and other factors may be of interest. In reviewing the related literature, vehicle configuration effects on large truck safety received the primary focus. A smaller body of literature was identified that focused on other aspects such as the effect of size and weight, vehicle design, and the vehicle's mechanical condition on safety.

Vehicle Configuration

Vehicle configuration is at the crux of an ongoing balance between efficient and economical freight movement and public safety. Efficiency proponents support the use of ever-larger trucks while safety proponents tout the risks involved. In line with this issue, a significant amount of literature focused on the use of twin trailer trucks (a truck-tractor pulling two trailers, "doubles") and longer combination vehicles (LCV, a truck pulling two or more trailers), as compared to traditional tractor semi-trailers (a truck-tractor pulling a single trailer, "singles"). Prior studies considered the effects of vehicle configuration on both crash frequency (i.e., crash rates) and crash severity.

Crash Frequency. A number of historical studies that attempted to link vehicle configuration to crash frequency were either inconclusive or deemed invalid because of methodological flaws, data insufficiencies, or obscuring effects of the operating environment. *Special Report 211* (TRB 1986) considered 14 different historical studies related to crash experience of singles and doubles. Of the 14 studies, only 5 were considered to be valid. Observed shortcomings in historical studies were reiterated in the more recent *Comprehensive Size and Weight Study* (FHWA 2000), finding no studies applicable for establishing differential crash rates for LCVs and non-LCVs. Council and Hall (1988) reported inconclusive findings in determining whether multiple-trailer vehicles have an increased frequency of crashes. In a separate study conducted the same year, Campbell et al. (1988) estimated a value of 1.1 for the ratio of double- to single-trailer fatal and non-fatal crash involvement rates but noted an obvious flaw in methodology; use of 1985 to 1986 travel data paired with 1980 to 1984 crash data may underestimate crash rates for doubles because of a rapid increase in miles traveled by these vehicles after 1982. Despite this shortcoming, Campbell's estimate was used in later work to determine impacts of changing size and weight regulations by TRB's *Truck Weight Limits* and *Twin Trailer Trucks* committees. Showing mixed results, Jovanis et al. (1990) found that doubles experienced lower crash rates than singles in 1983 and 1985 but experienced higher crash rates in 1984, which was a year of greatly expanding doubles operation. Large variations in year-to-year crash rates suggest potential small sample problems. Most recently, Scopatz and DeLucia (2000) noted a lack of reliable data on the exact configuration of vehicles involved in crashes, as well as a lack of specific measures of exposure. Without quality data on configuration and good measures of exposure, questions regarding the comparative safety of various vehicle configurations cannot be answered empirically.

Purporting conclusive evidence, Glennon (1981) and Graf and Archuleta (1985) reported a 6 percent and 12 percent higher overall crash rate for doubles than singles, respectively. Sparks and Beilka (1987) found that the percent of doubles within the truck fleet has the greatest influence on the estimated crash rates. Using the same case-control methodology previously employed to determine the effects of fatigue on large truck safety, Jones and Stein (1989) found that doubles were consistently over-involved in crashes by a factor of 2 or 3, independent of driver age, hours of driving, cargo weight, or type of fleet. Similarly, Mingo et al. (1991) found that multi-trailers, single trailers, and single-unit trucks have fatal crash involvement rates of 9.96, 6.01, and 3.00 per 100 million mi traveled, respectively. The ratio of fatal accident involvement rates for multi-trailers to single trailers and single-unit trucks is 1.66 and 3.32, respectively. Earlier efforts estimated the ratio of the total crash involvement rate of doubles to that of singles between 0.8 and 2.3, with most in the range of 0.9 to 1.1 (TRB 1986).

Contrary to these findings, Chirachavala and O'Day (1981) reported a 2 percent lower overall crash rate for doubles than singles. Seiff (1989) also found double trailer combinations to be underrepresented in crashes, while bobtail tractors are overrepresented. Consistent findings were reported as part of a multi-study effort to develop the safety-related aspects of the *Comprehensive Truck Size and Weight Study* (FHWA 2000). Using survey-based crash and travel data, Ticatch et al. (1996) estimated the following crash rates per million VMT: 1.79 for non-LCV combinations (tractor-semi-trailers and short doubles under 80,000 lb), 1.02 for turnpike doubles, 0.83 for triples, and 0.79 for Rocky Mountain doubles. The difference between the non-LCV and LCV crash rates was statistically significant; the differences among the types of LCVs were not. Fatal crash rates for LCVs and non-LCVs were found to be equal. The study is not conclusive because the survey-based data cannot be verified and because confounding factors were not adequately controlled for.

Using an alternate source of data (U.S. fatal crash and truck travel databases), the ratio of multi-trailer to single-trailer fatal crash involvement rates on all roads nationwide was estimated as 0.97 (FHWA 2000). The ratio ranged from 0.93 to 1.40, depending on road class. A weighted average ratio of 1.11 was computed, with weights assigned to the ratios by road class in an effort to eliminate the effect of differences between the two configurations in the distribution of travel by road class.

Providing a more detailed look at various vehicle configuration characteristics and the subsequent effects on large truck safety, Chirachavala and Cleveland (1986) observed higher crash rates for:

- 2-axle straight trucks,
- singles with 3-axle tractors,

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

Lyles et al. (1991) found no consistent difference between crash involvement rates for singles and doubles. More recently, Braver et al. (1997) observed no overall increase in crash risk between doubles and singles but noted that a lack of control of potential confounding factors, such as driver age and work operation attributes, limits these conclusions.

Crash Severity. Turning attention to crash severity, two general approaches have been used to determine the effects of vehicle configuration on large truck safety. The first examines the distribution of crash types by severity level (i.e., the proportion of crashes that result in casualty). The second approach expresses the average consequence of a crash (i.e., the average number of deaths per crash).

Historical studies that have considered the distribution of crash types by severity level suggest that a larger proportion of double-involved crashes result in death, and conversely, a larger proportion of single-involved crashes result in non-fatal injury (TRB 1986). TRB (1986) deemed these findings inconclusive, citing the aforementioned shortcomings related to methodological flaws, data insufficiencies, or obscuring effects of the operating environment.

In studies in which crash severity has been expressed by deaths or by fatal crash involvements, crashes involving doubles have usually been found to be more severe than those of singles (TRB 1986). Of the studies completed, comparable studies found that doubles have fatality crash rates ranging from 7 percent lower to 5 to 20 percent higher than single-unit trucks (TRB 1986).

Contrary to these general observations, a higher fatal or injury crash involvement rate for doubles was not observed by Carsten (1987), however, researchers note that doubles are used in safer operating environments and double drivers may be compensating for different vehicle handling characteristics. Similarly, Blower et al. (1993) found differences between single- and multiple-trailer vehicle involvement in injury and property damage crashes to be non-significant after adjusting for road type, time of day, and urban/rural locations, though there was some evidence of doubles having increased injury crash risk on smaller roads. In an earlier study, Chirachavala and Kostyniuk (1984) had similarly considered the combined effects of vehicle configuration and roadway type, noting the characteristics of particularly severe crashes as collisions involving straight trucks or loaded flatbed or tanker singles on undivided rural roads, passenger cars and van singles on undivided rural roads at night and passenger cars and doubles on divided rural roads.

More recently, Burke et al. (2002) observed an increased crash severity for single-unit, 2-axle vehicles. Though counterintuitive, this finding does complement the work performed by Chirachavala and Kostyniuk (1984) which found that particularly severe crashes resulted when collisions involved passenger cars and straight trucks (among other truck types) on undivided rural roads.

Size and Weight

Closely related to vehicle configuration is the vehicles' size and weight. Prior studies focused on vehicle configuration have, in fact, been criticized for not directly controlling for the effects of vehicle size and weight; the results reported may reflect the combined effects of configuration and size/weight (TRB 2002). The limited body of related research (this review did not consider studies related to permitted oversize/overweight movements or the effects of illegal overloading) indicates both an increasing trend and decreasing trend in crash risk with increasing vehicle weight. No studies were uncovered that considered the effects of increase vehicle size (outside of multi-trailer combinations) on large truck safety levels. Morris (2003) confirms the dearth of literature linking vehicle size and weight to large truck safety levels, noting that studies conducted over the last 60 years have not yielded definitive conclusions.

Vallette et al. (1981) concluded that truck crash rates varied inversely with truck weight for both double and single trailer combinations. Similarly, Polus and Mahalel (1983) observed a decreasing trend in crash rate and truck driver injury with increasing gross vehicle weight (GVW).

Conversely, Campbell et al. (1988) noted a moderate increase in single-unit and combination truck crash rates for higher gross weight, although the relatively small number of data points and the high degree of scatter make drawing conclusions from these data difficult.

Proponents of increased allowable size and weight vehicle limits purport little overall effect on highway safety; small possible increases in crash rates per truck-VMT would be approximately offset by the reduction in truck-VMT resulting from the new trucks' higher productivity. Crash rates per ton-mile of highway freight are predicted to decline (Stowers et al. 1983). Considering crashes involving heavy trucks between 1978 and 1987 - a time when truck sizes and weights dramatically increased in response to relaxed regulations in Manitoba, Canada - Clayton et al. (1989) reported essentially constant heavy truck crashes in terms of numbers and severity.

Vehicle Design

Significant research has been devoted to enhancing large truck safety through vehicle design. Much of the design characteristics considered relate to internal mechanical or material properties (i.e., anti-lock brake systems, low-tire pressure warning systems, reinforced saddle or transport tanks, baffle systems, etc.). This review considered only those design features which could feasibly be detected by enforcement personnel as a vehicle passes an inspection station. With this limiting criteria in mind, few studies were uncovered related to cab design, under-ride features, and vehicle lighting and conspicuity.

Two studies considered the effects of cab-over-engine versus conventional tractor designs on safety. Philipson et al. (1978) found that crashes involving cab-over-engine tractors were significantly more likely to result in a fatality or major injury. Campbell and Carsten (1981) supported this finding; the fatal crash involvement rate is greater for cab-over-engine tractors than for conventional tractors. Because of the heightened severity associated with crashes involving cab-over-engine tractors, enforcement personnel should be vigilant about performing inspections on these vehicles to prevent the occurrence of a crash.

Turning attention to under-ride features (i.e., guards), Krishnaswami et al. (2002) estimated a fatality reduction of 27 to 37 percent through prevention of front under-ride.

FMCSA (2002) found that 40 percent of trucks that were struck by other vehicles had one or more lighting violations, as opposed to only 13 percent of the trucks that struck other vehicles. These lighting violations included headlights, tail lights, brake lights, signal lights, and marker lights. Although conspicuity aids help reduce nighttime crashes into the rear and sides of trucks, more than 70 percent of rear-end collisions into trucks occur during daylight (FMCSA 2002). In a related study, Morgan (2001) found that the use of retro-reflective tape on trailers, as mandated by FMVSS 108, was beneficial in both daylight and dark conditions. Under all conditions, the tape reduced side and rear impacts by 29 percent. In dark-not-lighted conditions, the tape reduced impacts by 41 percent.

Mechanical Condition

Turning attention to the effects of mechanical condition on large truck safety, Jones and Stein (1989) found that 77 percent of single trucks involved in crashes had defective equipment warranting citation as compared to 66 percent of those randomly sampled and that 41 percent involved in crashes had defects warranting taking the vehicle out of service as compared to 31 percent of those not in crashes. Brake-related defects were most common, appearing in 56 percent of the crashes, while steering-related defects appeared in 21 percent of the crashes. Researchers observed no association between wheel and tire defects and vehicle crashes. Similarly, Gou et al. (1993) estimated that 13 percent of crashes involving heavy vehicles result from non-compliant mechanical components on those vehicles and that defects in the braking system is the most frequent cause of those crashes. Researchers estimated that heavy vehicles with major non-compliant components have a propensity to be involved in a crash five times higher than that of compliant vehicles. Similarly, Chang and Mannering (1998) observed a higher likelihood of a possible injury crash if the vehicle had defective equipment.

In a related study, Thakuriah et al. (2001) considered the relationship between inspections and crashes. Researchers found no evidence of a significant difference in the expected number of crashes involving vehicles incurring zero violations and vehicles incurring one or more violations. About 2 percent of all inspected, zero-violation vehicles were subsequently involved in crashes. With every increase in violation, the proportion of vehicles involved in crashes increases by about 0.04 percent. A smaller percentage of zero-violation vehicles that undergo Level I inspections are subsequently involved in crashes (compared with zero-violation vehicles that undergo Level II and Level V inspections), but, with every increase in violation, the proportion of vehicles involved in crashes increases at a higher rate for vehicles that undergo Level I inspections.

CARGO CHARACTERISTICS

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

Chirachavala and Cleveland (1986) found that tankers, flatbeds (singles and doubles) and straight trucks had a higher crash rate when loaded rather than empty. The proneness to crashes involving empty trucks varies from company to company depending on how much time they run empty trucks.

Considering the method of containment, Gou et al. (1993) estimated that improperly secured or unbalanced loads was a factor in 2 percent of large truck crashes.

Most recently, Burke et al (2002) found that carriers transporting household goods experience a decreased level of crash severity. Household goods are typically moved in enclosed containers, are relatively light in cargo weight, and may be moved for shorter than average distances.

CARRIER CHARACTERISTICS

Carrier characteristics that may be of interest when considering large truck safety include the location of the carrier's base state, the type of classification of carrier, the carrier's type of operation, the fleet size, driver base, and other. Few studies were found that investigated broader carrier-related characteristics and their effect on large truck safety. Burke et al. (2002) found that carriers based in Canada had an increased predicted crash severity, potentially attributable to regulatory differences in safety regulation, enforcement, vehicle size and weight, and driver qualifications between the U.S. and Canada. This same study reported that higher severity crashes resulted when the carrier's latest review was a compliance review. An observed frequency or severity of crashes may have prompted the compliance review; this study did not distinguish whether the review preceded or followed the observed crashes.

The majority of historical studies uncovered considered the effects of carrier fleet size on large truck safety levels. In a survey conducted by Campbell and Carsten (1981), the authors found that fleets with fewer than 50 trucks had an average fatal crash involvement rate more than twice that of fleets with more than 50 trucks. Researchers also found that fatal and injury crash involvement rates are greater for Interstate Commerce Commission (ICC) authorized carriers than for non-authorized carriers. In seeming contrast to these findings, McCarthy (1995) concluded that for a one-percent increase in truck fleet size, the fatality rate increased 0.612 percent. The Bureau of Motor Carrier Safety (BMCS 1983) confirmed that firms operating between 45 and 1,000 trucks report 20 percent higher crash rates than firms operating over 1,000 trucks. Moses and Savage (1994) observed that large trucking firms that operate ½ million miles a year (in the 9th decile) have a crash rate half that of the smaller firms. The very largest firms have a crash rate approximately one third that of smaller firms. Using the number of drivers as the metric, Burke et al. (2002) consistently observed crash severity to decrease as the number of intrastate drivers employed by a carrier increased. Conversely, crash severity was observed to increase as the number of trip-leased drivers utilized by a carrier increased in this same study.

