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16. Abstract

This study examines the relationship of heavy truck mechanical condition and crash risk. The LTCCS presents an opportunity to examine in more detail than previously possible the relationship of vehicle condition to crash risk. The report includes a review of existing literature, a full analysis of the results of the post-crash truck inspections, and a series of logistic regression models to test the association of vehicle condition and crash role.

Two specific hypotheses are tested: The first hypothesis is that trucks with defects and out of service conditions are statistically more likely to be in the role of precipitating a crash than trucks with no defects or out of service conditions. The second hypothesis is that defects in specific systems, such as the brake system, are associated with crash roles in which those systems are primary in crash avoidance, and that there is a physical mechanism that links the vehicle defect with the crash role.

Post crash inspections showed that the condition of the trucks in the LTCCS is poor. Almost 55 percent of vehicles had one or more mechanical violations. Almost 30 percent had at least one out of service condition. Among mechanical systems, violations in the brake (36 percent of all) and lighting system (19 percent) were the most frequent.

A brake OOS condition increased the odds of the truck assigned the critical reason (identifying the precipitating vehicle) by 1.8 times. Both HOS violations and log OOS increased by a larger amount—2.0 and 2.2 times respectively. In rear-end and crossing paths crashes, brake violations, especially related to adjustment, increased the odds of the truck being the striking vehicle by 1.8 times.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Truck Mechanical Condition and Crashes in the LTCCS Data

1 Introduction

The number of trucks involved in fatal accidents has remained relatively stable in recent years. The *Trucks Involved in Fatal Accidents Factbook, 2006* shows that about 5,200 trucks were involved in a fatal crash annually, between 2002 and 2006, with the annual totals ranging from 4,950 in 2002 to 5,343 in 2005. Similarly, crash rates for trucks have remained stable in the past five years. The National Highway Traffic Safety Administration's (NHTSA) *Traffic Safety Facts, 2007* shows that fatal crash involvements for heavy trucks per 100 million miles varied only between 2.02 in 2007 and 2.22 in 2004 and 2005.[1] Rates of injury and property damage only crash involvements slightly declined over the period, from 44 to 33 and from 156 to 147 per hundred million miles respectively. [Please see references 23, 13]

It is the mission of the FMCSA to reduce the toll of deaths and injuries in truck and bus crashes. The Motor Carrier Safety Improvement Act of 1999 (Public Law 106-159), which established the Federal Motor Carrier Safety Administration (FMCSA), required the Agency to "conduct a comprehensive study to determine the causes of, and contributing factors to, crashes that involve commercial motor vehicles." To meet that requirement, FMCSA joined with NHTSA to design and operate the Large Truck Crash Causation Study (LTCCS).

The LTCCS is largest and most ambitious study of truck crashes to date. The Federal Motor Carrier Safety Administration has identified four key safety areas in achieving the goal of crash reduction: commercial and passenger vehicle drivers; commercial vehicles; the roadway and environment; and motor carrier safety management practices. The LTCCS included detailed information in each of the four key safety areas. The LTCCS was designed to include all elements in a traffic crash—vehicle, driver, and environment. In addition, extensive information is collected about the operator of each truck involved, including details about driver compensation, vehicle maintenance, and carrier operations.

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[1] See Table 3 of *Traffic Safety Facts*.

The present study is a part of a series of studies funded by the FMCSA to use the LTCCS data to examine truck safety problems. Other studies have addressed prescription and other drug use and driver compensation issues, among other topics.

2 Problem Statement

This study examines the relationship of heavy truck mechanical condition and crash risk. Much recent attention in safety analysis has focused on the driver's role in traffic crashes. The results of the LTCCS to date has certainly contributed to this. The first report from FMCSA to the US Congress on the initial results of the LTCCS highlighted the result that 87 percent of crash involvements in the LTCCS were related to driver error, with all vehicle and environmental factors accounting for the remaining 13 percent.[21]

However, the LTCCS presents an opportunity to examine in more detail than previously possible the relationship of vehicle condition to crash risk. As will be shown here, the primary crash data sets available to researchers on truck crashes all contain very little information on vehicle condition. Roadside inspections consistently show high rates of out of service conditions and mechanical defects, yet the crash data available does not reflect this. But the LTCCS data include more detail on the condition of the truck and compliance with Federal Motor Carrier Safety Regulations (FMCSRs) from an extensive post-crash inspection of the trucks sampled for the study.

The results of the post-crash inspection, along with the detailed information capturing the events of the crash, provide the opportunity to determine the association of the inspection results with crash roles. The purpose of this study is to determine how truck mechanical condition affects the truck's involvement in traffic crashes.

3 Recent literature on the mechanical condition of trucks in crashes

The literature on the contribution of the mechanical condition of trucks involved to traffic crashes is not extensive. The Haddon Matrix classifies the factors associated with traffic safety into Human (primarily driver), Vehicle, and Environment (road, weather, and so on). Driver factors are much more frequently studied. The focus on driver factors is understandable on a variety of grounds. Drivers are actually at the controls leading up to the crash and can take actions to avoid the crash, and it is natural to focus on the element that is in a position to do something about the crash at the last minute. Outright catastrophic failures in vehicles are relatively rare, as are failures in aspects of the environment, such as the road system. Drivers are expected to compensate for degraded conditions in either. Drivers are expected to slow down if the road becomes slick, for example; "too fast for conditions" or something similar is a chargeable offense in many jurisdictions and covers not exceeding the posted speed limit but driving faster than is reasonable and prudent given conditions. And it is a sentiment sometimes expressed that truck drivers know when their brakes are degraded and should be able to compensate, such as by leaving more headway. And in any case, the driver is responsible for ensuring that the brakes are in good shape, so it is considered a driver factor after all.[2]

Moreover, conventionally-available crash data systems are not designed to support analysis of the role of mechanical defects in traffic crashes. All the primary crash data files—FARS, GES, and state crash data—are ultimately based on police reports. It is likely that crash reports capture mostly catastrophic vehicle failures, not degraded performance. Systematic vehicle inspections are not typically part of the post-crash investigation, especially for non-fatal crashes. Most police officers are not trained to do vehicle inspections to determine the pre-crash condition of the vehicle. And the officers have many other responsibilities, including protecting lives and property at the scene and enforcement of the law.

Accordingly, it is likely that mechanical defects are seriously underreported in the crash data. Massie and Campbell [18] reviewed national crash databases to evaluate their suitability for evaluating the CVSA out-of-service criteria. They examined the NASS GES file, as well as FARS, TIFA, crash data based on the MCS 50-T from the old Bureau of Motor Carrier Safety (BMCS), and from FMCSA's SafetyNet (MCMIS) crash file. Generally they found very low rates of reporting of mechanical defects. In GES (which is coded entirely from police reports, without access to any other materials) tires and brakes were the most common cited system, but only 0.7 percent of trucks were cited for a tire or brake defect. Only steering, signal lights, and wheels even amounted to 0.1 percent. The FARS and TIFA files (TIFA supplements FARS, and the vehicle condition variables in TIFA use the FARS variables) cover only fatal crash involvements which likely receive more intense investigation. But they are still based primarily on police reports. Massie and Campbell found that FARS/TIFA reported brake defects in 2.7 percent of truck involvements, and tire defects in only 1.1 percent. "Other light" system defects were recorded for 0.4 percent of trucks and trailer hitch for 0.3 percent. Defects were recorded for steering, suspension, power train in only 0.1 percent of involvements. SafetyNet does not record vehicle defects. And the crash data from the old MCS 50-T (now discontinued and superseded by the SafetyNet data) reported no defects for 97.2 percent of trucks, and no system accounting for more than 0.7 percent of trucks.

The Massie/Campbell work was published in 1996, but it is clear that there has been no significant change in the availability of data on vehicle condition in crash files based on police

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[2] See Haight, F., et al. *Review of Methods for Studying Pre-Crash Factors.* Highway Safety Research Center, US DOT, Washington DC. 1976. DOT-HS-$-00897. This report is a neglected classic and provides an excellent introductory discussion to the concept of "causation" in traffic safety. The ideas about driver responsibility in the paragraph have been expressed to me in conversation by enforcement personnel as well as by researchers and by people in the trucking industry.

reported data. Analysis of TIFA data from 2001-2003, roughly the period covered by FMCSA's LTCCS file, produces results very similar to those found by Massie and Campbell for 1991-1993. Defects in the brake system were most frequently cited, but in only 1.7 percent of trucks. No other system accounted for even one percent of the trucks. Tire defects were coded in 0.9 percent, trailer hitch in 0.2 percent, and only 0.1 percent in the steering, suspension, light, and power train/engine systems.

Table 1 Vehicle Defects in Fatal Truck Involvements
TIFA 2001-2003

Mechanical defects	Frequency	Percent
None	14,138	93.0
Brake System	262	1.7
Tires	137	0.9
Trailer Hitch	26	0.2
Steering	22	0.1
Suspension	22	0.1
Other Lights	20	0.1
Power Train/Engine	10	0.1
Wheels	7	0.0
Signals	6	0.0
Headlights	5	0.0
Body, Doors, Other	3	0.0
Exhaust System	2	0.0
Other	43	0.3
Unknown	247	1.6
Total	15,195	100.0

Total shows the total number of trucks involved, rather than the total number of defects. Percentages are calculated on the total number of trucks.

Randhawa et al. [20] reviewed 3,600 selected police reports from 6 states to determine the incidence with which mechanical factors are cited, as part of a project to evaluate CVSA out-of-service criteria. In the review, they read the reporting officer's narrative as well as any other information on the report, and found reporting levels comparable to those in FARS/TIFA and GES. Brakes were most often cited, but in only 1.7 percent of involvements, followed by tires, wheels, coupling (hitches), and load securement, all at about 0.4 percent. In the absence of special studies, the crash data that are typically relied upon for safety research are not able to comprehensively address the role of mechanical problems in truck crashes.

Two points are worth noting here. Researchers consistently find that mechanical defects are reported at low rates in the conventional crash data. The second point is that, even though seldom reported, the brake system and tires are most often cited.

The studies that have been performed thus far tend to rely on special data collections. Two general approaches have been taken to address the problem of understanding the effect of truck condition on truck safety. One is essentially a clinical evaluation of a sample of truck crashes. In this approach, a set of truck crashes is sampled from a known population. A team of experts in truck mechanics and crash reconstruction evaluates each truck and the role the truck played in the crash to determine whether and how the truck's mechanical condition contributed to the crash. This method depends on a crash-by-crash evaluation and relies on the specific expertise and judgment of the researchers involved. The second approach is more statistical in nature and is based on finding statistical associations between the mechanical condition of trucks and their representation in the crash population. Some of these studies use roadside inspection data to determine if vehicle inspections have an effect on the overall crash rate, or whether motor carriers with high rates of vehicle violations from the roadside inspections also have high rates of truck crashes. Another approach to finding statistical associations is to more directly compare the mechanical condition of trucks in crashes with a carefully-matched sample of trucks not in crashes.

The clinical approach was used in a study of truck mechanical condition in truck crashes in Quebec. [1, 10] In this study, 208 crashes involving 214 heavy trucks occurring within a 200 km radius of Montreal were studied by a team of three mechanical engineers trained in accident investigation. In the end, the team was able to cover 195 of the crashes. They evaluated each crash and classified it according to the role of mechanical defects. About 11 percent of the trucks had no defects, 49.2 percent minor defects, and 39.5 percent serious defects. Mechanical defects were judged as the exclusive cause in 18; high contribution in 12; and low contribution in four. Thus in 30 of the 195 crashes, mechanical defects played a role.