Campbell and Carsten (1981) considered the type of carrier operation and the effects on large truck safety levels. Researchers found fatal and injury crash involvement rates to be greater for local movements than for intercity movements. Chirachavala and Cleveland (1986) found higher overall crash rates for local service, particularly involving newer straight trucks, single vans, or tankers and over-the-road service using single or double flatbeds. Bruning (1989) reported higher crash rates for owner-operators than drivers employed by a company. Considering large truck safety levels for intrastate and interstate operations, NTSB (2002) found that intrastate operations experienced a higher vehicle out-of-service (OOS) rate but a lower driver OOS rate during roadside inspections when compared to that of interstate operations. No speculation was made on differences in crash risk based on these findings.

A number of studies attempted to link carrier financial performance and subsequent driver wages to large truck crash safety levels. Bruning (1989) observed that carrier profitability is inversely related to the crash rate for all carriers except the very smallest. Corsi and Keane (2002) found that firms with higher gross revenues tended to have better driver safety performance, as evidenced through lower Driver Inspection Indicator (DII) and Driver SEA scores. Conversely, firms with higher average hauls (in miles) tended to have poorer driver safety performance. Researchers also found higher driver wages to be negatively and significantly correlated with DII scores and Driver SEA scores (i.e., higher wages result in better driver safety performance). Similarly, Rodriguez et al. (2003) found that higher pay rates and pay increases are related to lower expected crash counts and to a higher probability of no crashes, all else held equal. Researchers also purport that human capital and occupational factors, such as pay, job tenure, and percentage of miles driven during winter months, have a significantly better explanatory power of crash frequency than demographic factors. In a related study, Wills et al. (2006) defined six firm-based “safety climate” factors (i.e., communication and procedures, work pressures, relationships, safety rules, driver training, and management commitment) and related these to four aspects of work-related driving (i.e., traffic violations, driver error, driving while distracted, and pre-trip vehicle maintenance). The safety climate factors accounted for significant amounts of variance in all four aspects of work-related driving, over and above the control factors of age, sex, and work-related driving exposure. Safety rules, communication, and management commitment were more strongly related to specific aspects of work-related driving behavior than others.

OPERATING ENVIRONMENT

Obviously, other factors such as roadway, traffic, and environmental characteristics contribute significantly to large truck safety levels, yet few studies have comprehensively addressed these confounding factors. The majority of these prior investigations has focused on the effects of roadway; significantly fewer studies have considered the effects of traffic or the environment (i.e., adverse weather) on large truck crash safety levels.

Roadway Characteristics

The U.S. General Accountability Office (formerly General Accounting Office, GAO) reports that the roadway environment - that is, those factors external to the driver and the vehicle that increase the risk of a crash - is the second most prevalent factor cited as contributing to a crash (GAO, 2003). Craft (2005), as part of the *Large Truck Crash Causation Study*, observed that the roadway was a related factor for 14 percent of the trucks and 16 percent of the other vehicles in two-vehicle crashes.

Most historical studies relating roadway characteristics to large truck safety levels have considered the effects of roadway setting (i.e., urban or rural), class, or geometrics on large truck crash frequency.

The GAO (2001) reported that rural roads handle only about 40 percent of all VMT, yet more than 60 percent of all fatalities occurred on rural roads. Truck crashes follow the same pattern. According to Matteson and Blower (2003), 66 percent of the 5,567 fatalities in truck-involved crashes occurred in rural areas. Hedlund (1977) found crashes to be more severe on rural highways than on urban highways. Similarly, Smith and Wilmont (1982) observed higher fatal and injury crash involvement rates on rural highways than on urban highways. In agreement with these earlier studies, Chang and Mannering (1998) observed a lower likelihood of less severe (i.e., possible injury) crashes in rural areas. Most recently, Khorashadi et al. (2005) noted significant differences in the magnitude and direction of explanatory variable impacts when considering urban and rural large truck crash occurrences. For example, in rural crashes involving tractor–trailer combinations, the probability of drivers' injuries being severe/fatal increased about 26 percent relative to crashes involving single-unit trucks. In urban areas, this same probability increased nearly 700 percent. In crashes where alcohol or drug use was identified as being the primary cause of the crash, the probability of severe/fatal injury increased roughly 250 percent in rural areas and nearly 800 percent in urban areas. Thirteen unique variables significantly influenced driver-injury severity in rural but not urban areas, and 17 unique variables significantly influenced driver-injury severity in urban but not rural areas.

With respect to roadway class, Seiff (1989) reported that limited-access highways are 4 times safer for trucks than other highways. Similarly, Lyles et al. (1991) found that crash rates for non-limited-access highways and local streets were typically 2 to 3 times higher and 7 to 10 times higher, respectively, than those for limited-access highways. Philipson et al. (1978) noted that the odds of a high-severity injury are greater on conventional highways than on freeways or expressways. Graf and Archuleta (1985) reported that the highest overall crash rate was observed for urban non-interstate freeways. In rural settings, researchers observed the highest crash rates on undivided highways and the lowest crash rates on rural interstates. Similarly, Chirachivala and Kostyniuk (1984) observed more severe crashes on undivided rural highways than on divided rural highways.

More recently, Solomon (1999) and Braver et al. (2002) considered large truck crashes on toll roads. Researchers reported that large trucks were significantly under-involved in single-vehicle crashes on all state toll roads, with a 27 to 58 percent lower likelihood of being in single vehicle crashes than passenger vehicles. In five of the seven states considered, large trucks were significantly over-involved in multiple-vehicle crashes relative to passenger vehicles; the exceptions were Kansas, where they had significantly lower multiple-vehicle involvement rates, and Indiana, where there were no significant differences in multiple-vehicle involvements by vehicle type. The risk of commercial motor vehicle involvement in multiple-vehicle crashes resulting in deaths or serious injuries was twice that of passenger vehicles in Ohio and Pennsylvania.

Considering the effects of roadway geometrics, Hedlund (1977) found crashes to be more severe on two-lane rural highways than on four-lane rural highways. Not distinguishing between urban and rural environments, Smith and Wilmont (1982) observed greater fatal and injury crash involvement rates on two and three lane highways than on freeways. For undivided highways, Garber and Joshua (1991) reported that lane width, slope change rate, shoulder width, and horizontal curvature all had varying degrees of significance, depending on the regression model technique used. Vogt and Bared (1998) obtained a similar result; lane width, shoulder width, horizontal curvature, and vertical gradient could all be used effectively to model truck crashes at intersections on two-lane rural roadways. Mohamedshah et al. (1993) found that the truck crash rates on two-lane rural roadways depended on shoulder width and horizontal curvature (>6 degrees); vertical gradient was not found to be statistically significant although the authors theorized that inadequate data might have led to this result. Pigman and Agent (1999) recommended roadway countermeasures to the Kentucky Department of Transportation based on the observed safety effects of lane width, truck stopping sight distance, grades, and truck speed on curves. Most recently, Golob and Regan (2004) found that the propensity of truck-involved crashes is a decreasing function of the number of lanes, factored by time of day and day of week effects and weather conditions.

With a more detailed look at roadway geometric characteristics, Wright and Burnham (1985) observed increasing crash rates with increases in the percent of:

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

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

Using an alternative methodology, Miaou and Lum (1993) and Miaou (1994) found that the expected number of truck crashes increases as each of the following increases:

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

None of these factors however, proved statistically significant using a chi-square test at a 5 percent significance level. Saccomanno and Buyco (1988) also found no significant relationships between roadway variables and truck crash involvement rates. Most recently, Robertson and Aultman-Hall (2001) reported no statistically significant relationship between ‘preferred’, ‘adequate’ and ‘less than adequate’ roadway features and truck crash history.

Closely related to roadway geometrics is the posted speed limit. Garber et al. (2003) concluded that neither differential or uniform speed limits for trucks and other vehicles on rural highways is consistently associated with reduced truck speeds or superior crash reduction. Similarly, Harwood et al. (2003) concluded that differentially reducing large truck speed limits by 5 MPH is likely to reduce their prevailing speeds by 1 to 3 MPH but that the safety effects of this are mixed or questionable. In a related study considering the effects of differential and uniform speed limits on safety, the results regarding truck-involved crashes were inconclusive (Srinivasan 2006).

Burke et al. (2002) considered the effects of roadway lighting, among other factor, on crash severity. Crashes that occurred at night but on a roadway lit with street lighting were predicted to be less severe. A driver who has increased night vision due to lighting may have a heightened ability to avoid a crash or minimize its severity.

Traffic Characteristics

It has been generally assumed that crash rates increase with increasing traffic volume; higher interaction among vehicles at higher volumes increases the probability of crashes. Studies have confirmed instead a U-shaped relationship between crash rate and traffic volumes. Crash rates are higher when the traffic volume is either very high or very low. Under very high traffic volumes, all vehicles travel at about the same lower speed, which in turn decreases the speed variance, resulting in lower crash rates.

Jovanis and Chang (1986) found that crash occurrence increases with automobile vehicle miles of travel (VMT) and truck VMT. Using the more commonly considered factor, average annual daily traffic (AADT), Mohamedshah et al. (1993) found that the truck crash rates increased with both truck and non-truck AADT. Similarly, Miaou and Lum (1993) and Miaou (1994) found that the expected number of truck crashes increases as AADT increases. Additionally, researchers observed a reduction in the expected number of truck crashes as the percent of trucks in the traffic stream increased. Both factors however, proved statistically insignificant using a chi-square test at a 5 percent significance level. Nearly a decade later, Golob and Regan (2004) replicated these findings with statistical significance, reporting that the propensity of truck-involved crashes is a decreasing function of AADT per lane, and an increasing function of truck percentages of AADT, factored by time of day and day of week effects and weather conditions. The likelihood of a truck being involved in a crash is particularly sensitive to proportion of large (five-axle or more) trucks. In a related study, Robertson and Aultman-Hall (2001) found AADT to be the only significant and consistent predictor of truck crash rates. Suggesting the combined effects of traffic volumes and reduced speeds, Chang and Mannering (1998) purported that a possible injury crash is less likely to occur during rush hour.

Adverse Weather

Significantly fewer studies considered the effects of weather on large truck safety levels. One explanation could be the relative infrequency of adverse weather events. In 2005, adverse weather conditions were reported in 14 percent of the fatal crashes and for 12 percent of the non-fatal crashes involving large trucks (FMCSA 2007). Rain was the most common adverse weather condition reported. Conversely, Kosior and Summerfield (2001) suggest that the role of inclement weather conditions in heavy truck crashes is likely under-estimated. Considering single vehicle incidents occurring in Manitoba, Canada, nearly 41 percent of large truck crashes occurred with poor roads and windy conditions.

Only a single study was uncovered that considered the statistical relationship between adverse weather conditions and large truck crashes. Jovanis and Chang (1986) found that overall crash occurrence increases with hours of snowfall. Researchers also observed automobile crashes to be much more sensitive to environmental conditions than truck crashes.

IMPLICATIONS FOR THIS INVESTIGATION

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

Driver Characteristics

- Fatigue was found to be a noted contributor to increased large truck crash frequencies and severities, though this driver condition was difficult to measure and often defined differently study to study.
    - Both increased hours (industrial fatigue) and days (cumulative fatigue) of driving were associated with higher crash risk. Hours of service violations were determined in one study to approximate 40 percent, likely contributing to the effects of fatigue.
    - Nighttime driving (circadian fatigue) was also associated with increased large truck crash frequencies and severities with few exceptions; local, short haul operators and long-haul operators traveling on freeways, Interstates or expressways were observed to experience safer driving conditions during nighttime hours.
    - Use of sleeper berths was associated with higher levels of fatigue and an increased risk of a fatality crash.
    - Similarly, operators of longer combination vehicles (LCVs) experienced higher levels of fatigue, but efforts to relate LCV operation to increased crash frequency or severity were inconsistent in their findings.
    - Inconsistent findings were also uncovered related to the effects of rest area availability and cargo loading/unloading tasks on fatigue and subsequent large truck safety levels.

- Noted effects of various driver health and medical conditions on large truck safety levels were inconsistent between studies.
    - Studies that considered drivers diagnosed with vision impairments or diabetes showed both higher and lower crash involvement rates when compared to larger commercial driver populations. Specific types of vision impairments (i.e., binocular vision problems) were associated with more severe crashes.
    - Similarly, studies that considered drivers diagnosed with sleep disorders showed both higher and lower crash involvement rates when compared to larger commercial driver populations.
    - Consistently, obese drivers had higher crash frequencies.
- The influence of alcohol and drugs were found to be a significant contributor to large truck crash rates, however, a very low proportion of large truck drivers were found to be in this state.
- Age and experience levels were found to be noted contributors to large truck safety levels.
    - Younger drivers were consistently reported to have higher crash involvement rates. Older, more experienced drivers were found to be safer drivers, but have an increased risk for fatality if over 51 should a crash occur.
    - Similarly, inexperienced drivers were reported to have higher crash involvement rates; drivers with more years of experience were observed to be safer drivers. Company-sponsored driver training programs were also shown to reduce crash frequencies.
    - Frequent job changes were reportedly associated with higher crash frequencies although the cause an effect aspect of this relationship is unclear (i.e., drivers may be let go because of high crash frequencies).
    - A history of traffic violations and convictions increases a driver's likelihood for a crash. If the driver was violating speed restrictions at the time of the crash, the crash will be more severe.
- No studies were uncovered that considered the effects of gender on large truck safety levels.

Vehicle Characteristics

- Conflicting findings related to both crash frequency and severity were found when investigation vehicle characteristics, particularly vehicle configuration, and their effect of large truck safety levels.

  - With some consistency, higher crash rates were noted with 2-axle trucks, local service activities, and tanker and flatbed trailers.

  - A single study observed higher severity levels for crashes involving single-unit, 2-axle trucks.

- Cab-over-engine designs were associated with higher fatality crash rates while use of front under-ride guards and retro-reflective tape on the trailer unit have been shown to reduce fatality and overall crash rates, respectively.

- The effects of gross vehicle weight (GVW) on crash frequency and severity were in agreement between studies; a higher GVW results in lower crash rates but a higher crash severity. Few studies have been conducted historically to confirm this relationship, however.

- Defective vehicle equipment was found to be a common crash cause, however, no significant association was found when comparing large truck safety levels and recorded roadside inspection violations.

Cargo Characteristics

- Limited information was found related to the effects of cargo characteristics. A single study found that crash rates were higher for loaded trucks rather than empty trucks. This study however did not adequately control for the percent of time that trucks operate empty and loaded so these findings may be invalid.

- A single study reported lower crash severity levels for household goods cargo.

- No information was found that investigated the effects of cargo method of containment on large truck safety.

Carrier Characteristics

- With respect to carrier characteristics and the effects of large truck safety, it was generally found that smaller carriers have higher fatal crash rates than larger carriers. The definition of a "small" carrier varied from study to study.

  - Crash severity was found to decrease as the number of intrastate drivers increased; crash severity was found to increase as the number of trip-leased drivers increased.

- Higher crash rates were reported for owner-operators than drivers employed by a company.

- Local operation carriers were observed to experience higher injury/fatality and overall crash rates than intercity operation carriers. Conversely, carriers with longer average hauls were observed to have lower safety levels.

- Higher gross revenues for the carrier and higher wages for the driver were both associated with higher levels of large truck safety.

- More severe crashes were observed for carriers whose latest review was a compliance review; this finding does not distinguish whether the review followed or preceded the observed crashes.

Operating Environment

- Investigation of operating environment effects on large truck safety was typically performed as a secondary exercise to limit confounding factors.

- Some consistency was noted in the effects of roadway characteristics on large truck safety levels.

    - Both large truck crash frequency and severity were found to vary by roadway type; rural roadways experience more severe but less frequent crashes.

    - The higher degree of either horizontal or vertical roadway curvature results in a higher crash frequency.

    - Limited access highways reportedly experienced a higher level of large truck safety while undivided and/or two-lane highways experience more severe crashes.

    - The effect of speed limits, either uniform or differential by vehicle type, on large truck safety levels was unconfirmed.

    - Roadway lighting was observed to reduce crash severity for nighttime crashes.

- Fewer studies considered the effects of traffic characteristics on large truck safety levels. Crash frequency was noted to increase as traffic volumes (AADT) and vehicle miles traveled (VMT) increase.

- Only a single study reported a direct relationship between adverse weather and large truck safety levels; crash frequencies were observed to increase with hours of snowfall.

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

CHAPTER 3.
METHODOLOGY

Incompatibility in the findings of past large truck crash studies can be attributed to two primary causes. First, most studies only examined a special population of trucks (i.e., from certain companies, states, or regions of the country). Often the selection of the samples was not random, making it difficult to use or extrapolate their findings at the national level. Secondly, when analyzing crash rates, researchers typically investigated the effects of one or two variables without adequately considering or controlling for other potentially significant "confounding" factors. While the first shortcoming is difficult to overcome since Texas-specific activity is of interest, the second shortcoming is more easily addressed through a well-developed methodology.

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

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

DATA COLLECTION

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

Data to support this investigation considers a three-year time span from January 1, 2004 to December 31, 2006. During this time, 44,012 total large truck crashes occurred in Texas. Data sources and specific elements of interest are detailed below.

Data Sources

Two types of data were required to perform this investigation: (1) historical crash information for large trucks in Texas and (2) carrier profile information describing size, operation, etc. (The historical crash information also contained information related to driver, vehicle, cargo, and operating environment characteristics.) These two types of data were collected from three sources:

- historical crash information was obtained electronically from the MCMIS Crash File,
- carrier profile information for *interstate* carriers (and select intrastate carriers) was obtained electronically from the MCMIS Census File, and

- *intrastate* carrier profile information was obtained electronically from the Texas Department of Transportation, Motor Carrier Division.

The MCMIS Crash and Census Files were combined into a single data set using common data elements such as USDOT number. Supplemental intrastate carrier profile information was manually matched to the MCMIS Crash File using carrier name and address identifiers. Of the 10,391 large truck crashes involving intrastate carriers, supplemental carrier profile information was identified for 4,962 crashes (47.8 percent).

Data Elements

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

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

Table 1 summarizes the combined set of available data elements germane to this investigation from MCMIS and the Texas Department of Transportation. While the list of available data elements was encouraging, the completeness of the data across all elements, particularly for intrastate carriers, was lacking.

Data Collection Challenges

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

Crash Data. Relatively few challenges were encountered when compiling the crash data for this investigation. Without a second data source for ready comparison, the data was assumed to be accurate. Some inconsistencies may result because of officer subjectivity in determining weather conditions, road surface conditions, etc.

Of greater concern, however, was the completeness of information contained in the MCMIS Crash File. Data related to driver condition and the number of vehicle axles, for example, were entirely omitted from the file (i.e., column headings were included but no data were present). This may reflect a change in FMCSA policy to either no longer collect, maintain, or provide publicly this information that was previously available.

Table 1. Relevant Combined Data Elements

Driver Characteristics	
• Number of Interstate Drivers Operating Within/Beyond 100-mile Radius	• Number of Intrastate Drivers Operating Within/Beyond 100-mile Radius
• Number of CDL-issued Drivers	
Vehicle Characteristics	
• Vehicle License State	• Gross Vehicle Weight Rating
• Vehicle Configuration	• Cargo Body Type
Cargo Characteristics	
• Cargoes Carried	• Hazardous Materials (HM) Carried
Carrier Characteristics	
• Carrier State	• Equipment Owned
• Carrier Operation	• Equipment Term-Leased
• Carrier Classification	• Equipment Trip-Leased
• Annual Mileage (MCS-150)	• Fleet Size Code
• Type of Latest Review	• Number of Drivers
• Date of Latest Review	• Number of Intrastate/Interstate Drivers
• Recordable Crash Rate	• Number Of Trip Leased Drivers
• Safety Rating	
Operating Environment Characteristics	
• Trafficway	• Road Surface Condition
• Access Control	• Light Condition
• Weather Condition	
Crash Characteristics	
• Crash Date	• Towaway
• Crash Time	• Number of Vehicles in Crash

Carrier Data. Unlike the crash data, which had relatively few challenges in collection, the carrier data was more difficult to collect and utilize in this investigation. Profile information contained in the MCMIS Census File was readily available for interstate carriers who were active at the time of the data request (December 2006). Matching carrier information from December 2006 to crashes occurring between 2004 and 2006 resulted in limited missing carrier information (i.e., if carriers ended operation prior to December 2006). Also, because only the most recent year's carrier profile was available, carrier characteristics may not match characteristics at the time of the crash (i.e., carriers may have increased fleet size, changed type of operation, etc.).

Profile information for intrastate carriers, obtained from the Texas Department of Transportation (TxDOT), Motor Carrier Division, had similar limitations. The intrastate motor carrier database contained only active carriers at the time of the data request (December 2006) and did not reflect changes over time in carrier characteristics (i.e., fleet size, etc.).

Additional limitations to the intrastate carrier profile information were more significant and included: (1) a reduced set of carrier profile variables and (2) a lack of common carrier identifier as compared to the MCMIS Crash and Census File.

The number of data elements collected from intrastate carriers was not as extensive as that collected for interstate carriers. No driver or vehicle characteristic information was available for intrastate carriers in TxDOT's intrastate motor carrier database. With respect to cargo characteristics, the MCMIS Census File categorizes more than 30 types of commodities while TxDOT's intrastate motor carrier database includes only three: tow truck, household goods, and hazardous materials. Similarly, TxDOT's intrastate motor carrier database include the number of power units/trucks owned by a carrier but does not distinguish between owned, term-leased, or trip-leased vehicles. No information is maintained on trailers used in intrastate operation. Consequently, much of the data set relating to intrastate operation was treated as missing data.

The lack of a common carrier identifier, such as a USDOT number, between the MCMIS Crash File and TxDOT's intrastate motor carrier database required significant effort to combine the two data sets. Intrastate carrier information was first automatically matched to the MCMIS Crash File using exact Carrier Name cell entries. Different first/last name order, use of company or owner names, misspellings, and use of punctuation and abbreviations produced few matches using this automatic procedure. Hence, researchers manually matched intrastate carrier profile information to crash data using a series of decision rules related to the similarity in carrier name between the two data sources, uniqueness of carrier name, carrier city location, neighboring city proximity, street address, etc. Despite efforts to use consistent decision rules, this manual matching process was highly subjective. In addition, this process may have biased the data towards larger carriers. A "match" was typically identified when both the carrier name and address were confirmed to be the same; if the carrier name was not particularly unique (i.e., Gonzales Trucking) and the addresses listed in the MCMIS Crash File and TxDOT's intrastate motor carrier database differed, no match was assumed. Smaller carriers, particularly owner-operators, may have more frequent changes of address than larger carrier and hence, may have had a higher rate of omission due to non-match in this dataset. Overall, this combined automatic and manual matching process provided additional intrastate carrier profile data for 4,962 out of 10,391 intrastate carrier-involved crashes (47.8 percent).

Also, it should be noted here that much of the information related to agricultural commodity movement is omitted from the carrier data. The agricultural industry is exempt from many of the formal regulatory and reporting requirements at State and Federal levels. For example, under the Federal Motor Carrier Safety Regulations (FMCSRs), agricultural exemptions exist related to controlled substances and alcohol use and testing; qualification of drivers; hours of service of drivers; commercial driver's license standards, requirements and penalties; vehicle parts and accessories necessary for safe operation; vehicle inspection, repair and maintenance; and employee safety and health standards. The Texas Administrative Code includes additional exemptions related to maximum widths, lengths, and weights of vehicles transporting agricultural commodities. These differences in regulation and subsequent reporting at both the State and Federal levels, results in a dearth of agricultural-related data.

METHODOLOGY

Prior to crash severity model development, general descriptive statistics describing large trucks crash characteristics were examined. The descriptive statistics considered crash, driver, vehicle, cargo, carrier and operating environment characteristics. Descriptive findings were expressed using histograms, pie charts, tables, and spatial maps to most clearly display the general trends of large truck crashes in the state of Texas. Findings are detailed in Chapter 4.

Review of Previous Methods to Model Crash Severity

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

Univariate Methods. Univariate statistical methods used in earlier studies include cross-tabulation, correlation analysis and hypothesis testing using the mean and variance of specific factors (Blomquist and Carson 2001). Cross-tabulation methods and the chi-squared test have been used by Brorsson et al. (1993) and Holubowycz et al. (1994) to compare the distributional differences among crash severity levels to identify high-risk groups. In particular, Holubowycz et al. (1994) investigated the relationship between severity levels, blood alcohol concentration (BAC), and various age and gender categories using the chi-square and t-test to confirm whether the noted differences were significant in comparison to the total population. Mercer (1987) used correlation analysis to examine the relationship between crash severity levels and alcohol and restraint device use to identify factors significantly contributing to specific severity levels. A study by Malliaris et al. (1996) used hypothesis testing with the mean and variance of light-vehicle occupant ejection factors, to test for significant differences among crash severity levels.

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

Multivariate Methods. Multivariate statistical methods allow analysis of several variables concurrently, overcoming the shortcoming of univariate methods. Shao (1987) used multivariate analysis techniques to identify a set of variables that assist in distinguishing crash severity levels. Evans (1986) used double-pair comparisons to determine the affect of vehicle occupant characteristics on the fatality risk in traffic crashes and Lassarre (1986) used time series approaches to develop a predictive model of crash severities utilizing traffic volume, speed, and seat belt use.

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

Logit Models. Several variations of logit models have been utilized to analyze crash severity including, binomial, multinomial, nested, and ordered logit. Binomial logit regression has been used frequently to analyze crash severity (Jones and Whitfield 1988, Shibata and Fukuda 1994, Lui et al. 1988). However, this method does not have the ability to compare between more then two levels of severity. For example, binomial logit models in the case of crash severity, can only distinguish between fatal and non-fatal severity levels. This does not allow for analyzing fatal, injury, and property damage only (PDO) severity levels, which is typically how crash severity is categorized.

Although multinomial logit models predict crash severity effectively, a problem was discovered related to the independence of error terms between severity levels. In order to address this inadequacy, the nested logit model was utilized in studies completed by Shankar et al. (1996) and Chang and Mannering (1998). This model grouped the possible correlated error terms into a "nest" by estimating a model when only individuals choosing the nested alternatives were included (Blomquist and Carson 2001).

Yet another variation, O'Donnell and Conner (1996) used the ordered logit model to identify the factors that increase the probabilities of serious injury and death. In the same study, researchers applied ordered probit methods to the same set of data to directly compare between the two model forms.

Ordered Probit Models. O'Donnell and Conner (1996) found that the main difference in theory between using the ordered probit model and the ordered logit model was in the error assumptions. In addition, although both methods developed comparable results in regards to crash severity (magnitude and direction of significance), the logit model always had higher coefficient estimates than the probit model. This led the researchers to the determination that the probit model would always predict a lower severity.

Blomquist and Carson (2001) investigated the use of ordered probit and multinomial logit models to identify specific weather-related impacts on crash severity. The nature of the debate over the appropriate analytical method for modeling crash severity data centers on whether the data classification indicates an order of response (i.e., there is a progression in the rank of the severity of an crash in such a manner that a fatality crash is considered more severe than an injury crash which is in turn more severe than a property damage only crash). Though intuitive that some inherent order exists in crash severity data, multinomial logit regression has been more widely applied.

> "Both models produced probabilities that were similar in order and magnitude to each other and were relatively accurate when compared to observed crash severity. With neither model showing much of a clear quantitative edge over the other, judgment as to which is more appropriate for modeling crash severity was based primarily on qualitative assessments. These qualitative assessments included ease of model estimation, ease of interpretation of results and the relative effect any of the specification issues may have had on model results. Regarding ease of model estimation and interpretation of results, the ordered probit model was superior to the multinomial logit model. The process of estimating the ordered probit model was much less time consuming than that for the multinomial logit model. Additionally the coefficients reported for the ordered probit model could be directly interpreted as a result of its simpler model form" (Blomquist and Carson 2001).

Most recently, Burke et al. (2002) successfully used ordered probability theory to identify key driver, vehicle, cargo, and carrier characteristics affecting large truck safety in the State of Montana.

Recommended Methodology

Given the most recent findings from Burke et al. (2002), Blomquist and Carson (2001) and to a lesser extent O'Donnel and Conner (1996), crash severity for this investigation was modeled using ordered probit regression. Ordered probit models define an unobserved variable, z, such that:

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

where

- β is a vector of estimable regression parameters determined by maximum likelihood methods,

- **X** is a vector of measurable factors (e.g., driver age, vehicle configuration, truck fleet size, etc.) that define ranking and

- ε is a random error term assumed to be normally distributed.

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

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

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

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

where

- y is the actual or observed severity level and

- μ is an estimable parameter that defines y.

For this effort:

$y = 0$, represents the severity level fatality,

$y = 1$, represents the severity level injury and

$y = 2$, represents the severity level property damage only.

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

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

where ln L_b is the log-likelihood at model convergence and ln L_0 is the initial log-likelihood. Values for ρ^2 range between zero and one, with one representing a perfect model (Mannering 1994).

Significance of Model Variables. A two-sided t-test is used to verify the significance of each model variable. A model variable is considered significant if its estimated coefficient, β_i is proven not equal to zero at a sufficiently high level of confidence. The level of confidence used for this investigation was 90 percent, which corresponds to a t-statistic $\geq|1.645|$. A two-sided t-test is used because model variables having both a significant positive relationship to crash severity and a significant negative relationship are of interest to this investigation.

The two-sided t-test assumes a normal distribution for the variation in value of model coefficients resulting from unobserved effects. Application of the two-sided t-test to estimated coefficients from the ordered probit model is more easily justifiable due to the assumed normal distribution of its error terms than for the multinomial logit model with assumed generalized extreme value distributed error terms (Blomquist and Carson 2001).

IMPLICATIONS FOR THIS INVESTIGATION

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

Challenges still exist with respect to large truck safety data, however. Although the number of data elements available for this investigation showed promise, much of the data was missing from the data set. In particular, data related to intrastate carrier operations was limited because it was either not collected or it could not be confirmed as a match given carrier identifier limitations between the MCMIS Crash File and TxDOT's intrastate motor carrier database. Agricultural movements are also omitted from this data set due to differences in regulatory and reporting requirements. Further, timeline inconsistencies between the MCMIS Census File that reflects active carriers at the time of the data request and the MCMIS Crash File that includes crashes occurring between 2004 and 2006 may introduce some error to the model development process. Lastly, the structure of the final combined dataset results in a number of repeat measures related to carrier characteristics; if a carrier has been involved in more than one crash between 2004 and 2006, the same carrier characteristics are repeated for each crash. Repeat measures may compromise the explanatory power of the statistical model.