Defects in the brake system were the most common problem found. About 20 percent of all defects recorded were in the brake system, followed by lights at 17.3 percent, chassis at 12.1 percent and suspension at 12.0 percent. Brake defects were deemed the cause of the crash most often, accounting for 16 percent of the crashes caused by mechanical defects, followed by tires (12 percent), chassis (5 percent) steering (4 percent), cab (3 percent), and lights/signals (2 percent).

The clinical approach is not used often. The clinical, case-by-case approach is very resource intensive, involving a heavy investment of expertise in evaluating each case. In addition, the judgments made are inevitably subjective. This does not mean that the judgments are incorrect, but that they are biased by the fact that a crash occurred. Traffic crashes do not occur in an experimental setting, so it is not possible to control for confounding factors in using clinical judgment. Controls thus rely on the judgment and experience of the reviewers. Statistical analysis, while also containing elements that are subjective, permits at least some confounding factors to be controlled and does not rely directly on the judgment of experts to establish association or lack of association. [For an expanded discussion, please see reference 2.] Statistical methods that rely on association are much more frequently used.

Rune Elvik used inspection and crash data from Norway to evaluate the effectiveness of vehicle inspections in reducing truck crash rates. [5] He used data on the total number of crashes, the number of vehicle inspections as well as estimates of vehicle miles traveled (VMT), and number of new drivers over 13 years. He fit a series of linear regressions to estimate the association of the number vehicle inspections with crash rates, controlling for new driver entrants and changes in economic conditions over the period. He fit three models, using different types of crash rates. None of the terms in the models met the usual criterion for statistical significance (probability that the observed effect is due to chance of 5 percent or less), but the number of inspections consistently had a negative effect (increase in the number of inspections associated with a reduction in the crash rate) in all models. Elvik estimated that eliminating inspections would result in an increase in the crash rate by 5 to 10 percent. The state of the economy, measured by gross national product (GNP) has the largest effect in the model.

Though Elvik's results were inconclusive, albeit suggestive, the paper includes a very useful discussion of the problem of inferring statistical causality. Some of the points may seem simple and obvious, but they are fundamental to valid inference. First, there should be a statistical association between the presumed cause and the effect, and the direction of causality should be clear. Statistical models are just equations and the equation itself does not establish the direction of causation. He points out that strong associations are more plausibly causal than weak ones, and that the statistical relationship should not disappear when confounding factors are controlled for. He also observes that if the cause can come in different amounts, there should be a dose-response relationship, such that a difference in the magnitude of the hypothesized cause is associated with differences in the magnitude of the response. And finally he argues that the causal mechanism should be known, that is, that there should be a known explanation of how the cause produces the effect.

Saccomanno, et al., used roadside inspection data from the Canadian Roadcheck program to identify high-risk carriers, i.e., those with a high risk of crash involvement. [22] The purpose of the study was to determine if roadside inspection data could be an efficient method to identify carriers for safety interventions. They established a method of weighting the violations uncovered in the inspections, based on the relative frequency with which different mechanical systems are cited in police-reported crashes. The brake system defects were most heavily weighted, followed by tire defects, and defects in the wheel/suspension. Applying these weights to the roadside violations, they ranked carriers in terms of their aggregate score and assigned the carriers to classes based on the percentile ranking. Carriers in the 95th percentile were classed as dangerous, those in the 75th as poor, and those below the 75th percentile as good. They found that the roadside inspection results were associated with the carrier's crash rate, especially for those crashes in which mechanical factors were cited. The link between roadside inspections and the overall rate was not as strong.

The Saccomanno study is a fairly high-level examination of the link between crash involvement and mechanical condition. The relationship is established in aggregate data, at the carrier level, and not at the vehicle level in specific crashes. The link is certainly plausible, and one notes that brakes, tires, and wheels are significant factors in the relationship. But the purpose of the research was not to establish the link per se, but simply to determine if the roadside inspection data could be used to effectively target motor carriers for inspection, and in that purpose it succeeds.

Jones and Stein used a case-control study design to examine the relationship between mechanical condition and tractor-semitrailer crash involvement.[14] Their cases consisted of a set of tractor-semitrailers involved in traffic crashes on two Interstate highways. Controls were sampled from the traffic stream at the crash location one week later, from 30 minutes before to 30 minutes after the time of day at which the crash occurred. Both groups were subject to a vehicle inspection, though the inspection was not a complete CVSA Level 1 inspection but rather restricted to brakes, steering, and tires. The data also included truck size, weight, and configuration; driver age, experience, and hours driving at the time of the crash (or when sampled as a control); carrier type and trip type.

Comparing the mechanical condition of the case vehicles with the controls showed that overall, crash-involved trucks were more likely to have mechanical defects and more likely to have at least one out-of-service (OOS) condition. Brake defects and steering defects were associated significantly with increased crash risk. The association for brakes was even stronger in rear-end crashes, though it is not clear if this means rear-end crashes in which the truck was the striking vehicle, or all rear-end crashes. If it is for crashes in which the truck is the striking vehicle, that would establish the physical mechanism linking the cause (defective brakes) and the effect (rear-end striking crash). Steering defects were significantly associated with sideswipe crashes. Again it is not clear if the association is for crashes in which the truck moves into the other vehicle.

The Jones and Stein work shows an association between the mechanical condition of the truck and crash involvement, and even appears to move toward testing the physical mechanism linking defects and specific crash types, but the overall thrust is to establish an association, accounting for some confounding factors such as driver hours and experience. The work also identifies brake and steering defects as significantly associated with crash risk. But it does not focus directly on the physical mechanism linking vehicle defects with crash risk, but instead relies, essentially, on comparing the incidence of defects in the crash case group with that in the control group to establish the overrepresentation of vehicle defects in crash-involved vehicles.

The present author attempted to draw a more direct link between mechanical defects and specific crash types, using a special set of crash data from Michigan.[3] Blower used data from Michigan's Fatal Accident Complaint Team (FACT) to examine the relationship between truck defects and specific crash types. The FACT program was in some respects a forerunner of FMCSA's LTCCS project. The FACT program included all medium and heavy trucks involved in a fatal crash in Michigan. For each truck involved, investigators collected an extensive physical description of the vehicle including configuration, lengths and weights of each unit, cargo body type, cargo type and amount, and other details. Data were also collected about the age and experience of the driver, the type of motor carrier operating the trucks, along with information about the crash environment (road type, weather, road condition, time of day, and so on) common to crash data. The central focus of the data collection was a detailed description of the events of the crash, similar to that used in the LTCCS, and a complete Level 1 truck inspection of each truck. The truck inspection identified mechanical defects existing prior to the crash. Collision-induced violations were excluded.

The approach of the study was to examine the association of specific mechanical defects with the role of the truck in the crash. It is noted that while vehicle defects are associated with crash risk, specific defects would not be expected to increase crash risk across all crash types. Brake defects would be expected to be associated with crashes in which the truck was the striking vehicle, but not those in which the vehicle was struck.

Overall, brakes were the most common defect, with 34.2 percent of the inspected trucks recorded with one or more violations of the brake condition requirements. Violations in the light/signal system was the next most common, with 23.7 percent of the trucks having a lighting violation. Almost 15 percent of trucks had a tire or wheel violation, and about 10 percent had violations in the suspension system. Almost 29 percent of the trucks had one or more OOS conditions prior to the crash. Almost 55 percent of the vehicles had one or more mechanical defects.

The study showed that brake violations were significantly associated with rear-end crashes in which the truck was the striking vehicle. About 50 percent of striking-vehicle trucks in rear-end crashes had one or more brake violations, compared with 27.3 percent of struck-vehicle trucks. To test if the association of brake defects with rear-end crashes was merely a marker for poorly maintained trucks in general, each mechanical system (lights, suspension, steering, and so) was tested for association with the crash type. No other vehicle system was significantly associated with the rear-end crash type, except for the lighting system. Moreover, when all violations were considered together, there was no statistical association with crash role in rear-end crashes. For lights, trucks with light system violations (e.g., head lamps, stop lamps, marker lights) were associated with rear-ends in which the truck was the struck vehicle. The association was particularly strong for violations on the rear of the truck. This finding suggests that conspicuity plays a role in rear-end crashes in which the truck is struck.

The work with the FACT data represents an effort to establish a link between a physical crash mechanism and defects in a truck's mechanical system. This work attempts to advance beyond statistical association to attempt to establish a causal link. It does this through both establishing a statistically significant association and also testing directly crash roles that the mechanical defect would be expected to affect.

The LTCCS data provides an opportunity to further explore the link, and to test whether the link stands up in a new and comprehensive data set. The LTCCS data shares some of the same data elements with the FACT program, including detailed crash type data in which crash role can be defined precisely, and a comprehensive post-crash inspection to determine the pre-crash compliance of the vehicle, driver, and carrier with critical Federal Motor Carrier Safety Regulations.

4 Hypotheses

The fundamental hypothesis of this study is that the mechanical condition of trucks is related to the role of the truck in the crash.

Two specific hypotheses are tested.

The first hypothesis is that trucks with defects and out of service conditions are statistically more likely to be in the role of precipitating a crash than trucks with no defects or out of service conditions.

The second hypothesis is that defects in specific systems, such as the brake system, are associated with crash roles in which those systems are primary in crash avoidance, and that there is a physical mechanism that links the vehicle defect with the crash role.

5 Data

The data used in this project come from the Large Truck Crash Causation Study, conducted by the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA). The LTCCS was a three-year project to collect detailed information on the crashes of medium and heavy trucks. [16, 17]

The data are intended to be nationally-representative. The sampling strategy was based on that used for NHTSA's General Estimates System and Crashworthiness Data system (GES and CDS) sampling structure. Crashes were sampled from 24 "primary sampling units" (PSUs) in 17 states. Researchers sampled crashes involving a serious injury and at least one truck with a gross vehicle weight rating (GVWR) of 10,001 pounds or more. A serious injury was defined as either a fatality, an A-injury or a B-injury. A- and B-injuries are based on the typical injury severity classification system used in police-reported crash data. An A-injury is incapacitating and usually requires transportation from the scene and immediate medical treatment. A B-injury is less than incapacitating but is a visible injury. Within each PSU, researchers would sample from qualifying crashes. Using the known sampling probability for each case, case sample weights are calculated so that population totals can be estimated.

Each sampled crash was investigated by a NHTSA researcher and a State truck inspector. In designing the data elements collected, the approach was to cover a broad range of areas, including drivers, vehicles, the environment at the crash, crash events, and the motor carrier responsible for the vehicle. All vehicles in the crash were investigated in similar detail, including non-truck vehicles and their drivers. While it is not possible or appropriate to collect identical data elements for all vehicle types, the study design was to collect equally comprehensive data on all vehicles and drivers involved.

A key element of the study design was the depth with which crash events were captured. A set of data elements were used—based on GES and CDS—that captured events from immediately prior to the initiating of the crash sequence until the vehicles involved were stabilized. In addition, researchers provided a detailed narrative of crash events and conditions for each vehicle and a summary for the crash as a whole.[3] Each crash is also documented by a detailed scene diagram and a series of photographs of each vehicle and the crash scene.

Finally, each truck was subject to a North American Standard Level 1 inspection by a State truck inspector, typically certified by the Commercial Vehicle Safety Alliance (CVSA). The protocol for the NAS Level 1 inspection was developed by the CVSA and adopted throughout North America. The Level 1 inspection determines compliance with the Federal Motor Carrier Safety Regulations (FMCSR) governing vehicle standards and certain driver and company standards. The vehicle domain covers all mechanical systems. The driver domain includes hours of service, licensing and certification requirements, and compliance with traffic laws. The items relating to carriers include compliance with registration and insurance requirements, and vehicle marking.

Crashes were investigated for the LTCCS from 2001 through 2003. The crashes investigated in the first few months were the pilot phase and have case weights of zero in the file. Crashes from the study phase have case weights. There are 963 crashes represented in the study phase data, with 1,123 trucks. Inspections were performed on 1,001 of the trucks, 89.1 percent of the 1,123 total trucks.

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[3] See *General Estimates System Coding and Editing Manual, 2007*, [9], pages 323-361 for a detailed discussion of the pre-crash variables. Similar variables and coding rules were adopted in the LTCCS.

6 Method

The overall approach here follows the method of statistical association. The goal is to determine if there is a statistical association between the mechanical condition of trucks and their crash risk. Because the LTCCS data are so rich, there may be a potential for taking a clinical approach, and reviewing each crash in detail to assign a judgment of the role of the truck's mechanical condition in the crash. But the best use, most consistent with the original design of the LTCCS, is to determine the nature of the relationship between mechanical condition and crash outcomes using statistical methods. The LTCCS data, unique among mass crash data sets, includes a detailed evaluation of the truck and the compliance of the driver and carrier with certain safety regulations. The data also provide as careful and circumstantial an account of the truck's role in the crash as is available in any crash file. The method used here attempts to bring together those two elements.

Defects in the mechanical systems of a truck are hypothesized to contribute to crash risk. Trucks with poor brakes or defective steering should have greater risk of being involved in a crash, all else being equal. Ideally, we would determine risk by some independent measure of exposure, such as vehicle miles traveled. In that way, we could compare the crash rates for trucks with mechanical defects with the crash rates for trucks that did not have a mechanical defect. But information about the relative exposure of trucks with and without mechanical defects is not available.

However, the LTCCS data can be used to identify groups within the set of trucks involved in crashes where vehicle condition should play different roles. The crash risk from defects in specific truck systems should not be the same across all the different crash types and crash roles. Defective brakes would not be expected to increase the risk of being struck while stopped at a stop light. Suspension problems would not play a role for a truck struck while passing through an intersection with the right of way. In general, mechanical problems would be more likely in crashes in which the movement of the truck precipitated the crash, and less likely where the crash was initiated by actions of other vehicles.

Thus, the approach is to establish a statistical association between crash types and the factors of interest, focusing primarily on mechanical defects. Statistical association, however, does not establish causation. The association itself does not indicate the direction of the causal arrow, so to speak. The second feature of the method is to establish a plausible physical mechanism that connects the events of the crash with the effect of the mechanical defect. Crash types are hypothesized to which a mechanical defect would be expected to contribute. Complement or control crash types in which the defect would have no role are identified, and then the incidence of the defect in the two groups is compared. Possible confounding factors, which might also play a role, are controlled for. This process addresses Elvik's point, from his own study of truck inspection results and crash risk, that the statistical analysis must include a causal mechanism that explains and connects the condition with the effect of the condition. [See reference 5; and also 2 and 12 for further discussion.]

The truck inspection results are the primary data used here, along with the detailed description of the crash events. The inspection results are aggregated into sets of defects in different truck systems. The method of aggregation is described in the next section. The overall approach is to compare incidence in the population with a control group, within the crash data. Initially, this is done is a series of two-way comparisons, comparing the incidence of specific defects in crash types where they would be expected to play a role with crash types in which they would not be expected to play a role. Then a series of logistic regression models are developed, to model the statistical association. The statistical models allow several factors to be considered at once, to control for potentially confounding factors. This is important because the mechanical defects do not exist in isolation from other aspects of the truck's operations. Poor mechanical conditions related to crash events may just reflect poor and risky overall operations, including negligent or unqualified drivers and shoddy overall condition of the vehicles. To the extent possible, an attempt was made to control for such factors.

In both the tables and the logistic models, the case weights were not used. Instead, unweighted case counts are used, using only cases from the full study. No cases from the pilot phase of the study are used. Case weights are not used because of a concern that the sample, when weighted, is not nationally-representative.

Comparisons between national estimates of certain crash types were made using the LTCCS on the one hand and the Trucks Involved in Fatal Accidents (TIFA) and General Estimates System (GES) files on the other. Both TIFA and GES are well-established, long-term files. The TIFA file is a census of all trucks involved in a fatal accident. The GES file is a nationally-representative file, compiled on a continuing basis for almost 30 years, of police-reported crashes. It appears that the proportion of single-vehicle crash involvements in LTCCS is about twice the proportion in TIFA, GES, and the combination of TIFA and GES covering the same crash population (fatal, A- or B-injury) as covered by the LTCCS. Similarly, the estimated national population of rollovers in LTCCS is about twice that from the TIFA and GES files.

Given questions about the nationally-representativeness of the LTCCS data, it was decided to use the data in this study as a very high-quality sample of crash investigations, without attempting to estimate national totals. The findings here are presented as valid for the set of serious truck crashes in the LTCCS data. The associations found are valid for serious truck crashes, but no estimate of national population totals is made.

6.1 Aggregating violations into categories

Inspectors identified a total of 194 different pre-crash violations of FMCSRs on the inspected trucks. Violations ranged from "operating without proper motor carrier authority" to "no or improper rear-end protection.” The inspection areas include driver requirements, vehicle mechanical condition regulations, and carrier compliance with insurance and certification requirements. For analytical purposes, the violations were aggregated into more general categories, simply because the sheer number and varying levels of specificity of the violations made analysis unwieldy without some more general aggregation. At one level, the violations were categorized into driver, vehicle, carrier, and other areas. At a more detailed level, the violations were classified into different subcategories within the more general categories and specific systems. Within each of the general categories, subgroups were aggregated. For drivers, violations were aggregated as licensing, qualifications, certification, hours of service (HOS), log, and traffic violations. Carrier violations were combined as carrier-related (registration and insurance, primarily) and vehicle marking. Within violations of mechanical systems, the systems were aggregated to specific systems such as brakes, lights, suspension, and electrical system. The 127 different violations coded for trucks were categorized into a total of fifteen different systems. Table 2 shows the general classification scheme, along with a count of the individual violation codes that went into each category and subcategory. A full accounting of the classifications of the inspection items is included in the Appendix.

Table 2 Classification of Pre-Crash Inspection Violations LTCCS Data

Category	Subcategory	Violation types coded
Carrier	Carrier	4
	Vehicle marking	3
Carrier Total		7
Driver	Driver licensing	4
	Driver qualification	9
	Driver, general	3
	Driving violations (speed etc.)	21
	HOS	5
	Log	5
Driver Total		47

Category	Subcategory	Violation types coded
Mechanical	Brakes	24
	Cab	18
	Coupling	6
	Electrical	4
	Exhaust	5
	Frame	3
	Fuel system	5
	Inspection/maintenance	7
	Lights	18
	Load securement	8
	Steering	5
	Suspension	6
	Tires	11
	Wheels	3
	Windshield	4
Mechanical Total		127
Other	Hazmat	9
	Impact guards	4
Other Total		13
Grand Total		194

Every effort was made to identify only violations that existed prior to the crash. The inspection table includes a variable ViolationType that nominally codes “if a violation was in effect prior to the crash, or if a violation was a result of a crash.” ViolationType code levels are Pre-crash, No, Crash-related, and Unknown. The Pre-crash, Crash Related, and Unknown code levels are unambiguous, but the No code is not. No, the violation was in effect prior to the crash, or No, the violation was a result of a crash? Analysis of the variable showed that almost all of the No values came from a single PSU, showing that the problem was limited. Moreover, review of the types of violations coded “No” showed that many were of a type that could only exist prior to the crash, such as log, hours of service, or medical certification violations, and not violations that could be caused by the crash. Furthermore, none of the violations that seem to necessarily pre-exist the crash were coded as crash related. Accordingly, the No category was included among the pre-crash violations.

Classifying and aggregating violation types uncovered certain problems that limited the types of analyses that could be undertaken. Some of the violations coded are general, for example, “brakes (general)” and “inoperable lamp (other than head/tail).” For brake violations, this non-specificity was not a big problem, but with the lighting system, it presented a problem. One of the intended analyses relied on the ability to assign light violations to different areas on the truck. But while some of the violations indicate that the lamp in question was on the front or the rear of the truck, many do not. Of the 191 trucks with light violations, it was not possible to determine the area on the vehicle with the violation in 101. This made it impossible to carry out the intended analysis. As detailed as the LTCCS data are, there is always a demand for more specificity!

6.2 Brake adjustment

The LTCCS crash data files include a table of brake adjustment measurements. The table includes the brake type (air, hydraulic, or electric), adjustor type, chamber size, chamber type, stroke type, and stroke length. These data can be used to determine the state of adjustment for each brake and to characterize the overall state of the truck's braking ability. These measurements are not a direct and complete estimate of the stopping power of the brake system of the truck as configured at the time of the crash, because that depends on other factors, such as the amount of cargo loaded and how it is distributed on the truck, the number of axles, the air pressure in the brake system (for air braked trucks), the state of the brake drums and pads, and the available roadway friction, among other factors. However, brake adjustment by itself does usefully identify trucks with reduced braking capacity, which may have safety consequences in situations in which braking is critical.

The Commercial Vehicle Safety Alliance (CVSA) developed and publishes a set of guidelines and procedures to measure brake adjustment and to identify vehicles required to correct brake adjustment. These guidelines are used in FMCSA's truck inspection program to determine if a truck may safety operate. The data in the LTCCS Brakes table can be used to apply the guidelines and classify trucks. The CVSA guidelines set a stroke-length limit for each brake chamber size at which the brake must be adjusted. Brakes with stroke lengths more than .6 cm beyond the adjustment limit are considered defective. A truck with too many brakes out of adjustment is placed out of service until the condition is corrected.

In the CVSA guidelines, brakes with stroke-lengths beyond the limit are counted as out of adjustment (OOA). If the stroke is more than 0.6 cm beyond the adjustment limit, the brake is considered defective. Two brakes OOA are counted as one defective brake, and if 20 percent or more of the brakes on a truck are defective, the vehicle is placed out of service because of brake adjustment.

An algorithm was developed to apply—brake by brake—the CVSA brake adjustment guidelines and to classify each brake as in adjustment, OOA, or defective. Table 3 shows the strokelength ranges for each adjustment category for each brake chamber size. Only air brakes are included. After the brake state is determined for each brake on a vehicle, the 20 percent rule was applied to identify trucks that qualified as OOS due to brake adjustment. Trucks were then classified as all brakes within adjustment limits, some brakes OOA, or truck OOS due to brake adjustment.

There was sufficient information in the Brakes table to determine brake adjustment on 826 trucks.

Table 3 Adjustment Rules for Stroke Length and Chamber Size[4]

Adjustment	Chamber size and type (LS means long stroke)			
	9, 12	16, 20, 24	30, 24LS	36
Okay	<=3.5 cm	<=4.5 cm	<=5.1 cm	<=5.7 cm
Out of adjustment	>3.5 cm to <4.1 cm	>4.5 cm to <5.1 cm	>5.1 cm to <5.7 cm	>5.7 cm to <6.4 cm
Defective	>=4.1 cm	>=5.1 cm	>=5.7 cm	>=6.4 cm

Of the 826 LTCCS trucks for which there was sufficient data to determine the status of brake adjustment, only 510 or 61.7 percent had all brakes within the appropriate adjustment limits. Almost 20 percent of the trucks had one or more brakes out of adjustment, though not enough to put the vehicle out of service. Almost 20 percent of the trucks had enough brakes out of adjustment or inoperable to qualify as OOS due to brake adjustment alone.

Table 4 Truck Brake Adjustment, LTCCS

Adjustment status	Trucks	Percent
All brakes within adjustment limits	510	61.7
One or more brakes OOA, but not OOS	154	18.6
Truck OOS due to brake adjustment	162	19.6
Total	826	100.0

7 Results

In this section, we present and discuss the results of the NAS Level 1 inspections that was part of the investigation protocol for the trucks in the LTCCS crash file. The results of the inspections are stored in the TruckInspection data set. The TruckInspection data set provides a violation code that indicates the specific section of the Federal Motor Carrier Safety Regulations Code of Federal Regulations that was violated. For each violation, there is a field to indicate whether the defect was crash-related. Another field indicates whether the violation resulted in an "out-of-service" condition. There are valid inspection records for 1,001 (89.1 percent) of the 1,123 trucks involved in an LTCCS crash.