CHAPTER 4.
RESULTS

This Chapter details the findings related to large truck safety in Texas. Specifically, this Chapter provides summary statistics related to crash, driver, vehicle, cargo, carrier, and operating environment characteristics and reveals statistically significant factors affecting large truck crash severity. This Chapter concludes with a discussion of the implications of these results for safety regulatory and enforcement efforts in Texas.

DESCRIPTIVE STATISTICS

Descriptive statistics are categorized by driver, vehicle, cargo, carrier, and operating environment characteristics. The descriptive statistics consider the full data set comprising 44,012 crash records documented over a three-year period, from January 1, 2004 to December 31, 2006 (see Figure 1). The majority of these crashes (65.98 percent) involved two vehicles although a sizeable number of crashes (8,420 or 19.13 percent) involved a single vehicle (see Figure 2). Not surprisingly, the majority of these crashes resulted in property damage only (PDO, 57.04 percent), with injury and fatality crashes comprising 39.84 percent and 3.13 percent, respectively (see Figure 3).

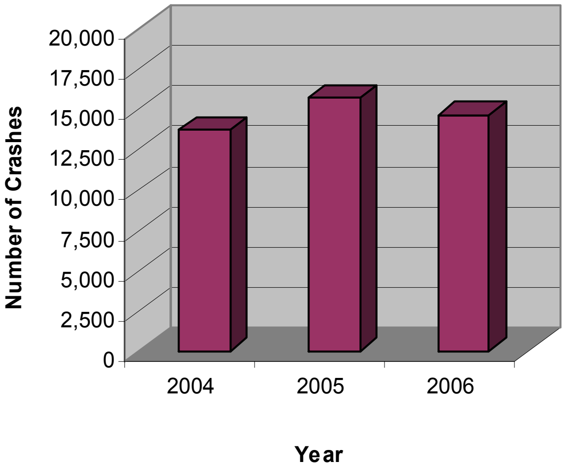

Figure 1. Texas Crashes by Year

Note that none of the findings reported in this Chapter have been normalized to reflect prevalence of use, miles traveled, etc.

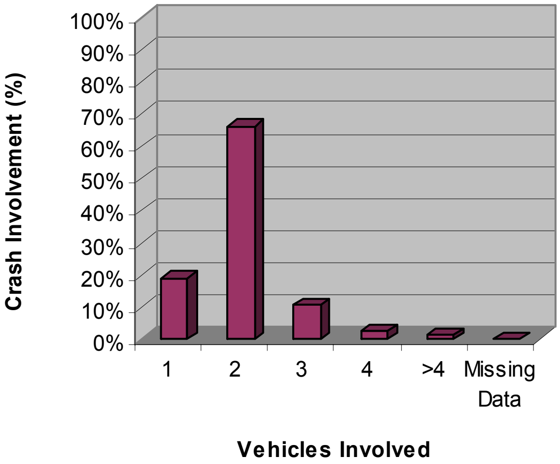

Figure 2. Texas Crashes by Number of Vehicles Involved

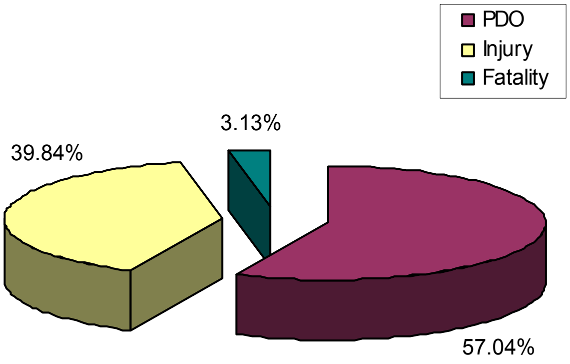

Figure 3. Texas Crashes by Severity

Driver Characteristics

Observed large truck crashes involved local and long-distance drivers (i.e., authorized to operate within and beyond 100 miles) in almost equal proportions (45.16 and 54.54 percent, respectively, see Figure 4). Crash involvement based on commercial driver licensing (CDL) mimicked previously published findings related to carrier size; small carriers with less than 100 CDL drivers and large carriers with greater than 10,000 CDL drivers were involved in 28.11 percent and 3.36 percent of observed crashes, respectively (see Figure 5).

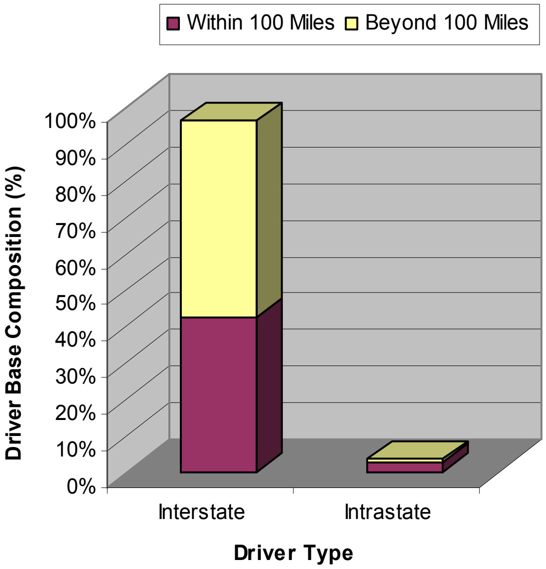

Figure 4. Texas Crashes by Driver Composition

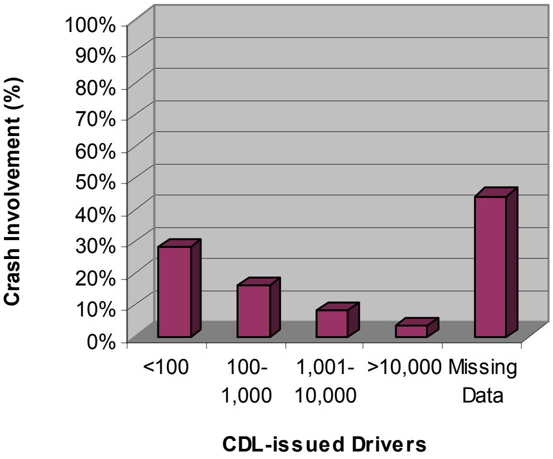

Figure 5. Texas Crashes by Number of CDL-issued Drivers

Vehicle Characteristics

The majority of large trucks included in this sample were licensed in the state of Texas (71.82 percent) (see Figure 6). The remaining sample proportion comprised trucks licensed in 48 other U.S. states, 7 Canadian provinces, 5 Mexican states, and one Central American country. When considered individually, trucks licensed in other states or provinces generally made up less than one percent of the overall sample. Exceptions included the U.S. states of Oklahoma, Illinois, Indiana, Tennessee, Louisiana, Missouri, and California.

The predominant (57.11 percent) type of large truck involved in crashes in Texas, reflective of its prominence in operation, is a five-axle, tractor semi-trailer (see Figure 7). Secondary truck types involved in crashes included single-unit, two-axle trucks (15.18 percent), single-unit, three-axle trucks (10.65 percent), and truck trailer combinations (11.19 percent).

Likely related to the commonality of truck type, trucks greater than or equal to 26,000 pounds were involved in the highest percentage (76.11 percent) of large truck crashes (see Figure 8). Trucks with a gross vehicle weight rating of 10,001 to 26,000 pounds comprised an additional 19.77 percent of observed crashes.

Cargo body types involved in crashes showed somewhat greater diversity across the sample (see Figure 9). Van/enclosed box body styles were involved in 35.07 percent of the crashes. Flatbed, dump, and cargo tank body styles were involved in 18.24 percent, 11.00 percent, and 7.84 percent of crashes, respectively. A sizeable proportion of the sample denoted cargo body type as *Not Applicable*; the interpretation of this classification by enforcement officials is uncertain.

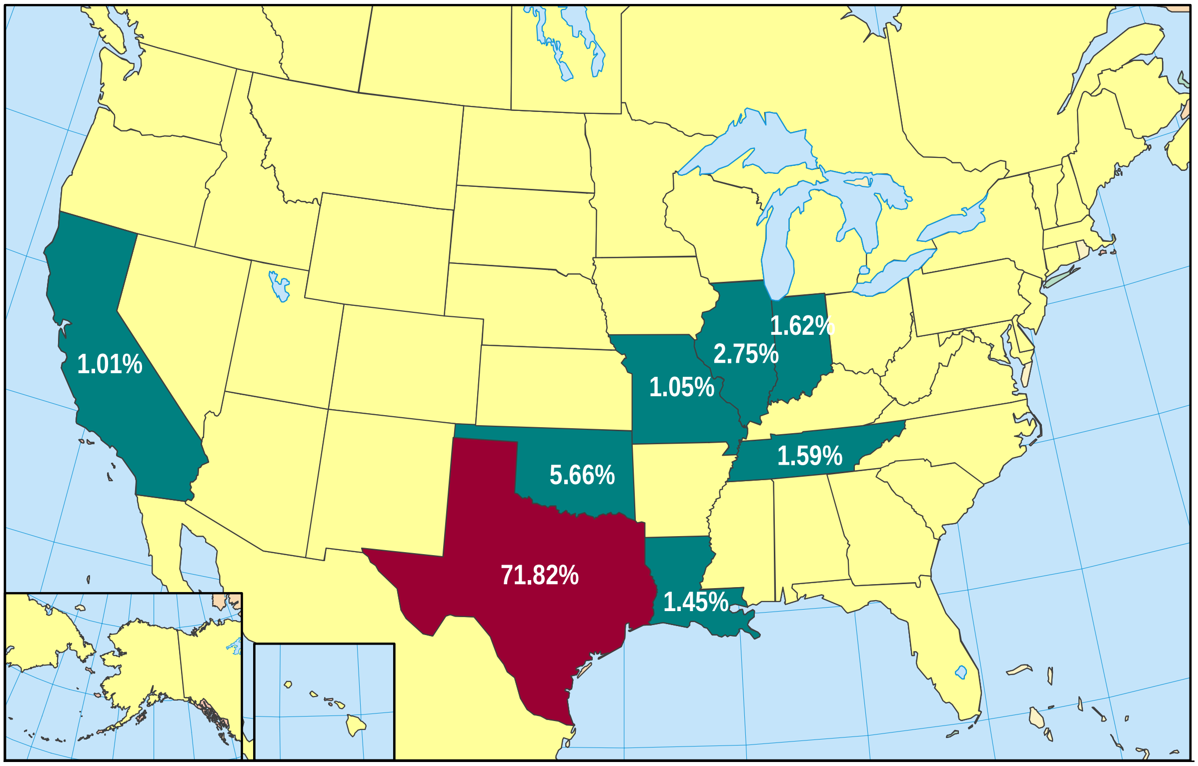

Figure 6. Texas Crashes by Vehicle License State

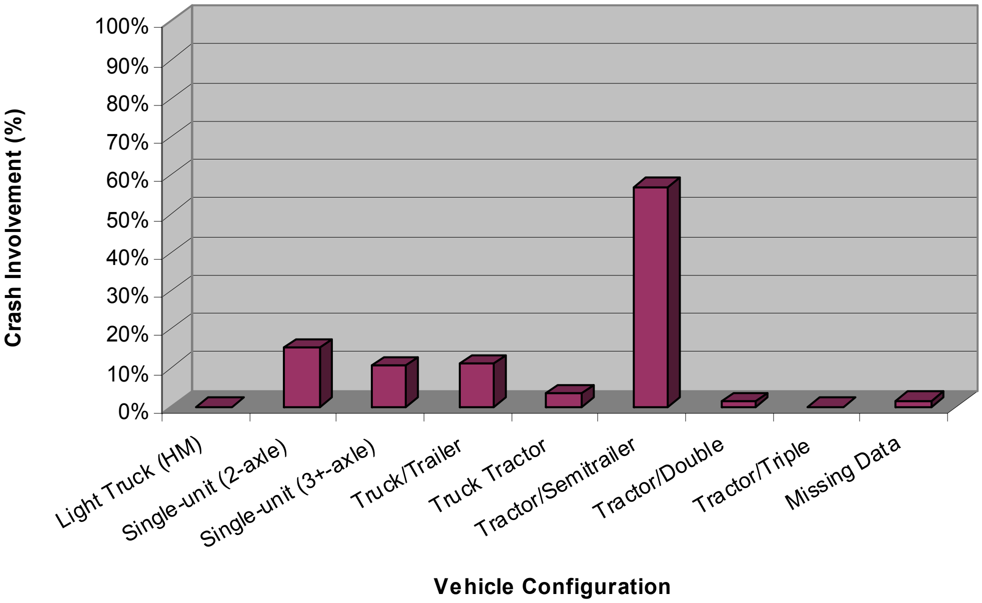

Figure 7. Texas Crashes by Vehicle Configuration

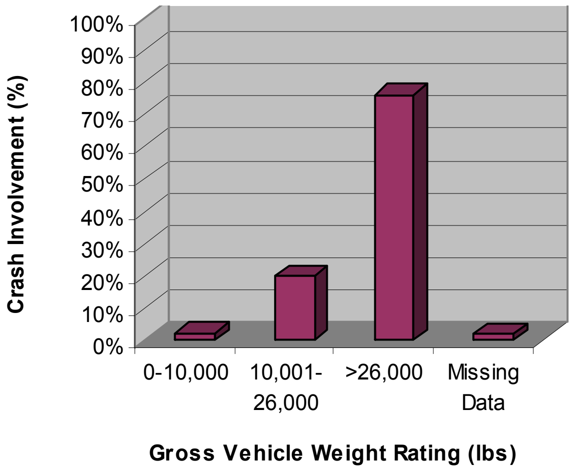

Figure 8. Texas Crashes by Gross Vehicle Weight Rating

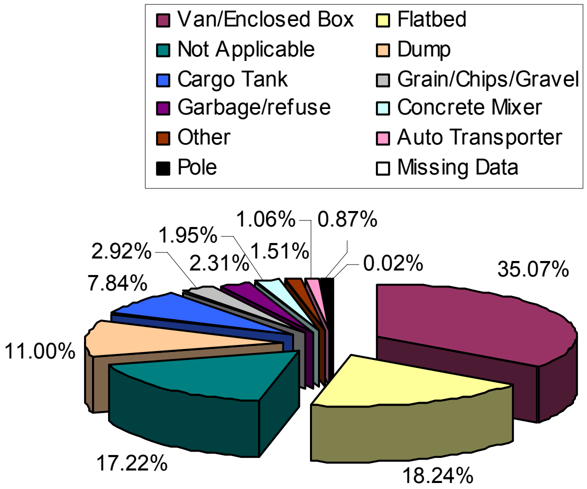

Figure 9. Texas Crashes by Cargo Body Type

Cargo Characteristics

General freight comprises the largest share of cargo types involved in large truck crashes in Texas (13.10 percent, see Table 2). Building materials; household goods; paper products; machinery; sheet, coil, or roll metal; and chemicals were also commonly involved (ranging from 4.06 percent to 5.34 percent) in the sample of observed crashes. Agricultural movements, such as fresh produce (3.39 percent), grain/feed/hay (2.29 percent), and livestock (0.57 percent) are likely underrepresented here; the agricultural industry is exempt from many of the formal reporting requirements and as such, this data may be lacking.