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[4] Adapted from CVSA North American Standard Out-of-Service Criteria Reference Charts, Appendix A of *North American Uniform Out-of-Service Criteria*. Commercial Vehicle Safety Alliance, 1997.

For these tables, as well as elsewhere in this report, only violations or OOS conditions that are coded as existing prior to the crash are included in the counts. Every effort has been made to exclude crash-induced damage. The TruckInspection table includes a field, ViolationType, that "indicates if a violation was in effect prior to the crash, or if the violation was a result of the crash." Possible codes are "pre-crash," "No," and "crash-related." Pre-crash and crash-related are clear, but it is not clear what the "no" code is intended to convey. However, it was determined that almost all the violations coded "no" were from a single PSU and further that many of the violations coded "no" were paper-work type violations, which on their face cannot be crash-induced. Accordingly, the violations coded "no" on ViolationType were all counted as pre-crash violations.

7.1 Incidence of violations and OOS conditions

Inspection results are available for 1,001 of the 1,123 medium and heavy trucks in the LTCCS crash file, which is about 89.1 percent of all the trucks. The tables show the number of trucks with an OOS condition or violation in separate sections of the table, and provide the number of trucks coded OOS (or violation) and the percentage of inspected trucks with the OOS (or violation). The frequencies in Table 5 through Table 8 are counts of trucks, not violations. (Data on the number of violations per truck will be presented subsequently.) In each case, the percentages in the tables are of the 1,001 trucks that were inspected. For example, Table 5 shows that 354 trucks were found with a pre-crash OOS condition on any inspection item, which amounts to 35.4 percent of the 1,001 trucks inspected. A total of 661 of the trucks had one or more violations of any inspection item.

The overall rates of OOS conditions and lesser violations are high. (See Table 5.) Over a third of the trucks involved in an LTCCS crash would have been placed out of service had they been inspected prior to the crash. Almost two-thirds of the trucks had one or more violations of the vehicle, carrier, or driver regulations. Classified broadly, there were more violations of vehicle-related regulations than those related to the driver or the carrier itself. This might be expected because many of the regulations have to do with vehicle systems, but there are also many related to driver licensing, qualifications, medical certification, and hours of service. Overall, 11.7 percent of the drivers had violations severe enough to be placed out of service, and over a third of the LTCCS truck drivers had one or more violations of the CFR. Considering vehicle-related inspection items, almost 30 percent had one or more OOS condition, and almost 55 percent had at least one violation.

Table 5 Aggregate Inspection Results for Drivers, Carriers, and Vehicles

	OOS		Violations	
	N	%	N	%
Any inspection item	354	35.4	661	66.0
Driver	117	11.7	349	34.9
Carrier	0	0.0	34	3.4
Vehicle	291	29.1	550	54.9

Table 6 isolates and provides more detail about driver-related OOS conditions and violations found in the inspections. The full and detailed set of violations, by CFR section number, can be found in the Appendix. Moving violations, that is, traffic violations related to the crash, are the most frequent category of driver violations, although log violations are the most common OOS condition. Log violations include false report, no record of duty status, or failure to keep the record of duty status current. Violations of driver qualification requirements—often a lack of medical certification or an expired certification—were the next most common set of driver violations, with about 6.2 percent of the drivers. Fewer than four percent of the drivers had hours of service (HOS) violations, and fewer than two percent had licensing problems (most often operating a vehicle without a commercial drivers license).

Table 6 Driver-related Inspection Results

Driver-related category	OOS		Violations	
	N	%	N	%
Moving violations	24	2.4	175	17.5
Driver log	63	6.3	169	16.9
Driver qualifications	11	1.1	62	6.2
Hours of service	18	1.8	38	3.8
Driver licensing	14	1.4	14	1.4
Driver, general	0	0.0	7	0.7
Driver, any item	117	11.7	349	34.9

Carrier items are shown separately to capture some of the inspection items that do not seem to reasonably capture characteristics of the vehicle or driver, but instead are more reflective of the motor carrier itself. The primary violation captured relates to vehicle markings. Either the vehicle did not have the proper DOT markings or the name and address of the carrier was not displayed. The "general" category in the table includes failing to possess the correct operating authority or failing to have liability insurance or a copy of the vehicle registration. None of the carrier violations constituted OOS violations.

Table 7 Carrier-related Inspection Results

	OOS		Violation	
	N	%	N	%
Vehicle marking	0	0.0	25	2.5
Carrier, general	0	0.0	9	0.9
Carrier, any	0	0.0	34	3.4

The most numerous violations recorded were for items that cover the mechanical condition of the truck. (Table 8.) The brake system accounts for both the highest percentage both of OOS vehicle conditions and of vehicle violations. Light system items (head lamps, marker and identification lights, tail lamps, and so on) are the second most numerous in terms of both OOS conditions and violations, but significantly lower percentages than the brake system for both OOS conditions and violations. Almost 20 percent of the inspected trucks had one or more violations in the light system (compared with over 36 percent for the brake system), but only 4.4 percent of the trucks had an OOS condition related to lights, which is much lower than the 19.1 percent who had a brake OOS condition.

Table 8 Vehicle-related Inspection Results

	OOS		Violation	
	N	%	N	%
Brake system	191	19.1	362	36.2
Lights	44	4.4	191	19.1
Inspection, maintenance	22	2.2	147	14.7
Tires	40	4.0	121	12.1
Cab & equipment	3	0.3	83	8.3
Load securement	35	3.5	50	5.0
Suspension	26	2.6	42	4.2
Exhaust system	0	0.0	29	2.9
Wheels	9	0.9	26	2.6
Windshield & windows	2	0.2	26	2.6
Steering system	11	1.1	21	2.1
Frame	6	0.6	20	2.0
Fuel system	7	0.7	12	1.2
Trailer coupling	7	0.7	12	1.2
Electrical system	0	0.0	10	1.0
Rear impact protection	0	0.0	4	0.4
Vehicle, any item	291	29.1	550	54.9

The inspection/maintenance items (including OOS and violations) were the next most common vehicle category. These items consist mostly of failure to inspect and violating the section of the CFR requiring “parts and accessories shall be in safe and proper operating condition at all times.” Over 12 percent of the inspected trucks had one or more violations of the requirements covering tire condition. The most common tire violations was inadequate tread depth, in some cases to the extent that the fabric of the tire carcass was exposed. Under-inflation was also a frequent tire problem, but not to the extent of the wear problems, though of course under-inflation and tire wear are often associated.

Many of the other systems had much lower rates of violations and problems. Load securement violations were noted for only 5.0 percent of the trucks; suspension problems for only 4.2 percent. Exhaust system, wheels, windshield and steering violations were identified in fewer than three percent of the trucks, and fuel system, trailer coupling, electrical system, and rear-impact protection in less than two percent. By far the most common violations of the CFR are violations in the braking system and in the lights.

Table 5 through Table 8 show the proportion of trucks with the inspection violations in mechanical systems, driver qualification and certification, and motor carrier. But many of the inspections turned up multiple violations for the same vehicle. Figure 1 shows the distribution of inspected trucks by the number of pre-crash vehicle violations identified. These are violations of any inspection item, and including those related to the vehicle, driver, or the motor carrier. Of course, 34.0 percent had no violations of any requirement prior to the crash, but about 17 percent had one violation and almost half had two or more violations. Twenty-three trucks, or 2.3 percent of all inspections, had ten or more violations, and there was one inspection with 19, one with 17, and one with violations to 16 inspection items.

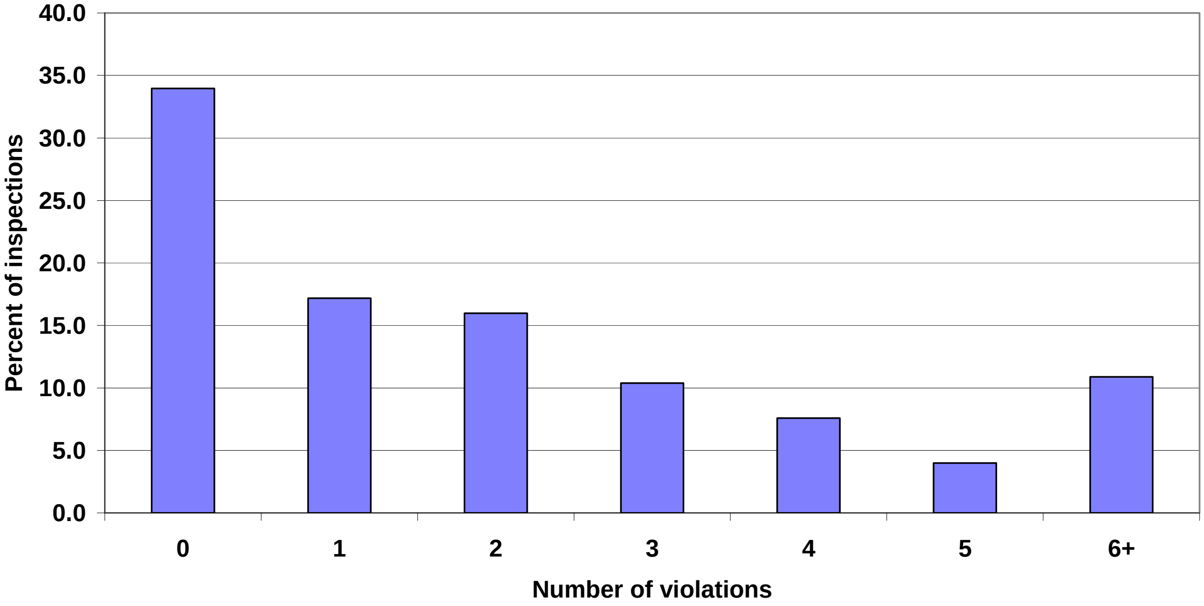

Figure 1 Number of Inspection Violations per Inspection, LTCCS

Figure 2 shows the distribution of driver violations alone, and shows that the large majority, 65.1 percent, of the drivers had no violations in any driver requirement. An additional 20.8 percent had only one violation, so over 85 percent of the inspections turned up zero or just one violation of the driver requirements. There were relatively few drivers with more than one violation. About 10 percent of the drivers had two, and only 4.5 percent had three or more. There was one driver who had violated six driver regulations, five who had violated three, and fourteen with four violations.

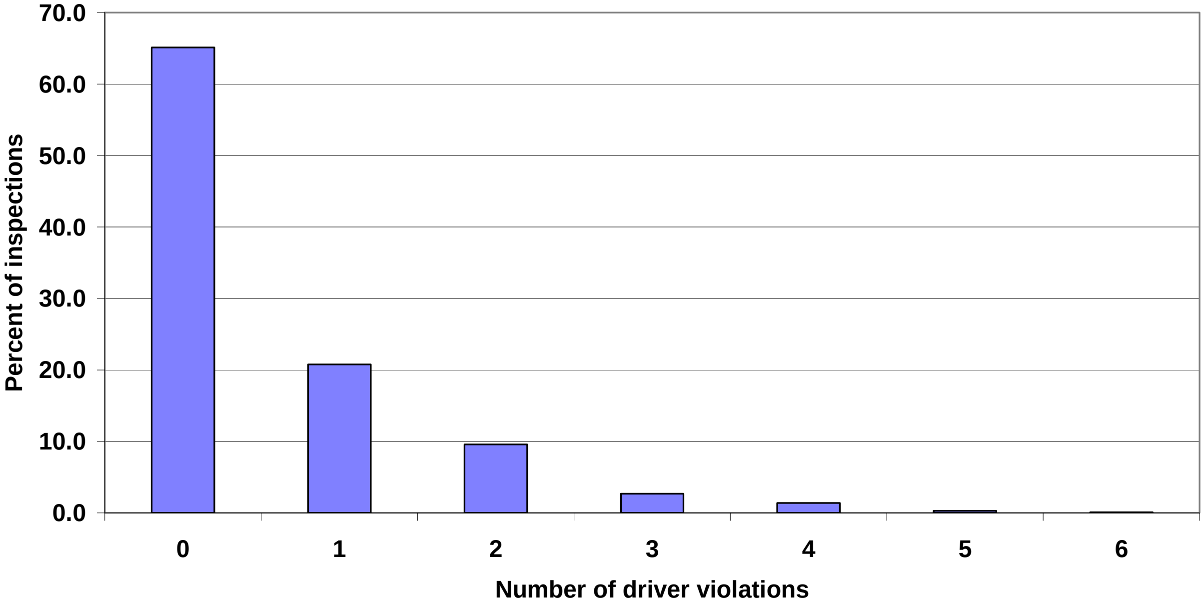

Figure 2 Number of Driver Violations per Inspection, LTCCS

Figure 3 shows the distribution of the number of vehicle violations coded per truck. Forty-five percent of the trucks in the LTCCS were found with no vehicle violations, and almost 63 percent had zero or only one violation. However, many trucks had multiple vehicle violations. Fifteen of the trucks had ten or more vehicle violations, with one truck each having 13, 14, 15, or 16 respectively. And this is just vehicle violations. In total, 37.1 percent had two or more vehicle violations, and 6.7 percent had six or more.

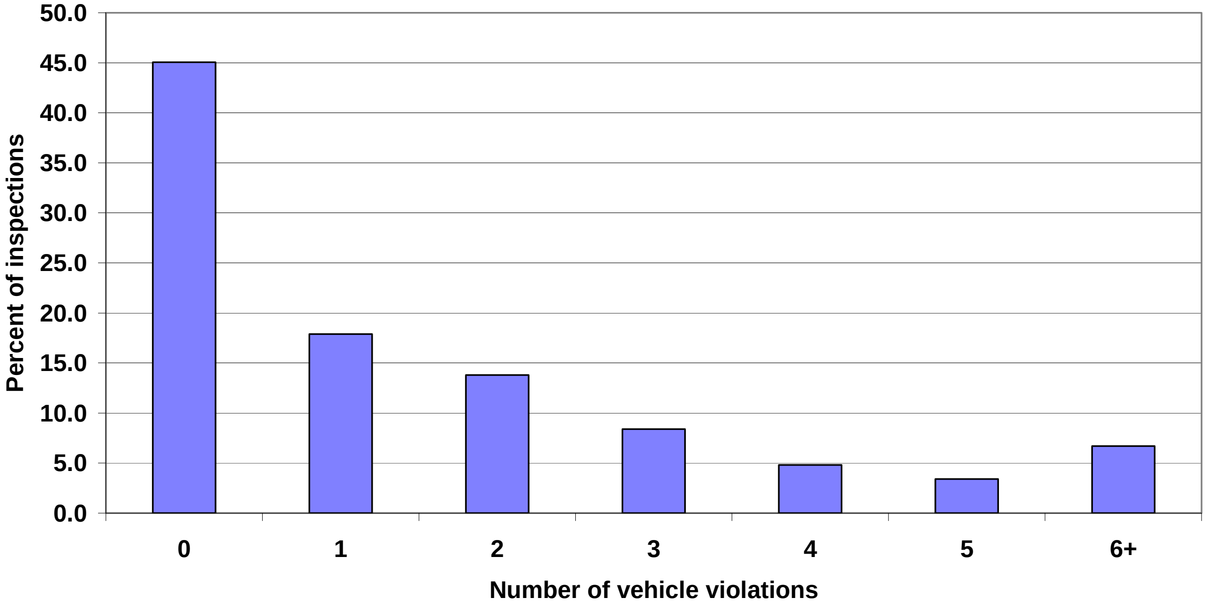

Figure 3 Number of Vehicle Violations per Inspection, LTCCS

Figure 4 shows the distribution of pre-crash OOS conditions by the number of OOS conditions per inspection. Almost 65 percent of the inspections showed no OOS conditions. Of the inspections that uncovered an OOS condition, in most cases it was only one. But many inspections found multiple pre-crash OOS conditions. Almost 10 percent had two OOS conditions, and almost seven percent had three or more. There were six inspections that found six OOS conditions, one with eight and one with 11 conditions, any one of which, if found prior to the crash, would have put the truck or driver out of service.

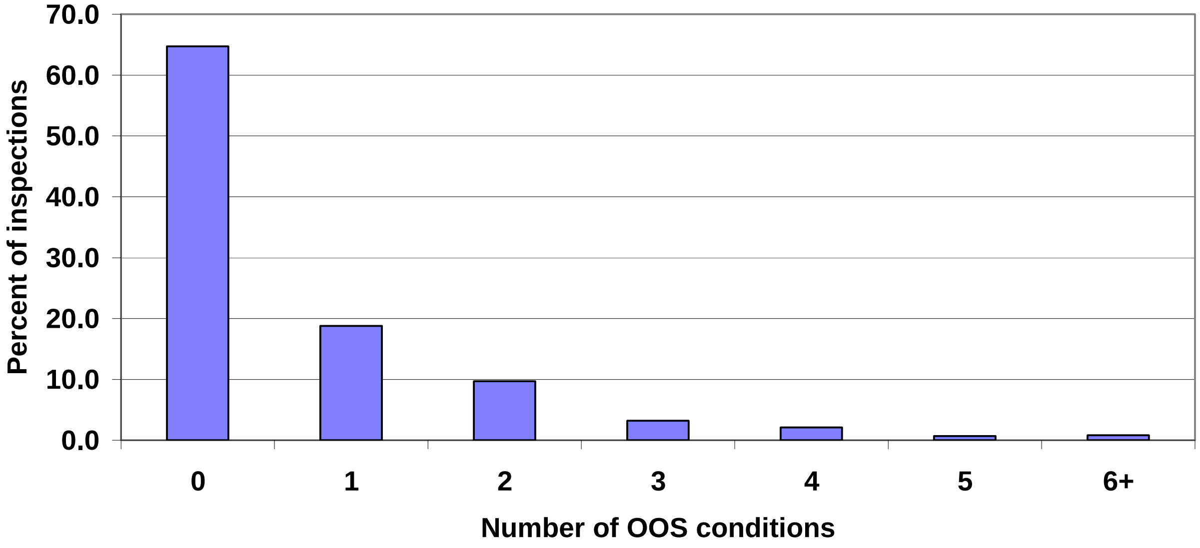

Figure 4 Number of OOS Conditions per Inspection, LTCCS

Figure 5, in combination with Figure 4, effectively shows that OOS conditions related to truck vehicle systems account for most of the pre-crash OOS conditions discovered in the truck inspections. The shape of the histogram in Figure 4 is very similar to that in Figure 5, and the histogram bars are just slightly lower for counts of one through six plus. While one might observe that the inspection is primarily oriented toward vehicle systems, in fact, many of the driver-related issues currently the focus of much research and regulatory attention are covered in the inspection, including unsafe driving acts, hours of service, driver logs, driver licensing, and medical certification. So it is fair to conclude that mechanical systems account for the bulk of OOS conditions identified in the post-crash inspections in the LTCCS.

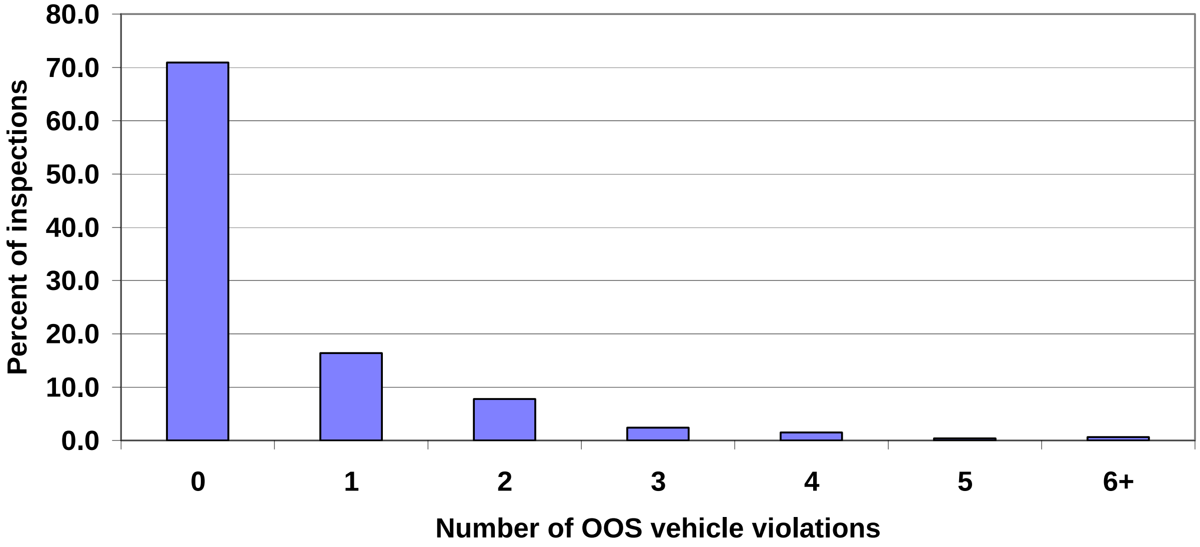

Figure 5 Number of Vehicle OOS violations per Inspection, LTCCS

The next set of tables (Table 9 through Table 11) show inspection results aggregated by truck configuration. Truck configuration is classified into standard categories, most of which are self-explanatory. A straight truck is a power unit with a permanently mounted cargo body, like a dump truck or a concrete mixer. A "bobtail" here refers to a tractor without a trailer. The tractor-trailer combination are almost all tractor-semitrailers. The tractor-doubles combination is a tractor with two trailers. (There were no triple-trailer combinations among the LTCCS crashes.) The "other" category consisted of one military vehicle with an unusual (in the civilian world) power unit/trailer combination.

The tables show the percentage of a given truck configuration recorded with a defect identified in the inspection, either an OOS condition or just a violation. Table 9 focuses on the incidence of OOS conditions by configuration, while Table 10 is limited to violations. For each proportion shown in a cell, a statistical test was performed, comparing the proportion of the item for that configuration against the aggregate for all other trucks. Thus, for example, it is shown in Table 9 that 36.6 percent of straight trucks were recorded with at least one OOS condition. A test was performed to determine if that proportion is significantly different from the proportion for the aggregate of all other trucks in an LTCCS crash. Proportions where the test has a *p* value of 0.05 or less are indicated with an asterisk in the tables.

Note that the tables show in the "total" row proportions for all trucks, but the comparisons by configuration were not made with the proportion for all trucks, but with the proportion for all other truck configurations. That proportion obviously differs for each configuration and is not shown separately in the tables.

The purpose of these tables is to examine the distribution of inspection defects by truck configuration, to see if there is any significant variation in vehicle condition by configuration. Different truck configurations can be used in potentially quite different trucking operations, so it would be important to know if significant variations in truck or driver condition, as reflected in the inspection results, are associated with different truck configurations. For example, tractor-doubles combinations are typically used in long-haul freight operations, terminal-to-terminal, on high speed, often Interstate-quality roads. On the other hand, straight trucks are more often used in local operations, such as pick up and delivery or dump truck operations. If there were a significant association of inspection results with truck configuration, it would be necessary to include truck configuration in examining the relationship between mechanical condition and crash involvement.