Table 2. Texas Crashes by Cargoes Carried

CARGO	PERCENT	CARGO	PERCENT
General Freight	13.10%	Meat	2.48%
Other	5.38%	Construction	2.32%
Building Materials	5.34%	Grain, Feed, Hay[1]	2.29%
Household Goods	5.33%	Oilfield Equipment	2.08%
Paper Products	4.70%	Motor Vehicles	1.52%
Machinery, Large Objects	4.49%	Farm Supplies	1.14%
Sheet, Coil, Roll Metal	4.33%	U.S. Mail	0.95%
Chemicals	4.08%	Driveaway, Towaway	0.92%
Beverages	3.74%	Garbage, Refuse, Trash	0.63%
Liquids, Gases	3.74%	Livestock[1]	0.57%
Refrigerated Food	3.69%	Utility	0.48%
Dry Bulk Commodities	3.44%	Coal, Coke	0.25%
Fresh Produce[1]	3.39%	Passengers	0.23%
Logs, Poles, Beams, Lumber	3.36%	Water Well	0.12%
Intermodal Containers	2.66%	Mobile Homes	0.09%
		Missing Data	13.14%

[1] Likely underreported due to differences in regulatory and reporting requirements for agricultural movements.

Carrier Characteristics

The majority of carriers operating the large trucks observed in this sample had physical addresses outside of the state of Texas; Texas-based carriers comprised only 38.53 percent of the sample (see Figure 10). The remaining sample proportion comprised carriers based in 47 other U.S. states, 8 Canadian provinces, and 10 Mexican states. When considered individually, carriers based in other states or provinces generally made up less than one percent of the overall sample. Exceptions included the U.S. states of Arkansas, Oklahoma, Louisiana, Tennessee, Florida, Arizona, Illinois, Missouri, California, and Indiana.

More than half (50.32 percent) of the large truck crashes observed involved interstate carriers (see Figure 11). Intrastate carriers, including hazardous material carriers, were involved in 15.10 percent of observed crashes although a high proportion of missing data (31.79 percent) suggests that this involvement rate may be underestimated. Nearly 40 percent (38.98 percent) of these carriers are classified as *Authorized-for-Hire* (see Figure 12). Carriers classified as *Private Property* carriers were involved in 14.18 percent of the observed crashes. Again, the high proportion of missing data (40.79 percent) suggests that various carrier classifications, particularly those more predominant in intrastate operations, may be underrepresented.

Carrier size can be described by a variety of factors, including fleet size or driver base. In the sample of observed crashes, 37.00 percent and 27.24 percent of crashes involved small carriers with less than 100 power units and less than 100 drivers, respectively (see Figures 13 and 14). Large carriers, with greater than 10,000 power units and greater than 10,000 drivers were involved in 3.20 percent and 3.55 percent of observed crashes, respectively. The majority of crash-involved trucks, tractors, and trailers were owned by the carriers; significantly fewer

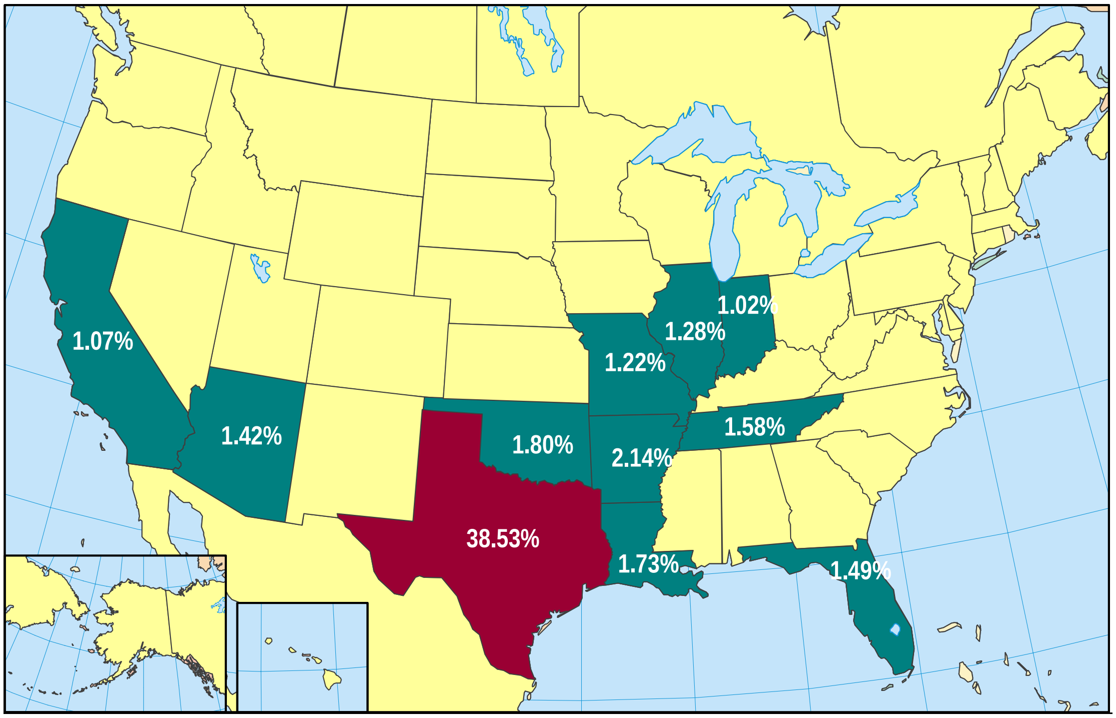

Figure 10. Texas Crashes by Carrier State

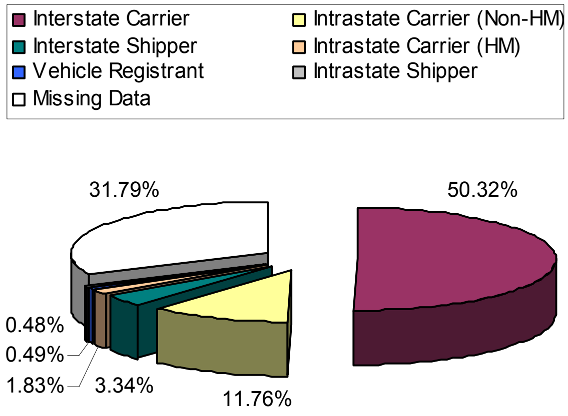

Figure 11. Texas Crashes by Carrier Operation

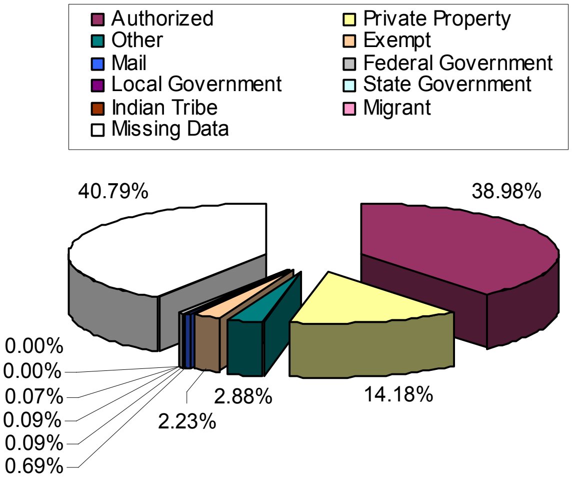

Figure 12. Texas Crashes by Carrier Classification

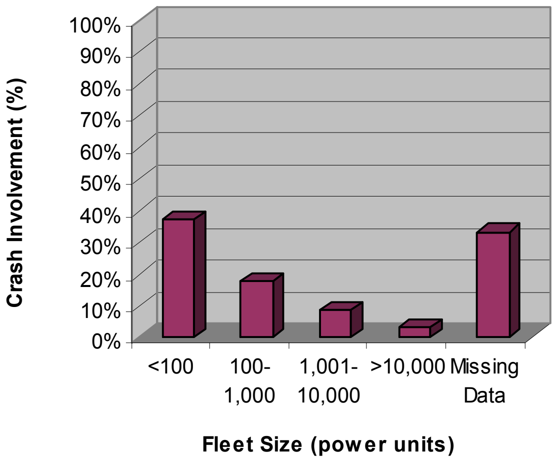

Figure 13. Texas Crashes by Fleet Size

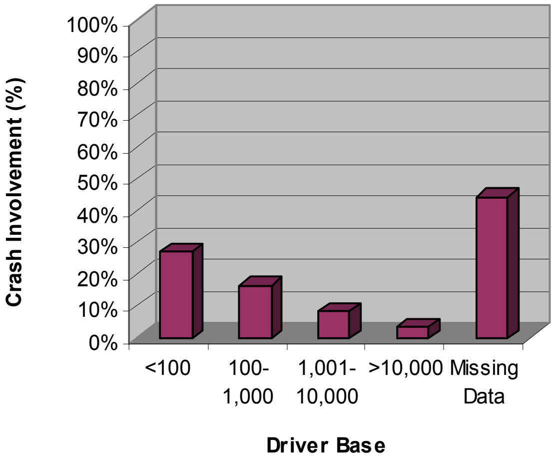

Figure 14. Texas Crashes by Driver Base

vehicles were term-leased and trip-leased, respectively (see Figure 15). Carriers with a low utilization of trip-leased drivers (i.e., less than 10 per month) were involved in the majority (55.55 percent) of observed crashes (see Figure 16).

With respect to a carrier's safety regulation or enforcement experience, 36.37 percent of carriers involved in crashes had undergone compliance reviews as their most recent type of review (see Figure 17). A significantly smaller proportion (1.45 percent) of carriers had undergone safety reviews most recently. Outcomes of these reviews were very positive (see Figure 18). More than 90 percent (91.02 percent) of carriers who had undergone a review were rated as satisfactory (37.18 percent of the overall sample). Less than one percent (0.42 percent) of reviewed carriers were rated as unsatisfactory (0.17 percent of the overall sample).

Approximately 60 percent of the carriers involved in crashes had either not undergone any type of review or this data was missing from the data set. In addition, the time elapsed since a

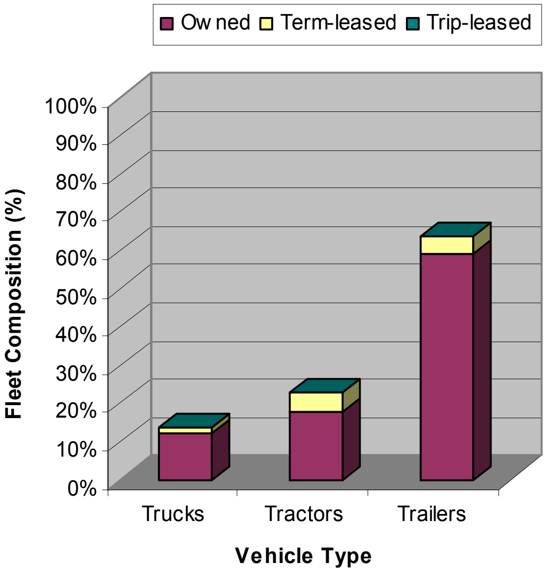

Figure 15. Texas Crashes by Fleet Composition

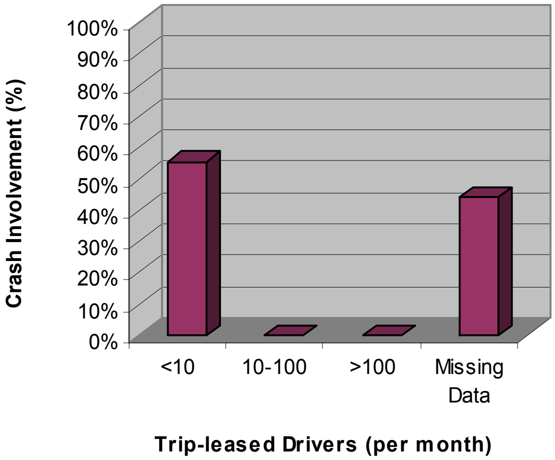

Figure 16. Texas Crashes by Number of Trip-leased Drivers

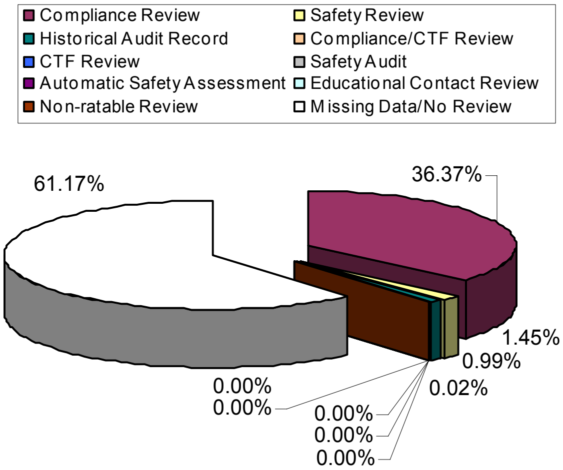

Figure 17. Texas Crashes by Type of Latest Review

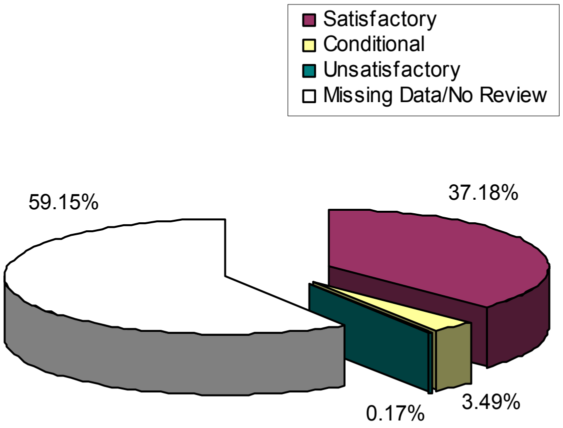

Figure 18. Texas Crashes by Safety Review Rating

carrier’s most recent review was in some cases lengthy (see Figure 19). Of the crashes involving carriers who had previously been reviewed, 15.95 percent of the reviews preceded the crash by more than 10 years (6.51 percent of the overall sample). More than 40 percent (40.62 percent) of the crashes involving reviewed carriers had reviews between one and 10 years prior (16.66 percent of the overall sample). When the crash preceded the review, 13.50 percent and 13.72 percent of crashes were followed by a review within 10 years and within one year, respectively (5.51 percent and 5.60 percent of the overall sample).

Consistent with findings related to review outcomes, carriers with lower historical crash rates were involved in a higher proportion of observed crashes. Carriers with a recordable crash rate less than one and one to five were involved in 29.84 percent and 7.24 percent of the total observed crashes, respectively (see Figure 20).

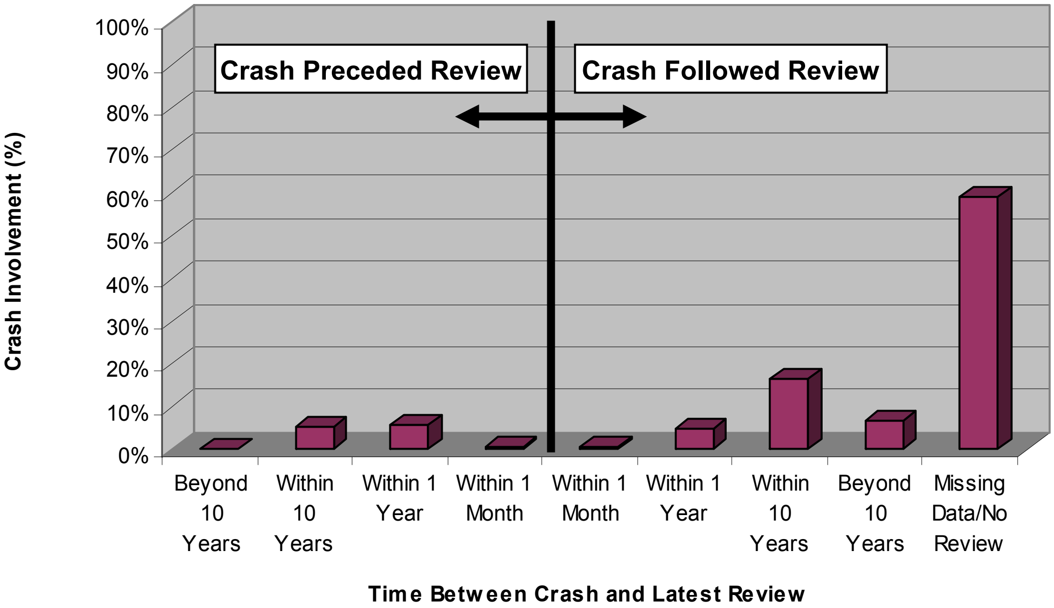

Figure 19. Texas Crashes by Elapsed Time Between Crash and Review

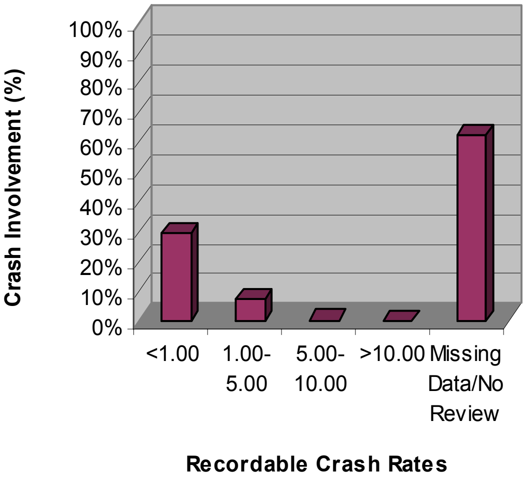

Figure 20. Texas Crashes by Recordable Crash Rate

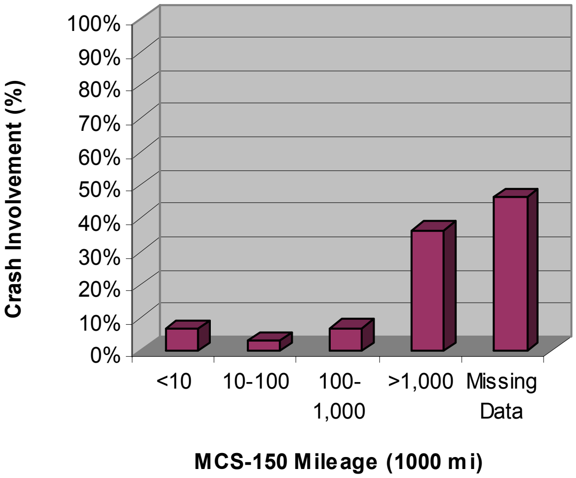

Figure 21. Texas Crashes by MCS-150 Mileage

Suspected more of contributing to crash frequency rather than crash severity, carriers reporting greater than 1,000,000 fleet miles per year were involved in 36.45 percent of the total observed crashes (see Figure 21). Carriers reporting between 10,000 and 100,000 fleet miles per year had the lowest crash involvement rate (3.11 percent) in the observed sample.

Operating Environment Characteristics

Operating environment characteristics have been proven to be influential in large truck safety. For this investigation however, these factors are secondary in interest to driver, vehicle, cargo, and carrier characteristics.

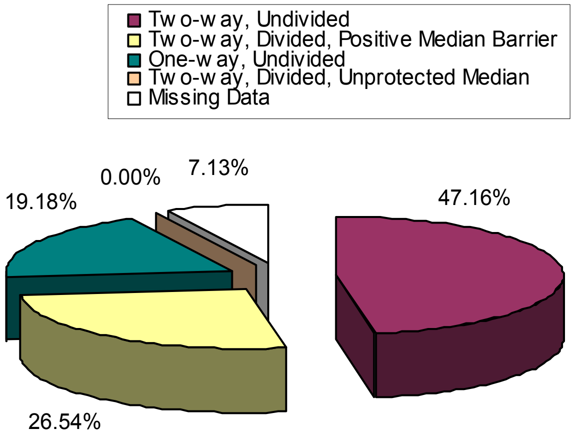

Figure 22. Texas Crashes by Trafficway

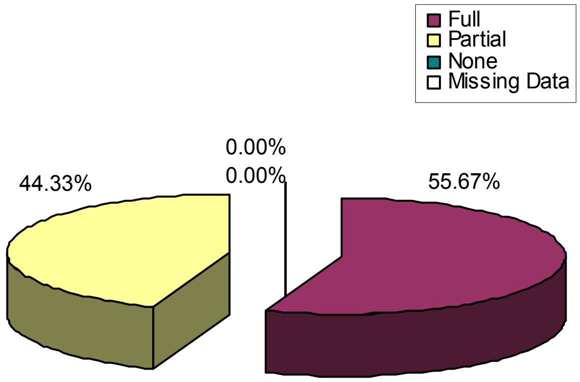

Figure 23. Texas Crashes by Access Control

With respect to roadway facility characteristics, nearly half (47.16 percent) of the crashes occurred on undivided, two-way roadways (see Figure 22) and 55.67 percent occurred on roadways with full access control (see Figure 23).

Nearly 75 percent (74.27 percent) of the crashes occurred during daylight hours (see Figure 24). Similarly, the majority of crashes occurred between 6 AM and 6 PM with no pronounced peak throughout the day (see Figure 25). These results likely reflect the time of day that most travel occurs and does not take into account crash exposure considerations.

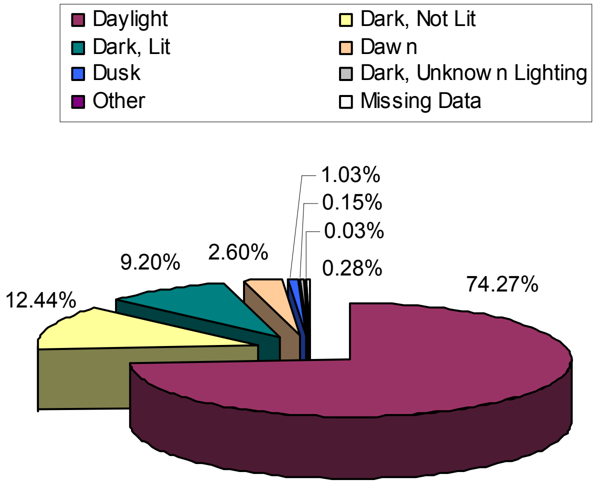

Figure 24. Texas Crashes by Light Conditions

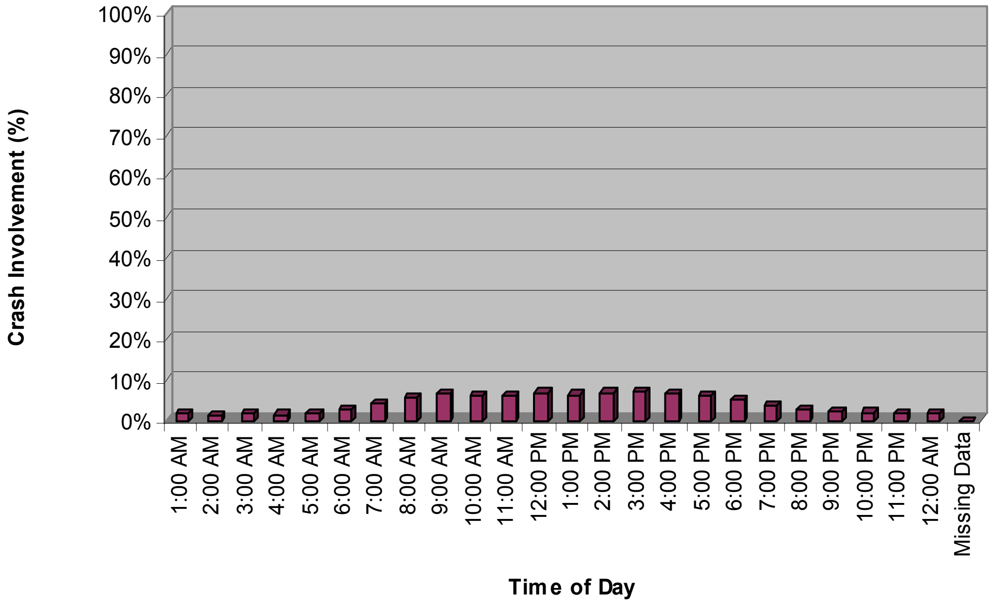

Figure 25. Texas Crashes by Time of Day

The majority (86.86 percent) of observed large truck crashes occurred when no adverse weather conditions existed (see Figure 26). Of the approximately 13 percent of the crashes attributable to adverse weather, 9.88 percent were rain-related. Since Texas experiences moderate temperatures throughout the year, it is not surprising that adverse weather (snow, sleet, ice, etc.) does not play a larger role in large truck crashes.

Closely related to weather conditions, adverse roadway surface conditions were also found to contribute little to large truck crash occurrence (see Figure 27). More than 83 percent (83.91 percent) of the crashes occurred during dry road conditions and an additional 13.89 percent occurred when the roadway was wet. Only 1.49 percent of large truck crashes were attributed to icy road conditions. Consistent with these findings, the proportion of crashes occurring per month throughout the year is relatively constant (see Figure 28).

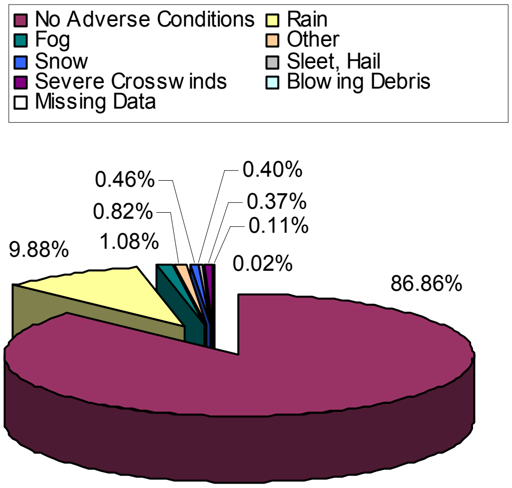

Figure 26. Texas Crashes by Weather Conditions

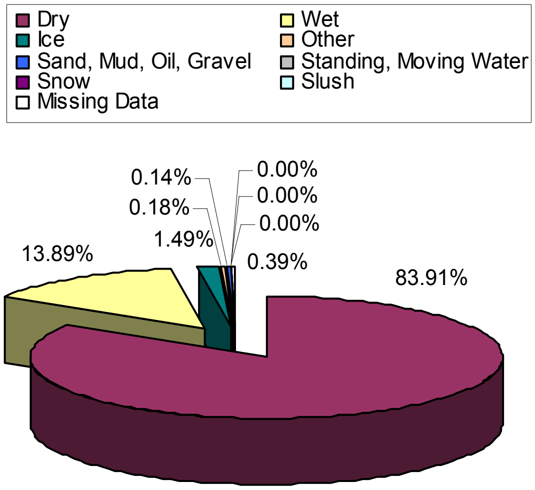

Figure 27. Texas Crashes by Road Surface Conditions

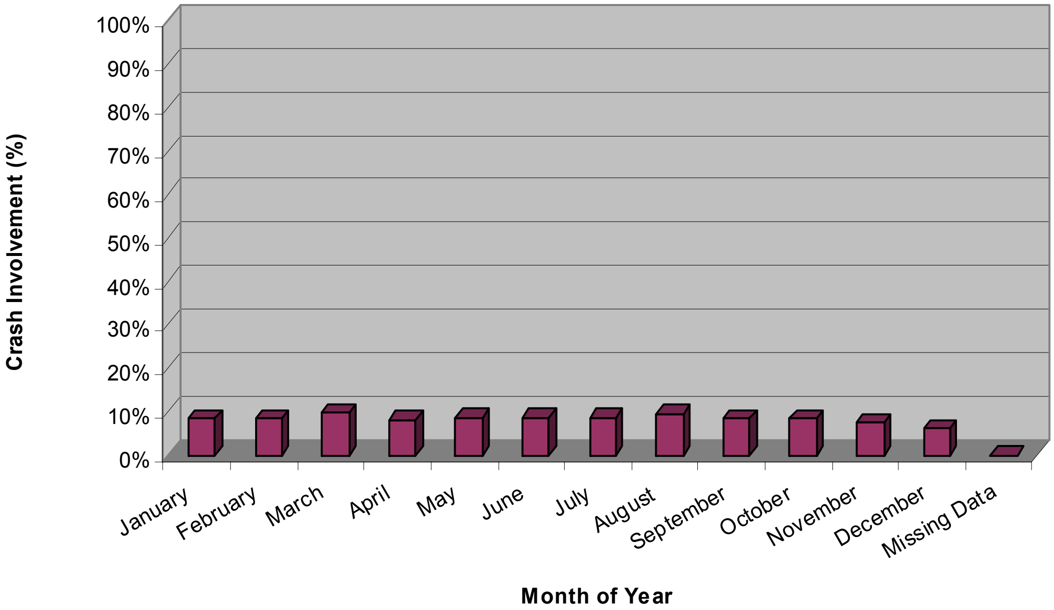

Figure 28. Texas Crashes by Month of Year

CRASH SEVERITY MODEL

Large truck crash severity was modeled using ordered probit regression and standard maximum likelihood methods. Missing data, particularly for intrastate carriers, was a limiting factor in this modeling exercise. From the 44,012 large truck crashes in the original three-year sample, 24,099 crashes had sufficiently complete data for model estimation. This section details the factors found to significantly affect large truck crash severity and discusses the overall model's success in accurately describing the sample data (i.e., model goodness of fit).

Significant Factors Affecting Large Truck Severity

Because the data set was coded such that 0=fatality, 1=injury and 2=property damage only, a positive estimated coefficient (β_i) decreases the likely severity of a crash. Conversely, a negative coefficient increases the likely severity of a crash. Variables were retained in the estimated model if they had an estimated t-statistic of $\geq|1.645|$ denoting a confidence level of 90 percent. Specific vehicle, cargo, carrier, crash, and operating environment characteristics affecting large truck crash severity are summarized in Table 3 and detailed below. Note that no driver-related characteristics were found to significantly affect large truck severity in this investigation.