Table 9 shows the proportion of OOS conditions on selected items by truck configuration. The items are any OOS condition, an OOS condition related to the driver, an OOS condition related to the vehicle, a brake OOS condition or an OOS condition related to the light system. The number of trucks is also provided to show the amount of data available for the comparisons. For each inspection category, the percentage of the truck configuration with the condition is compared to the aggregate of all other trucks in the LTCCS. For the comparison of any item, vehicle, brakes, or lights, none of the percentages for any configuration is statistically significantly different from all other trucks. There is some variation across the configurations, of course. Almost 39 percent of straight trucks with a trailer had an OOS condition on at least one inspection item, while only 25.9 percent of bobtails had an OOS condition, but neither of those percentages were statistically significantly different from the proportion for all other trucks, respectively. This is in part due to the fact that there were only 39 straights with trailer and only 27 bobtail tractors in the LTCCS, but overall there is little evidence here to support any significant difference in OOS conditions by truck configuration.

Table 9 Proportion with OOS Condition, Selected Items, by Truck Configuration, LTCCS

Truck configuration	Percentage with OOS condition					Number of trucks
	Any	Driver	Vehicle	Brakes	Lights	
Straight truck	36.6	9.7	29.0	16.8	5.0	238
Straight + trailer	38.5	12.8	30.8	15.4	7.7	39
Bobtail	25.9	3.7*	22.2	18.5	7.4	27
Tractor-trailer	35.6	13.2*	29.1	20.9	3.6	646
Tractor-doubles	30.0	6.0	26.0	10.0	8.0	50
Other	0.0	0.0	0.0	0.0	0.0	1
Total	35.4	11.7	28.8	19.1	4.4	1,001

* Statistically different from the aggregate of all other truck configurations, $p<0.05$.

Overall, 28.8 percent of trucks had at least one vehicle OOS, but the range of proportions is reasonably tight across the different configurations, ranging from 22.2 percent for bobtails to 30.8 percent for straight trucks with a trailer. The vehicle OOS rate is virtually identical for the most common configurations—tractor with one trailer and straight truck with no trailer. These two combinations account for 884 of the 1,001 trucks inspected (88.3 percent). Similarly, the range for brake OOS conditions is also reasonably tight. Only 10.0 percent of tractor-doubles had a brake OOS condition, but since there were only 50 doubles combinations in the data, the percentage was not significantly different from the proportion for all other trucks.

The only significant differences were for the driver OOS category, and only for bobtails and tractor-semitrailers. Only 3.7 percent of bobtail drivers were found with an OOS driver condition, while 13.2 percent of tractor-semitrailer drivers had an OOS condition. The percentage difference from all other trucks is large (over eight percentage points) for bobtail drivers, but the number of bobtails is small, with only 27. On the other hand, the percentage for tractor-semitrailers was only four percentage points higher than the average for all other trucks, but tractor-semitrailers account for almost 65 percent of the trucks.

There were almost no significant differences by truck configuration when comparing the proportion of violations, either. (Table 10.) Only tractor-semitrailers and tractor-doubles differed significantly and then only for driver violations. Almost 38 percent of drivers of tractor-trailers had at least one driver violation, which is 7.8 percent higher than the proportion for all other trucks. Only 22.0 percent of tractor-doubles drivers had a violation, which is 13.5 percentage points lower than the average for all other configurations. But in terms of any inspection item, or any vehicle item, or violations in the brake system or lighting system, there were no significant differences between the truck configurations. There are variations of course, but the size of the variations are not large enough to meet the 0.05 criterion for statistical significance.

Table 10 Proportion with Violations, Selected Items, by Truck Configuration, LTCCS

Truck configuration	Percentage with violation					Number of trucks
	Any	Driver	Vehicle	Brakes	Lights	
Straight truck	66.0	31.1	52.5	31.5	18.9	238
Straight + trailer	64.1	28.2	59.0	38.5	12.8	39
Bobtail	55.6	37.0	44.4	29.6	22.2	27
Tractor-trailer	67.2	37.6*	53.9	37.9	18.9	646
Tractor-doubles	60.0	22.0*	54.0	38.0	26.0	50
Other	0.0	0.0	0.0	0.0	0.0	1
Total	66.0	34.9	53.4	36.2	19.1	1,001

* Statistically different from the aggregate of all other truck configurations, $p<0.05$.

Finally, Table 11 focuses just on brake adjustment, as recorded in the Brakes table. It shows the percentage of each truck configuration with one or more brakes out of adjustment, and the percentage OOS due to brake adjustment, along with the number of trucks for which there was sufficient data to determine brake adjustment. In terms of brakes out of adjustment, there were no significant differences between truck configurations. It is notable that about 37 to 39 percent of each configuration had one or more brakes out of adjustment, except for bobtails (44.0 percent) and tractor-doubles (42.9 percent). But these differences are not large enough to be meaningful. It is only when OOS due to brake adjustment is considered that there is a significant difference. Only 10.2 percent of tractor-doubles had enough brakes out of adjustment to be OOS. The rate for the aggregate of all other configurations is about 9 percentage points higher. The rate for doubles is also about half of the rates for some of the other individual configurations, such as straight trucks and tractor-trailers, the two most common configurations. The lower rate for doubles may reflect the operations of the vehicles, which may be less demanding on the brake system. But other than that one exception, there are no significant differences by truck configuration in brake adjustment.

Table 11 Brake Adjustment by Truck Configuration, LTCCS

Configuration	Percent with one or more brakes out of adjustment	Percent out of service due to brake adjustment	Number of trucks
Straight truck	38.8	19.4	170
Straight + trailer	38.5	15.4	26
Bobtail	44.0	20.0	25
Tractor-trailer	37.3	20.5	555
Tractor-doubles	42.9	10.2*	49
Other	100.0	100.0	1
Total	38.3	19.6	826

* Statistically different from the aggregate of all other truck configurations, $p<0.05$.

7.2 Association of inspection results and crash role

The effect of vehicle mechanical condition on crash risk can be examined in two basic approaches, in two different ways. The first way partitions the crashes using the critical reason variable. The critical reason (CR) in the LTCCS records the specific driver, vehicle, or environmental reason for the precipitating event in the crash. Only one vehicle in a crash is assigned a critical reason, so the variable can be used to broadly classify vehicles by whether they initiated the crash or not. This approach classifies the vehicles by whether some action of the truck or driver precipitated the crash, or not. Trucks that are not given a "critical reason" can be considered as playing a secondary role or even not contributing to the crash. In these cases, some action of another vehicle initiated the crash sequence, so no failure or condition within the truck was primarily responsible for initiating the crash. Of course, crashes can be the product of a whole series of failures and errors, and vehicles not assigned the critical reason can contribute to the crash. But the variable does identify the vehicle that precipitated the crash, and therefore the vehicle where the initiating failure occurred.

The second approach to evaluating the effect of mechanical condition on crash risk more directly connects the mechanical condition of the vehicle to the events of the crash. The mechanical systems of the truck affect the performance and behavior of the vehicle in different ways. The brake system is responsible for slowing and stopping the vehicle. The steering system is used to maintain directional control. The lighting system aids the driver to see in low light conditions, and also provides markers and information to other drivers on the road, through signals and stop lamps. The securement of the load affects the handling of the vehicle in maneuvers. Thus, defects in mechanical systems would be expected to affect the behavior of the truck in different ways, and to contribute to different types of crashes. Brakes are critical to stopping the vehicle, so the braking system would affect crash roles where stopping or slowing is the primary means of avoiding the crash. In other crash roles, for example, where the truck is already stopped, brakes are not important. Accordingly, this method proceeds by identifying crash types and crash roles that implicate a particular mechanical system and by developing a model to test if the hypothesized association is consistent with the data.

This latter method provides the strongest evidence that mechanical condition of trucks contributes to crash risk. The statistical model can show a reliable association between the vehicle condition or factor and a crash, but the physical mechanism provides the underlying explanation for the association.

It should be noted that a detailed evaluation of vehicle condition is only available for trucks. There was no similar inspections of the automobiles and other light vehicles involved in the crash. There is some data on the condition of light vehicles, but it is only captured in the most egregious cases.

In the discussion that follows, the two methods will be taken up in turn. First, the results of an analysis of the assignment of critical reason is presented, showing the association of the assignment of critical reason with different violations and defects uncovered by vehicle inspection. Two statistical models are developed to test the association and control for confounding factors. Next, a "brake-relevant" crash type is developed. The association of the inspection results with the brake-relevant crash type is explored, and three statistical models developed to show how the condition of different mechanical systems are related.

7.3 Crash role defined by critical reason

The "critical reason" is the immediate reason for the precipitating event in the crash, which is known as the "critical event." Only one vehicle in a crash is assigned the critical reason; critical reason thus identifies the vehicle that precipitated or initiated the crash, as well as specifies the immediate failure that led to the critical event. In this way, critical reason can be used to identify the driver/vehicle that primarily contributed to the crash. And, of course, the critical reason identifies the immediate failure in that driver/vehicle.

In this section, we use a variable CR, which is binomial, coded 0 where the vehicle is not assigned the critical reason and 1 where the vehicle is assigned the critical reason. CR can serve as a convenient high-level identification of the driver/vehicle that primarily contributed to the crash. The critical reason variable itself is constructed of sets of "sub-reasons" that identify specific failures—in driver actions or inaction, vehicle failures, and environmental conditions that precipitated the crash. These failures are just the immediate failure or reason. They do not preclude other factors that may have contributed. In fact, the thrust of the design of the LTCCS data set is to enable researchers to identify multiple factors that may contribute to a crash. If a driver decision is implicated in precipitating a crash, the design of the LTCCS allows the identification of other factors that may have also contributed to the crash, including factors that may have pre-conditioned or constrained the driver's decision or action.

Accordingly, if vehicle condition or the other items covered by the inspection contribute to the failures that lead to crashes, one would expect there to be an association with critical reason. Table 12 shows the set of vehicle, driver, and carrier factors covered in the vehicle inspection, along with a number of additional factors of interest. Each factor is examined separately for association with the assignment of CR. The column labeled "cases w/condition" shows the number of trucks with the inspection result. For example, 22 of the inspected trucks had a pre-crash OOS condition categorized as related to the carrier. The driver had an OOS condition in 117 inspections, and so on. The next two columns show the percentage of trucks with the condition that were assigned the CR in the crash; and the percentage of trucks without the factor that were assigned the CR. The last column shows the p-value of a t-test of the difference between the two percentages. Values less than 0.05 are considered statistically significant.

The top of the table displays the results for condition that cause a vehicle or driver to be placed out of service. The bottom of the table shows three factors present in the crash, though not part of the inspection. These are Daylight, Load, and Surface. Daylight and Surface both capture important factors in the environment that may be associated with CR or interact with specific inspection results. Daylight is developed from the LTCCS variable for light condition at the time of the crash, and is aggregated into daylight and all other light conditions (chiefly dark, unlighted). Surface is derived from the road surface variable, and is categorized as dry or all other conditions (chiefly wet). Load reflects cargo load, represented as the percentage of cargo capacity occupied by the cargo, and is split between trucks with less than 50 percent of capacity and those with more. In developing this variable, it was noted that the distribution of cargo capacity is strongly bimodal, reflecting that most trucks are either virtually empty or almost full. The mean percentage of capacity for cases assigned Load=0 is 10.2 percent, while the mean for the Load=1 condition is 91.4 percent. Thus the population of trucks falls naturally into the two groups. For each of the inspection items, the results are recorded as present or not present.