Table 3. Ordered Probit Model Results

VARIABLE		ESTIMATED COEFFICIENT, β	T-STATISTIC
Constant		2.02656448	71.672
Vehicle License State	Mexico	0.22981373	2.740
	California	0.15659205	2.305
Vehicle Configuration	Single-unit, three axle	-0.06987720	-2.053
	Truck Tractor (Bobtail)	-0.08803110	-2.234
Cargo Body Type	Tank	-0.08213026	-3.170
Cargo Classification	Driveaway/Towaway	0.06722387	1.674
	Mobile Homes	0.29774333	2.326
	Livestock	0.08756263	1.667
	Grain, Feed, Hay	-0.06127432	-2.128
	Beverages	0.04624574	2.040
Carrier State	Arizona	0.07609348	1.786
	Illinois	-0.14659194	-2.697
	Oklahoma	0.15332126	3.346
Carrier Classification	Private Property	-0.03301011	-1.828
Fleet Composition	Owned Trailers	0.401483E-05	4.356
Crash/Operating Environment	Number of Vehicles	0.01598364	1.666
	Fog	-0.12906938	-1.809
Threshold Value, μ		1.83465427	96.109
Initial Log Likelihood		-18,237.07	
Log Likelihood at Convergence		-18,183.77	
Number of Observations		24,099	

Vehicle Characteristics. The effect of vehicle characteristics on large truck safety has been the focus of numerous previous investigations. This study identified factors related to vehicle license state (or country), vehicle configuration, and cargo body type as either increasing or decreasing the predicted severity of large truck-involved crashes. Unlike previous studies that consistently identified a vehicle's gross vehicle weight (GVW) as a contributing factor for large truck crash severity, this study did not confirm such a relationship.

Variable: Vehicle License State–Mexico, California
Result: Decreased Severity of Crash

Vehicles licensed in both Mexico (no distinction was made by Mexican state) and California were predicted to have less severe crashes in this investigation. Vehicles from these locations were involved in a small proportion of overall observed crashes; 0.57 percent and 1.01 percent, respectively. At first, this finding seems counterintuitive; Mexican vehicles are often presumed to be less safe because of that country's limited historical regulatory requirements and oversight. However, Mexican carriers are largely limited to local/drayage operations within the commercial border zones and may be subject to higher scrutiny by U.S. regulatory and enforcement personnel. This operational limitation and increased regulatory and enforcement scrutiny likely explain the reduced severity levels observed here. An explanation regarding reduced severity levels for California-licensed vehicles is not immediately intuitive.

Variable: Vehicle Configuration–Single-unit/Three-axle Truck, Truck Tractor (Bobtail)
Result: Increased Severity of Crash

With respect to vehicle configuration, large trucks involved in long-haul, higher speed operations carrying sizable cargo loads were initially thought to result in the highest severity crashes. In particular, based on their prior focus in the literature, longer combination vehicles (LCVs), including tractor/double trailer and tractor/triple trailer combinations, were suspected of contributing to more severe crashes. Instead, this study found that small trucks, likely operating in more local, urbanized, controlled-speed areas, were likely to be involved in higher severity crashes. Specifically, this study observed single-unit, three-axle vehicles to have a higher predicted crash severity; prior studies noted a similar relationship for single-unit, two axle trucks. Single-unit, three-axle vehicles were involved in 10.65 percent of the overall observed crashes.

Truck tractors traveling without a trailer (bobtail) were also found to result in higher severity crashes. This vehicle type may experience less stability when performing evasive maneuvers just prior to a crash, resulting in a higher occurrence of rollover. This propensity for rollover likely contributes to the increased predicted severity of a crash. Truck tractors were involved in 3.27 percent of the overall observed crashes.

Variable: Cargo Body Type–Tank
Result: Increased Severity of Crash

Stability issues may also explain the predicted likelihood of higher severity crashes with tank-style trailers. Tank trailers, designed to transport liquid cargoes, may experience less stability when performing evasive maneuvers just prior to a crash because of liquid "slosh" effect. Despite attempts to increase the stability of these cargoes, primarily through the use of interior baffles, these vehicles may experience a higher occurrence of rollover leading to more severe crashes. Previous studies have confirmed higher crash rates for tank trailers, but no related findings were uncovered related to crash severity. Tank trailers were involved in 7.84 percent of the overall observed crashes.

Cargo Characteristics. Despite the significance of the tank trailer cargo body type described above, bulk liquid cargoes were not found to significantly affect large truck crash severity. In fact, few of the cargoes initially thought to result in more severe large truck crashes were confirmed in this investigation. It was hypothesized early on that cargoes that are difficult to package and secure, are relatively heavy, and may shift in transport (i.e., logs, machinery, liquids, livestock, coal, etc.) would result in higher severity crashes. With the exception of livestock, none of the suspected cargoes were confirmed as contributing to large truck severity levels. Further, the observed effect of livestock transport on large truck crash severity levels is contrary to expectation.

Variable: Cargo Classification-Driveaway/Towaway, Mobile Homes, Livestock, Beverages
Result: Decreased Severity of Crash

With the exception of beverage-related cargoes, each of the cargoes identified as decreasing the likely severity of large truck crashes were involved in less than one percent of the total observed crashes. (Note that the crash involvement rate for livestock transport may be underestimated because of differing reporting requirements for agricultural movements.) Beverage-related cargoes were involved in 3.74 percent of the total observed crashes.

As mentioned previously, the positive effect of livestock transport on large truck crash severity is surprising given the shifting nature of the cargo. Also surprising is the similar effect observed for driveaway/towaway and beverage transport. While these cargoes don’t exhibit any of the traits thought to contribute to more severe large truck crashes (i.e., difficulty in packaging and securing, excessive weight, shifting load), these types of cargoes were thought to be transported predominantly in smaller trucks operating locally. In apparent conflict with these cargo-related findings, this investigation observed single-unit, three-axle vehicles to have a higher predicted crash severity.

The involvement of mobile home transport in less severe crashes is more intuitive. Mobile home transport is a relatively infrequent and highly visible operation, often accompanied by leading and trailing pilot cars if the cargo is oversized. This increased visibility may allow other drivers time to react appropriately (i.e., decelerate) to reduce severity just prior to a crash. Further, mobile homes are relatively light in weight and collapsible upon impact, further reducing the threat of serious injury.

Variable: Cargo Classification - Grain/Feed/Hay
Result: Increased Severity of Crash

The transport of grain, feed, and hay (categorized as a single cargo type) was predicted to result in an increased severity for large truck crashes. Grain/feed/hay transport comprised 2.29 percent of the overall observed crashes, although this may be underestimated because of differing reporting requirements for agricultural movements. One reason for this may be the relative infrequent or seasonal nature of the transport. Drivers for agricultural commodities, while they may possess the appropriate training and qualifications, may not benefit from the same level of experience as drivers for other non-seasonal cargoes. Drivers for agricultural movements may act as drivers during the peak harvest seasons but may perform a variety of other supporting duties throughout the year. This difference in experience and exposure to the driving environment may affect their ability to react appropriately to reduce the severity of an impending crash. Note that this same effect was expected but not observed for livestock transport.

Carrier Characteristics. Despite limitations related to carrier-related characteristic data, particularly for intrastate carriers, a number of significant carrier-related characteristics affecting large truck crash severity were identified as part of this investigation. Unlike previous studies, this investigation did not identify any safety-related differences related to interstate and intrastate operation, use of trip-leased drivers, or historical safety reviews or performance. A high proportion of missing data and an infrequency of safety reviews may, in large part, explain the absence of a statistical relationship between these variables and large truck crash severity.

Variable: Carrier State – Arizona, Oklahoma
Result: Decreased Severity of Crash

Similar to vehicle license state, carrier state was examined to determine whether practices or conditions inside or outside of Texas had an effect on large truck crash severity levels observed within the state. Carriers who were physically based in both Arizona and Oklahoma, comprising 1.42 and 1.80 percent of the overall observed crashes, respectively, were predicted to be involved in lower severity crashes. Information is insufficient to determine whether this effect on crash severity is a result of differences in state-level large truck regulation and enforcement (i.e., more stringent enforcement) or differences at the individual carrier levels (i.e., carrier training programs) for companies based in each state. It is interesting to note however, that both Arizona and particularly Oklahoma are in close proximity to Texas. Drivers traveling to Texas directly from either of these states may be less likely to suffer from the effects of either industrial fatigue (related to hours of driving) or circadian fatigue (related to nighttime driving) and subsequently may be better able to react appropriately to reduce the severity of an impending large truck crash.

Variable: Carrier State - Illinois
Result: Increased Severity of Crash

Supporting this theory related to geographic proximity, carriers who were physically based in Illinois were predicted to be involved in higher severity crashes. Illinois-based carriers comprised 1.28 percent of the overall observed crashes. With a minimum state border to state border distance of more than 550 miles or 8 hours of drive-time, drivers traveling to Texas directly from Illinois would likely suffer from the effects of industrial and/or circadian fatigue and subsequently, may be less able to react appropriately to reduce the severity of an impending large truck crash. Recall that Jones and Stein (1990) found that drivers driving in excess of eight hours had a crash involvement rate almost twice that of drivers who had driven fewer hours. Similarly, Lin et al. (1993) found crash risk to increase significantly by approximately 80 percent and 150 percent in the eighth and ninth hours of driving, respectively. Note that these prior studies considered the effects of industrial fatigue on crash risk but not crash severity.

Variable: Carrier Classification – Private Property
Result: Increased Severity of Crash

Private property carriers, involved in 14.18 percent of the overall observed crashes, were predicted to be involved in higher severity crashes. This is somewhat surprising. Private property carriers were assumed to typically include larger carriers and have more effective driver training and vehicle/equipment maintenance programs when compared to the broader spectrum of carriers in operation. These assumed carrier traits were thought to contribute to reduced severity levels but this was not observed here. No other carrier classifications were found to positively or negatively affect large truck crash severity.

Variable: Fleet Composition - Number of Owned Trailers
Result: Decreased Severity of Crash

Under the same assumption that did not prove true for private property carriers, larger carriers can likely provide more effective driver training and vehicle/equipment maintenance programs as part of their operations; explaining, in part, the trend of increased safety levels with increased carrier size. Further, if the vehicles and equipment are owned rather than leased, the carrier has a vested interest in and greater control over their maintenance. This is consistent with earlier studies that found crash frequencies to decrease as carrier size (measured in terms of equipment or driver base) increases.

According to this investigation, the severity of a crash is predicted to decrease as the number of trailers owned by a carrier increases. Other fleet size measures, including the number of trucks, tractors, power units, or drivers (i.e., total, interstate, intrastate, trip-leased, etc.) were not found to be significant in affecting large truck safety. Of the fleet characteristics reported and linked with the observed crash data, nearly all of the trailers were owned (92.57 percent); the use of term-leased or trip leased trailers was relatively infrequent.

Crash/Operating Environment Characteristics. As mentioned previously, crash and operating environment characteristics are of secondary interest in this study. Despite considering a wide range of crash, roadway, weather, and temporal characteristics affecting large truck crash severity, only two factors – the number of vehicles involved in the crash and the weather condition, fog – were found to be significant in affecting large truck crash severity.

Variable: Number of Vehicles Involved
Result: Decreased Severity of Crash

Intuitively, crash severity might be assumed to increase with the number of vehicles involved in a crash; as more vehicles are involved, a greater number of individuals are exposed to risk of injury or fatality. However, single vehicle crashes, comprising 19.13 percent of the overall observed crashes, typically result in elevated severity due to the nature of collision (i.e., run-off-the-road) and the higher, unimpeded travel speeds. Crashes involving two vehicles, comprising 65.98 percent of the overall observed crashes, may also occur at generally higher, unimpeded travel speeds. Conversely, it is likely that minor severity crashes, occurring in congested, low-speed conditions, involve more than two vehicles due to close following distances and inadequate driver reaction times.

Variable: Weather Condition - Fog
Result: Increased Severity of Crash

Not surprisingly, crashes occurring during fog conditions were predicted to be higher in severity. Fog-related crashes comprised only 1.08 percent of the overall observed crashes in this investigation. Fog often results in disparate travel speeds, given varying driver route familiarity and comfort levels. Resulting crashes may involve vehicles traveling at significantly different speeds (i.e., a vehicle traveling at the near-posted speed limit colliding with a vehicle traveling at a significantly lower speed) or may involve a vehicle failing to negotiate the geometrics of the roadway, running off the road and colliding with a fixed object. Either of these crash causes would be expected to result in a higher severity crash.

Overall Model Goodness of Fit

Each of the factors described above achieved a high level of significance as denoted by their estimated t-statistic of $\geq|1.645|$ denoting a confidence level of 90 percent. Despite their individual significance for contributing to large truck crash severity levels, these factors in combination achieved a poor overall goodness of fit with a ρ^2 value of 0.0029 as the log-likelihood converged from –18,237.07 to –18,183.77 (see Table 3). Recall that a ρ^2 value of 1.00 indicates a perfect model.

A low ρ^2 value generally suggests that there are other significant factors contributing to large truck safety levels that are not being adequately captured or reflected in the existing data to support such investigations. In this investigation, challenges related to: (1) missing data, particularly related to intrastate carrier operations; (2) timeline inconsistencies between the MCMIS Census File that reflects active carriers at the time of the data request and the MCMIS Crash File that includes crashes occurring between 2004 and 2006; (3) and the structure of the final combined dataset that resulted in a number of repeat measures related to carrier characteristics may more readily explain the compromised explanatory power of the statistical model.

IMPLICATION OF FINDINGS FOR SAFETY MONITORING EFFORTS

Recall, that the intent of this effort is to characterize large truck safety levels in Texas on the basis of driver, vehicle, cargo, and carrier traits in an effort to focus regulatory and enforcement efforts and ultimately reduce the likelihood of severe crashes in the future. For roadside and on-site, carrier-based safety monitoring efforts, factors of most interest include the following:

- Single-unit, three-axle and truck tractor (bobtail) vehicle configurations
    - To date, safety regulation and enforcement has likely been focused on larger vehicle configurations with greater weight-carrying capacity. This investigation's findings suggest that safety efforts should include smaller vehicle configurations and tractors without trailers, as well.
    - This information will aid in improving the effectiveness of roadside inspection practices related to both vehicle configurations identified; each has readily identifiable characteristics to support selection at the point of inspection. In addition,

  on-site, carrier-based safety monitoring activities may be focused on carriers with fleets comprised predominantly of single-unit, three-axle trucks. Truck tractor (bobtail) trips without a trailer are likely too unpredictable to address through on-site, carrier-based safety monitoring activities.

- Tank cargo body type
  - This investigation's findings suggest that safety regulation and enforcement should focus on tank cargo body types, irrespective of cargo transported. To date, safety efforts have likely focused on tank vehicles transporting dangerous or hazardous cargoes. Less focus has likely been put towards tank vehicles transporting innocuous cargoes such as water or milk.
  - This information will aid in improving the effectiveness of both roadside inspection practices and on-site, carrier-based safety monitoring activities. Roadside inspections can be conducted more frequently for tank cargo body types, irrespective of cargoes transported. In addition, on-site, carrier-based safety monitoring activities may be focused on carriers with fleets comprised predominantly of tank cargo body types.