Table 12 Association of Vehicle Inspection Results and Other Factors with Assignment of Critical Reason

Factor	Cases w/factor	% CR given factor	%CR w/o factor	T-test of difference
Out of service measures				
Any OOS	354	57.1	47.9	0.01*
Carrier OOS	22	63.6	50.9	0.24
Driver OOS	117	70.1	48.6	<0.0001*
Mechanical OOS	291	55.3	49.4	0.09
HOS OOS	18	55.6	51.1	0.71
Log OOS	63	73.0	49.7	0.00*
Brake OOS (adjustment)	162	63.0	48.4	<0.001*
Brakes OOS	191	57.6	49.6	0.05*
Cab OOS	3	66.7	51.1	0.59
Coupling OOS	7	57.1	51.1	0.75
Frame OOS	6	83.3	50.9	0.11
Fuel OOS	7	14.3	51.4	0.05
Load securement OOS	35	54.3	51.0	0.71
Lights OOS	44	52.3	21.1	0.88
Steering OOS	11	72.7	50.9	0.15
Suspension OOS	26	53.9	51.1	0.78
Tires OOS	40	60.0	50.8	0.25
Wheels OOS	9	66.7	51.0	0.35
Windshield OOS	2	50.0	51.2	0.97
Violations				
Any violation	661	55.8	42.1	<.0001*
Carrier	34	50.0	51.2	0.89
Driver	349	63.9	44.3	<0.0001*
Mechanical violation	550	52.6	49.5	0.33
HOS	38	65.8	50.7	0.07

Factor	Cases w/factor	% CR given factor	%CR w/o factor	T-test of difference
Log	169	62.7	48.8	0.00*
Brakes	362	56.4	48.2	0.01*
Cab	83	47.0	51.5	0.43
Coupling	12	50.0	51.2	0.94
Electrical	10	50.0	51.2	0.94
Frame	20	55.0	51.1	0.73
Fuel	12	25.0	51.5	0.07
Lights	191	49.2	51.6	0.55
Load securement	50	58.0	50.8	0.32
Steering	21	61.9	50.9	0.32
Suspension	42	45.2	51.4	0.43
Tires	121	56.2	50.5	0.24
Wheels	26	65.4	50.8	0.14
Windshield	26	50.0	51.2	0.91
Selected additional measures				
Daylight	741	54.4	41.9	0.00*
Load	456	55.5	44.9	0.00*
Surface	839	51.9	47.5	0.31

* significant <0.05 level

Several items of inspection results are shown to be associated with the assignment of CR. An OOS condition itself, from any source, is strongly correlated with the assignment of CR, for example. Over 57 percent of trucks placed OOS for any reason were assigned the CR, compared with only 47.9 percent of trucks not OOS. The relationship with Driver OOS was even stronger. Over 70 percent of trucks with a Driver OOS condition were assigned the CR, compared with 48.6 percent of those with no Driver OOS condition. Driver OOS is obviously a subset of the overall OOS, and the other general classifications—OOS due to any mechanical condition and OOS due to a carrier-associated factor—were not significantly associated with CR. Among subsets of the driver items, OOS due to log violations (Log OOS) was significantly correlated with CR, while OOS related to hours of service violations (HOS OOS) was not correlated.

In general, specific mechanical systems OOS conditions were not found to be associated with CR. Load securement, Lights, Steering, Suspension, Tires, Wheels, and Windshield all failed to show a statistically significant association with CR. However, it is worth pointing out that in many cases, trucks with the condition were disproportionately assigned the CR, but the number of cases was not large enough to achieve statistical significance. For example, 72.7 percent of trucks with a steering system OOS condition were assigned the CR, compared with only 50.9 percent of trucks with no steering OOS condition. But there were only 11 trucks with the Steering OOS condition, too few for reliable results. Similarly, trucks identified as Tire OOS were coded with the CR in 60.0 percent of cases, compared to 50.8 percent CR for trucks without a Tire OOS condition. The difference is substantial and of practical significance, but it is not statistically reliable, because it is based on only 40 trucks with the Tire OOS condition.

However, note that brake OOS due to brake adjustment is strongly associated with CR. About 63.0 percent of trucks OOS due to brake adjustment were assigned the CR, compared to only 48.4 percent of trucks that did not have a brake OOS due to adjustment. This difference is highly significant, since the number of trucks with the brake OOS condition related to adjustment was large, 162. In addition, any brake OOS condition was also associated with CR. Of the 191 trucks with an OOS brake condition, 57.6 percent were assigned the CR, compared to 49.6 percent of trucks with no OOS brake condition. The brake system, especially brake adjustment, was the one system associated with the assignment of CR.

The same pattern was visible for violations short of OOS. Driver, especially log, violations were associated with being assigned the CR. The CR was slightly overrepresented among trucks that had any violation in any mechanical system, but, even though the number of trucks with a mechanical violation was large (550 trucks), the difference was too small to be significant, statistically or otherwise. However, as in the case of the brake OOS condition, brake violations were associated with CR, and the difference was statistically significant at the 0.01 level.

Three non-inspection items were also included in Table 12. Trucks involved in crashes in daylight were more likely to be assigned the CR than trucks in crashes at other times. In 54.4 percent of daylight crashes, the truck was assigned the CR in the crash, compared with 41.9 percent in other light conditions. It is unknown why this might be the case, though it could be speculated that the difference may be partially explained by the overrepresentation of impaired drivers of other vehicles (i.e., passenger cars) at night. Conspicuity of the truck at night might also play a role, as well as the greater traffic density during daylight hours. Recalling that the Load variable categorizes trucks as lightly loaded (mean of 10.2 percent of cargo capacity) and loaded (mean of 91.4 percent of cargo capacity). Note that 55.5 percent of trucks in the heavily loaded condition were assigned the CR, compared to only 44.9 percent of the lightly loaded. One explanation could be related to degraded handling and performance of heavily loaded vehicles. Finally, road surface condition was examined, to test if road surface friction was related to CR, and no association was found.

7.3.1 Statistical models

Logistic regression is an appropriate statistical tool when the outcome variable is binomial, that is, 1 or 0. In this study, two outcome variables are modeled: whether the truck is assigned the critical reason (CR=1 or CR=0) and whether the truck is in the BR=1 crash role (BR=1 or BR=0). Logistic regression allows statistical models to be developed to describe the relationship between the predictor or explanatory variables and the response or outcome variable, where the outcome variable is either 1 or 0. Statistical models allow factors to be evaluated in the presence of other factors that also influence outcomes, in effect to "control" for the effect of different factors. Logistic regression is a standard method of modeling binary outcomes, i.e., outcomes that are either one (the outcome of interest) or zero (the appropriate comparison group).

The form of the logistic regression for a single predictor variable is:

$$\log\left[\frac{\pi(x)}{1-\pi(x)}\right] = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_n x_{in}$$

Where $\pi(x)$ is the probability of the outcome variable, given x;

α is the intercept
β_n are the parameter coefficients;
x_{in} are the predictor variables.

In a logistic regression model, the parameter coefficients (β_n) show the effect of the predictor variables (x_{in}) relative to the *baseline* case. The baseline case is usually chosen to be the case with the lowest probability of the outcome variable. In the case of the CR models, the baseline case is the case with the lowest probability that the truck is assigned the CR, so it would be the case that has the fewest of the risk factors, e.g., no driver OOS, no brake OOS, and so on. The parameters then estimate the *increase* in the probability of CR when the risk factors are added, for example, when the driver is OOS, brakes are OOS, and so on.

The parameter coefficients in the logistic regression model can be interpreted as *odds ratios*, that is, the ratio of the odds of the outcome variable given the factor of interest to the odds of the outcome variable without the factor of interest. Another way of putting it is the odds of the outcome in the cases to the odds in the controls. Table 13 provides data for a simple example of the use of odds ratios. The data are frequency counts of trucks by assignment of CR in the crashes (CR=1 or CR=0) and by whether the trucks had a brake OOS condition.

Table 13 Contingency Table of CR Assignment by Brake OOS Condition

Outcome	Brake OOS	No brake OOS
CR=1	102	387
CR=0	60	423

The odds of brake OOS for CR=1 case = 102/387 ≈ 0.26. The odds of brake OOS for the CR=0 case = 60/423 ≈ 0.14. The odds ratio is 0.26/0.14 ≈ 1.9, indicating that brake OOS increases the odds of the CR=1 crash role compared to CR=0 by a factor of about 1.9.

7.3.2 Logistic regression model of critical reason

The motivation for modeling CR is to estimate the effect of vehicle factors that are associated with CR, while controlling for the effect of other factors. Logistic regression is an appropriate tool to model a categorical response or outcome variable. In this case, we model a binomial response variable (CR=0 or 1), with predictor or explanatory variables. Table 14 shows the variables in the CR Model 1. CR is the response variable: the truck is either assigned the critical reason (CR=1) or it is not. The other variables in the table are the predictor variables, and capture information from the vehicle inspections or other factors in the crash. HOS indicates that the driver had committed an hours-of-service violation. Log OOS indicates that the driver's log had sufficient violations to place him out-of-service. Brake OOS captures trucks with sufficient brake adjustment violations to be placed OOS. The Load variable captures the percentage of cargo capacity occupied by the load. It has two levels—less than 50 percent and more than 50 percent--but the reader is reminded that the distribution of load capacity occupied was strongly bimodal, with most of the cases in the <50 percent of capacity having 10 percent or less, and most in the >50 percent of capacity having 90 percent or more. Finally, Daylight distinguishes day light conditions from all others (primarily dark).

Table 14 Factors and Definitions in CR Model 1

Factor	Definition
CR	0=Truck not assigned critical reason. 1=Truck assigned critical reason.
HOS	0=No HOS violations 1=One or more HOS violations
Log OOS	0=Not OOS due to log violations 1=OOS due to log violations
Brake OOS (adjustment)	0=Not OOS due to brake adjustment 1=OOS due to brake adjustment
Load	0=Less than 50% capacity 1=More than 50% capacity
Daylight	0=Not daylight 1=Daylight

In the modeling, the baseline case was chosen to be the case with the following values for the predictor variables:

HOS:	0=No HOS violations
Log OOS:	0=Not OOS due to log violations
Brake OOS:	0=Not OOS due to brake adjustment
Load:	0=Less than 50% capacity
Daylight:	0=Not daylight

Initially, all the factors listed in Table 12 above were considered in developing the model. However, most were found to have no association with CR, but the factors listed in Table 14 were found to produce a satisfactory model. Table 15 shows the parameter coefficients, standard errors, and statistical significance of the factors in the model. All of the factors except HOS are significant at better than the 0.05 level. The HOS variable is retained because the statistical significance is very close to the 0.05 level and the size of the effect is large. Note that the factors in the model include driver (HOS and log), vehicle (brakes and load), and environmental (daylight) factors.

Table 15 Parameter Estimates, Standard Errors, and Significance
Logistic Regression Model 1 of CR

Parameter	DF	Coefficient	Standard error	Chi-Square	Pr > ChiSq
Intercept	1	-0.7630	0.1772	18.5482	<.0001
HOS	1	0.6941	0.3658	3.6008	0.0578
OOS_log	1	0.7996	0.3242	6.0851	0.0136
Brake_OOS	1	0.6095	0.1943	9.8404	0.0017
Load	1	0.3962	0.1472	7.2394	0.0071
Daylight	1	0.5047	0.1710	8.7064	0.0032

Table 16 shows the odds ratios associated with the factors in CR Model 1, along with the 95 percent confidence intervals. OOS_log has the largest effect, increasing the odds of being assigned the critical reason by over 2.2 times, with a range of 1.2 to 4.2 times. HOS violations (not necessarily OOS) increases the odds of CR=1 by about two times, ranging from 1.0 to 4.1, though the range just includes one. Brake_OOS (out of service due to brake adjustment) increases the odds by 1.8 times, with a 95 percent confidence interval from 1.3 to 2.7, while being loaded over 50 percent capacity increases the odds of CR=1 compared with the baseline case by 1.5 times. Finally, the odds of being CR=1 are increased by 1.7 times, with a range of 1.2 to 2.3, in daylight compared to the baseline case.