- Grain/feed/hay cargo classification
  - Vehicles transporting relatively lightweight cargoes such as grain, feed, or hay may currently receive less safety regulation and enforcement focus. Further, drivers, vehicles, and carriers transporting agricultural commodities are exempt from many of the formal regulatory requirements at State and Federal levels. At the Federal level, agricultural exemptions exist related to controlled substances and alcohol use and testing; qualification of drivers; hours of service of drivers; commercial driver's license standards, requirements and penalties; vehicle parts and accessories necessary for safe operation; vehicle inspection, repair and maintenance; and employee safety and health standards. The Texas Administrative Code includes additional exemptions related to maximum widths, lengths, and weights of vehicles transporting agricultural commodities. These differences in regulation at both the State and Federal levels may further diminish the regulatory and enforcement focus for grain, feed, and hay cargoes. This investigation's findings suggest that safety efforts should, however, include grain, feed, and hay transport.
  - This information will aid in improving the effectiveness of roadside inspection practices; each cargo type is readily identifiable to support selection at the point of inspection. In addition, on-site, carrier-based safety monitoring activities may be focused on carriers who predominantly transport grain, feed, and hay. State and Federal regulatory exemptions for drivers, vehicles, and carriers transporting agricultural commodities may limit safety enforcement and monitoring practices to some extent.

- Carrier state of Illinois
  - To date, safety enforcement has likely not distinguished efforts by carrier state or even vehicle license state (vehicle license state is more readily identifiable on the roadside; carrier state is identifiable through a database query). This investigation

  suggests, however, that carriers based in Illinois should be a focus for safety monitoring. Although not confirmed in this investigation, carriers based in states that are a similar geographic distance from Texas may also have an increased level of severity based on the estimated driving distances and resulting industrial and circadian fatigue effects.

  - This information will aid in improving the effectiveness of roadside inspection practices and, to a lesser extent, on-site, carrier-based safety enforcement activities. Vehicle license state may serve as an adequate surrogate for carrier state to support enhanced roadside inspection efforts (i.e., roadside inspectors may select drivers of vehicles licensed in Illinois for inspection to capture carriers based in Illinois). On-site, carrier-based safety monitoring activities may be focused directly on carriers with a physical address in Illinois, although, if the predicted safety risk is attributable to driver fatigue, roadside inspections may be more effective in addressing this phenomenon. On-site, carrier-based safety enforcement activities may best focus on driver hours of service and log records for carriers in Illinois and other states with similar driving distances.

- Private property carriers
  - Authorized, for-hire carriers are the most common type of classification and as such, may receive a proportional safety regulation and enforcement focus. This investigation suggests that private property carriers, the second most common type of classification, should receive added focus, as well.
  - This information will aid in improving the effectiveness of both roadside inspection practices and on-site, carrier-based safety enforcement activities. Private property carriers are typically easily identified by company advertisements on the vehicle for inspection selection. In addition, on-site, carrier-based safety monitoring activities may be focused on private property carriers.

- Fog conditions
  - Though not applicable for selecting specific drivers, vehicles, or carriers for safety regulation and enforcement, this finding does allow for a shift in enforcement resources at fog-prone locations and during fog-prone times of the year.

Several variables, such as Vehicle License State –Mexico, California; Cargo Classification - Driveaway/Towaway, Mobile Homes, Livestock, Beverages; Carrier State – Arizona, Oklahoma; and Fleet Composition - Number of Owned Trailers; and Number of Vehicles Involved showed a noted *reduction* in predicted large truck crash severity. Less attention can be put towards safety-related regulation and enforcement when these factors are present. Yet other factors, such as the number of vehicles involved in crash, are difficult to control for. Hence, while it was important to include these factors in the predictive severity model, they are of less interest than the factors highlighted above in improving overall large truck safety levels.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

This final Chapter summarizes the overall findings from this investigation including the state of the practice at the time this study was initiated, challenges related to this investigation, the appropriateness of the methodology used and recommendations for implementation of these results into truck safety monitoring practices.

STATE OF THE PRACTICE

Numerous and diverse investigations have been conducted with a focus on large truck safety. In general, these studies considered only a small subset of causative or confounding effects rather than comprehensively examining potential influential factors. Further, many of the studies were conflicting in both direction and magnitude of influence for certain factors, particularly with respect to vehicle configuration effects.

With respect to driver characteristics, fatigue was found to be a noted contributor to increased large truck crash frequencies and severities, though this driver condition was difficult to measure and often defined differently study to study. Both increased hours (industrial fatigue) and days (cumulative fatigue) of driving were associated with higher crash risk. Hours of service violations were determined in one study to approximate 40 percent, likely contributing to the effects of fatigue. Nighttime driving (circadian fatigue) was also associated with increased large truck crash frequencies and severities with few exceptions; local, short haul operators and long-haul operators traveling on freeways, Interstates or expressways were observed to experience safer driving conditions during nighttime hours. Use of sleeper berths was associated with higher levels of fatigue and an increased risk of a fatality crash. Similarly, operators of longer combination vehicles (LCVs) experienced higher levels of fatigue, but efforts to relate LCV operation to increased crash frequency or severity were inconsistent in their findings. Inconsistent findings were also uncovered related to the effects of rest area availability and cargo loading/unloading tasks on fatigue and subsequent large truck safety levels.

Noted effects of various driver health and medical conditions on large truck safety levels were inconsistent between studies. Studies that considered drivers diagnosed with vision impairments or diabetes showed both higher and lower crash involvement rates when compared to larger commercial driver populations. Specific types of vision impairments (i.e., binocular vision problems) were associated with more severe crashes. Similarly, studies that considered drivers diagnosed with sleep disorders showed both higher and lower crash involvement rates when compared to larger commercial driver populations. Consistently, obese drivers had higher crash frequencies. The influence of alcohol and drugs were found to be a significant contributor to large truck crash rates, however, a very low proportion of large truck drivers were found to be in this state.

Age and experience levels were found to be noted contributors to large truck safety levels. Younger drivers were consistently reported to have higher crash involvement rates. Older, more experienced drivers were found to be safer drivers, but have an increased risk for fatality if over 51 should a crash occur. Similarly, inexperienced drivers were reported to have higher crash involvement rates; drivers with more years of experience were observed to be safer drivers.

Company-sponsored driver training programs were also shown to reduce crash frequencies. Frequent job changes were reportedly associated with higher crash frequencies although the cause an effect aspect of this relationship is unclear (i.e., drivers may be let go because of high crash frequencies). A history of traffic violations and convictions increases a driver's likelihood for a crash. If the driver was violating speed restrictions at the time of the crash, the crash will be more severe. No studies were uncovered that considered the effects of gender on large truck safety levels.

Conflicting findings related to both crash frequency and severity were found when investigating vehicle characteristics, particularly vehicle configuration, and their effect on large truck safety levels. With some consistency, higher crash rates were noted with 2-axle trucks, local service activities, and tanker and flatbed trailers. A single study observed higher severity levels for crashes involving single-unit, 2-axle trucks. Cab-over-engine designs were associated with higher fatality crash rates while use of front under-ride guards and retro-reflective tape on the trailer unit have been shown to reduce fatality and overall crash rates, respectively. The effects of gross vehicle weight (GVW) on crash frequency and severity were in agreement between studies; a higher GVW results in lower crash rates but a higher crash severity. Few studies have been conducted historically to confirm this relationship, however. Defective vehicle equipment was found to be a common crash cause, however, no significant association was found when comparing large truck safety levels and recorded roadside inspection violations.

Limited information was found related to the effects of cargo characteristics. A single study found that crash rates were higher for loaded trucks rather than empty trucks. This study however did not adequately control for the percent of time that trucks operate empty and loaded so these findings may be invalid. A single study reported lower crash severity levels for household goods cargo. No information was found that investigated the effects of cargo method of containment on large truck safety.

With respect to carrier characteristics and the effects of large truck safety, it was generally found that smaller carriers have higher fatal crash rates than larger carriers. The definition of a "small" carrier varied from study to study. Crash severity was found to decrease as the number of intrastate drivers increased; crash severity was found to increase as the number of trip-leased drivers increased. Higher crash rates were reported for owner-operators than drivers employed by a company. Local operation carriers were observed to experience higher injury/fatality and overall crash rates than intercity operation carriers. Conversely, carriers with longer average hauls were observed to have lower safety levels. Higher gross revenues for the carrier and higher wages for the driver were both associated with higher levels of large truck safety. More severe crashes were observed for carriers whose latest review was a compliance review; this finding does not distinguish whether the review followed or preceded the observed crashes.

Investigation of operating environment effects on large truck safety was typically performed as a secondary exercise to limit confounding factors. Some consistency was noted in the effects of roadway characteristics on large truck safety levels. Both large truck crash frequency and severity were found to vary by roadway type; rural roadways experience more severe but less frequent crashes. The higher degree of either horizontal or vertical roadway curvature results in a higher crash frequency. Limited access highways reportedly experienced a higher level of large truck safety while undivided and/or two-lane highways experience more severe crashes.

The effect of speed limits, either uniform or differential by vehicle type, on large truck safety levels was unconfirmed. Roadway lighting was observed to reduce crash severity for nighttime crashes. Fewer studies considered the effects of traffic characteristics on large truck safety levels. Crash frequency was noted to increase as traffic volumes (AADT) and vehicle miles traveled (VMT) increase. Only a single study reported a direct relationship between adverse weather and large truck safety levels; crash frequencies were observed to increase with hours of snowfall.

This information from previous efforts to investigate large truck safety supported this investigation by ensuring that no key factors were omitted from consideration and that any wildly conflicting results were adequately accounted for.

INVESTIGATION CHALLENGES

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

Relatively few challenges were encountered when compiling the crash data for this investigation. Of greatest concern was the completeness of information contained in the MCMIS Crash File. Data related to driver condition and the number of vehicle axles, for example, were entirely omitted from the file (i.e., column headings were included but no data were present). This may reflect a change in FMCSA policy to either no longer collect, maintain, or provide publicly this information that was previously available.

The carrier data was more difficult to collect and utilize in this investigation. Profile information contained in the MCMIS Census File was readily available for interstate carriers who were active at the time of the data request (December 2006). Matching carrier information from December 2006 to crashes occurring between 2004 and 2006 resulted in limited missing carrier information (i.e., if carriers ended operation prior to December 2006). Also, because only the most recent year's carrier profile was available, carrier characteristics may not match characteristics at the time of the crash (i.e., carriers may have increased fleet size, changed type of operation, etc.).

Profile information for intrastate carriers, obtained from the Texas Department of Transportation (TxDOT), Motor Carrier Division, had similar limitations. The intrastate motor carrier database contained only active carriers at the time of the data request (December 2006) and did not reflect changes over time in carrier characteristics (i.e., fleet size, etc.). Additional limitations to the intrastate carrier profile information were more significant and included: (1) a reduced set of carrier profile variables and (2) a lack of common carrier identifier as compared to the MCMIS Crash and Census File. TxDOT's intrastate motor carrier database: contains no driver or vehicle information; reports only three commodity categories (MCMIS categorized more than 30 commodities); reports the number of power units/trucks owned by a carrier but does not distinguish between owned, term-leased, or trip-leased vehicles; and contains no trailers information. Consequently, much of the information relating to intrastate operation was treated as missing data.

The lack of a common carrier identifier (i.e., USDOT number) between the MCMIS Crash File and TxDOT's intrastate motor carrier database required significant effort to combine the two data sets. Intrastate carrier information was first automatically matched to the MCMIS Crash File using exact Carrier Name cell entries. Different first/last name order, use of company or owner names, misspellings, and use of punctuation and abbreviations produced few matches using this automatic procedure. Researchers next manually matched intrastate carrier profile information to crash data using a series of decision rules related to the similarity in carrier name between the two data sources, uniqueness of carrier name, carrier city location, neighboring city proximity, street address, etc. Despite efforts to use consistent decision rules, this manual matching process was highly subjective. In addition, this process may have biased the data towards larger carriers who have less frequent changes of physical address (i.e., a "match" was typically identified when both the carrier name and address were confirmed to be the same). Overall, this combined automatic and manual matching process provided additional intrastate carrier profile data for 4,962 out of 10,391 intrastate carrier-involved crashes (47.8 percent).

Also, much of the information related to agricultural commodity movement is omitted from the carrier data. The agricultural industry is exempt from many of the formal regulatory and reporting requirements at State and Federal levels.

APPROPRIATENESS OF METHODOLOGY

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

The use of ordered probit regression methods proved generally successful in identifying significant driver, vehicle, cargo, carrier, and crash/operating environment characteristics affecting large truck crash severity. The relationship between the significant (denoted through t-statistics values $\geq|1.645|$) explanatory variables and crash severity was for the most part intuitive and in agreement with previously reported findings. Despite their individual significance for contributing to large truck crash severity levels, these variables in combination achieved a poor overall goodness of fit with a ρ^2 value of 0.0029.

A low ρ^2 value generally suggests that there are other significant factors contributing to large truck safety levels that are not being adequately captured or reflected in the existing data to support such investigations. In this investigation, challenges related to: (1) missing data, particularly related to intrastate carrier operations; (2) timeline inconsistencies between the MCMIS Census File that reflects active carriers at the time of the data request and the MCMIS Crash File that includes crashes occurring between 2004 and 2006; (3) and the structure of the final combined dataset that resulted in a number of repeat measures related to carrier characteristics may more readily explain the compromised explanatory power of the statistical model.

For this type of dataset and this degree of repeated measures, univariate and/or multivariate repeated measures analyses may result in greater statistical power relative to sample size. Univariate statistical methods (i.e., omnibus tests) consider a random factor crossed with repeated measures as a fixed factor (Barcikowski and Robey 1984). In multivariate techniques, the repeated measures become a series of dependent variables (Lewis, 1993, Stevens 1996). These repeated measure techniques have been widely used in the social sciences but have been less commonly applied in safety-related analyses such as this.

RECOMMENDATIONS FOR IMPLEMENTATION

For roadside and on-site, carrier-based safety monitoring efforts, efforts should be focused towards the following vehicle, cargo, and carrier characteristics:

- single-unit, three-axle and truck tractor (bobtail) vehicle configurations,
- tank cargo body types,
- grain/feed/hay cargo classifications,
- carriers based in Illinois, and
- private property carriers.

Focusing safety efforts toward these characteristics, which have shown a significant influence on the severity of a potential crash, provides a more proactive approach to enhancing large truck safety; the use of historical safety ratings is reactive.

Informally, regulatory and enforcement personnel in the State of Texas can be made aware of these focus areas simply through a chain-of-command informational memo. On a more formal basis, these results could ultimately be integrated into both the ASPEN/ISS system for targeting roadside safety inspections and the SAFESTAT system for targeting compliance reviews and educational contacts. Prior to this occurring however, further evaluation is required to determine if targeting of these characteristics does in fact improve large truck safety levels in Texas and whether these results are transferable to other areas of the country.

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