Table 16 Odds Ratios and 95% Confidence Intervals
for Parameters of Model 1 of CR

Effect	Ratio	Odds ratio	95% confidence interval	
			Lower bound	Upper bound
HOS	1 vs. 0	2.002	0.977	4.100
OOS_log	1 vs. 0	2.225	1.179	4.199
Brake_OOS	1 vs. 0	1.840	1.257	2.692
Load	1 vs. 0	1.486	1.114	1.983
Daylight	1 vs. 0	1.656	1.185	2.316

The interpretation of some of these factors is obvious, but others might be more subtle. Both HOS and log violations might be related to fatigue, and HOS certainly indicates driving excessive hours. Log violations severe enough to warrant an OOS condition also are consistent with excessive hours, and many of the violations were for falsifying the log. With respect to the mechanical condition of the vehicle, the condition that came through was an OOS condition due to brake adjustment. That is, the brakes on the truck were sufficiently out of adjustment to warrant placing the vehicle out of service.

The effect of the Load variable may be because a heavily loaded vehicle is less maneuverable and takes longer to stop. (The significance of this variable raises the possibility of an interaction with the Brake_OOS variable.) Finally, Daylight is associated with a higher probability of CR=1 for the truck compared with the baseline. This has no direct and obvious interpretation, but note that the baseline case is primarily at night, and all types of crashes are included. Some work has shown that at night, other drivers are much more likely to be fatigued and under the influence of alcohol. So the reason that the Daylight variable is significant could be partly explained because other drivers are more likely to be assigned the critical reason at night, because of fatigue or alcohol.

The CR Model 1 fits the data quite well. Table 17 shows the results of the Hosmer Lemeshow test, a standard option in many statistical software packages to test how well the model fits the data. Hosmer Lemeshow partitions the data into different groups formed by the combination of the levels of the factors. For each group thus created, the number of cases observed with CR=1 in the group and the number predicted by the model are shown. The groups are formed in terms of increasing probability of CR=1. That is, group 1 is the baseline case, and the other groups are aggregated to have an increasing probability of CR=1. When the test is performed on the data in CR Mode 1, the number predicted for each of the groups is quite close to the number observed, which indicates that the model predicts the data well. The Chi-square test statistic shows that the distribution of the observed and expected counts is quite similar.

Table 17 Test of Goodness-of-Fit CR Model 1 (Hosmer Lemeshow Test)

		CR=1		CR=0	
Group	Total N	Observed	Expected	Observed	Expected
1	62	23	19.7	39	42.3
2	82	34	33.6	48	48.4
3	220	98	95.9	122	124.1
4	18	6	8.5	12	9.5
5	225	112	120.2	113	104.8
6	82	47	48.0	35	34.1
7	106	81	75.1	25	30.9

Chi-square=5.1698; DF=5; p=0.3955

The discussion of CR Model 1 noted the possibility of an interaction between brake adjustment, as captured in the Brake_OOS variable, and cargo loading, captured in the Load variable. The physical basis of the interaction is that lightly-loaded or empty trucks may have all the stopping power they need even if their brakes are not fully adjusted, simply because they are not fully loaded and so do not demand the same amount of stopping power as a fully loaded vehicle. On the other hand, a truck that is heavily loaded needs fully adjusted brakes to stop within limits.[8] Thus the combination of Load=1 and Brake_OOS=1 would be expected to have a larger effect on CR=1 than either factor alone.

In Model 2 of CR, an interaction term was added to the model, interacting Load and Brake_OOS. Table 18 shows the resulting parameter coefficients, standard errors, and statistical significance of each term. The coefficients for HOS, OOS_log, and Daylight are all virtually the same as their values in CR Model 1 (Table 15). Each is statistically significant at about the same level as in CR Model 1. But the coefficients for the main effects of Brake_OOS and Load are much smaller than in the earlier model, and neither is statistically significant here, while in the earlier model, they were each highly significant. On the other hand, the coefficient for the interaction term—where Load=1 and Brake_OOS=1—is the largest in the model and it just barely fails the 0.05 test of significance. The risk of CR=1 is much greater for a loaded truck with OOS brakes due to adjustment, than for either a truck with OOS brakes or a loaded truck by itself.

Table 18 Parameter Estimates, Standard Errors, and Significance
Logistic Regression Model 2 of CR

Parameter	DF	Coefficient	Standard Error	Chi-Square	Pr > ChiSq
Intercept	1	-0.6851	0.1813	14.2852	0.0002
HOS	1	0.6966	0.3674	3.5942	0.0580
OOS_log	1	0.7502	0.3272	5.2563	0.0219
Brake_OOS	1	0.2017	0.2853	0.4998	0.4796
Load	1	0.2697	0.1605	2.8222	0.0930
Daylight	1	0.4953	0.1715	8.3414	0.0039
Brake_OOS*Load	1	0.7727	0.3986	3.7581	0.0526

Table 19 shows the odds ratios for the parameters that were not interacted. The odds ratios are about the same for each as they were in CR Model 1 (Table 16). Odds ratios for Brake_OOS, Load, and Brake_OOS*Load are not shown. Because of the interaction term, neither is meaningful by itself, in comparison with the baseline case. But the effect of the combination of a loaded truck with an OOS brake condition can be estimated by summing the appropriate coefficients and exponentiating. Note that in the equation below, the total effect of Brake_OOS and Load is estimated by adding the main effects for Brake_OOS and Load and the interaction effect for Brake_OOS*Load:

$$e^{(0.2017+0.2697+0.7727)} = e^{1.2441} = 3.4798$$

The effect of the combination of brake adjustment OOS and a full load is to increase the odds of a truck being assigned the critical event by 3.5 times.

Table 19 Odds Ratios and 95% Confidence Intervals for Parameters of Model 2 of CR

Effect	Ratio	Odds ratio	95% confidence interval	
			Lower bound	Upper bound
HOS	1 vs. 0	2.007	0.977	4.124
OOS_log	1 vs. 0	2.117	1.115	4.021
Daylight	1 vs. 0	1.641	1.173	2.296

The addition of the interaction term significantly improves the fit of the model. Table 20 shows the Hosmer Lemeshow Test, with the number observed and expected with the data partitioned into groups ordered by the probability of CR=1. The fit is very tight. The Chi-square test of association shows the distribution of the observed cases and the expected cases across the groups is almost identical.

Table 20 Test of Goodness-of-Fit CR Model 2 (Hosmer Lemeshow Test)

Group	Total	CR=1		CR=0	
		Observed	Expected	Observed	Expected
1	74	25	25.4	49.0	48.7
2	82	34	32.6	48.0	49.4
3	220	98	99.6	122.0	120.4
4	51	29	25.7	22.0	25.3
5	225	112	117.0	113.0	108.0
6	70	47	44.6	23.0	25.4
7	73	56	56.2	17.0	16.8

Chi-square=1.8138, DF=1; p=0.87

7.4 Crash roles related to defective systems

In thinking about the association of the mechanical condition of the truck and crash involvement, the essential method is to consider the different systems and how they relate to crash involvement.

In crashes involving other vehicles, there are primarily two active means of evading the crash, either by stopping or by steering around the conflict. Some crashes might be evaded by acceleration, but trucks typically are not capable of rapid acceleration, so that mode of crash avoidance will be excluded here.

Accordingly, the primary means of active crash avoidance in terms of the mechanical systems of the truck are those that aid in stopping the vehicle and those that aid in controlling the vehicle in maneuvers.

Passive crash avoidance can be accomplished by the conspicuity of the vehicle, that is, the extent to which the vehicle is readily perceived by other road users. In terms of the physical and mechanical systems of the vehicle, conspicuity is primarily accomplished though the light system on the vehicle. The light system includes tail and stop lamps, marker and identification lamps, as well as the reflective tape systems on trailers.

Brake system violations were the most common mechanical system violations found in the inspection data on the LTCCS crashes. Over 36 percent of inspected trucks had one or more brake violations and 19.1 percent had sufficient brake violations to warrant an OOS condition. That is, the condition of the brake system was such that the vehicle would have been placed out of service, if it had been inspected prior to the crash.

The light system was the second most common mechanical system to be found in violation in the post-crash inspections. Over 19 percent of the inspected trucks were found with one or more pre-existing violations in the light system, though few qualified as OOS conditions. Only 4.4 percent of the light system violations qualified as an OOS condition, meaning that the condition must be corrected before the truck is allowed to operate.

It should be noted that brakes are the primary system where this analysis can be done, given the limited number of cases in the LTCCS data. The prevalence of light violations raises the possibility of a more detailed evaluation of the effect of defects in the light system on crashes. But that analysis depends on establishing details about which lights were in violation and where they are located, and that cannot be recovered in over half of the trucks with light violations.

In light of the predominance of brake violations, it is useful to identify crash types in which the brake system is particularly relevant. These would be crash configurations where stopping the vehicle is the primary means of avoiding the crash. In these crashes, the brake system itself is the primary vehicle system contributing to crash avoidance, though other systems may also contribute. Tires transmit the friction generated by the brake system to the pavement, so defects in the tires such as low tread depth may be important also. The suspension contributes to maintaining the tires on the road, so that system might be related as well.

Thus it would be expected that brake and tire defects would be more prevalent in crashes in which the truck's ability to stop is the primary means of avoiding the crash. Suspension or tire defects may also play a role. By the same argument, brake, tire, and suspension defects should not be overrepresented in crash roles where braking ability plays no role in avoiding a crash. The problem then is to identify crash types and roles within crash types where braking is the primary crash-avoidance mechanism.

Rear-end crashes are an obvious first choice for a crash type in which braking is the critical crash-avoidance system. For the striking vehicle, clearly the ability to get stopped is the issue.

Avoidance can also be achieved by steering around the other vehicle but braking is the primary crash-avoidance mechanism. Rear-end crashes also have the virtue of providing a ready-made comparison or control group: where the truck is the struck vehicle in a rear-end crash. The braking system for the vehicle struck in the rear clearly plays no role in preventing the crash. The condition of the brakes, tires, and suspension should not play a role in the crash, and thus should not increase the risk of being struck in the rear.

Thus, rear-end crashes can be defined as *brake-relevant*, that is, braking is relevant to the crash since braking is the primary means of avoiding the crash. For the striking vehicle in the crash, the brake system is the primary means of avoiding the crash. For the struck vehicle, the brake system has no effect.

A second crash configuration may also be identified as brake-relevant, i.e., crashes at intersections, where the vehicles are on crossing paths. For the vehicle that does *not* have the right-of-way, the braking is the primary means of avoiding the crash, while for the vehicle that *does* have the right-of-way, braking is less critical. The distinction is not as clean as in rear-end crashes, where braking clearly plays no role for the struck vehicle. There are instances where the vehicle that has the right-of-way does have an opportunity to evade the crash by stopping. For example, a driver with the right-of-way at a signal-controlled intersection may notice that the crossing vehicle does not appear to be slowing and may brake as a defensive measure. However, if for no other reason than the other vehicle has the right-of-way, braking is primarily implicated for the vehicle in these crashes that does not have the right-of-way.

Accordingly, *brake-relevant* crashes, abbreviated as BR crashes, are defined as crashes in which the ability to stop or slow is the primary crash-avoidance mechanism in the crash. These crashes include rear-end crashes and crashes at intersections where the vehicles involved are crossing paths. Within BR crashes, we can distinguish two *roles*. The first role is the one in which braking is the primary mechanism to avoid the crash. Essentially it is the vehicle in the crash pair that bears the onus to avoid the crash by slowing or stopping. In rear-end crashes, this is the vehicle that is the striking vehicle. In intersection/cross-paths crashes it is the vehicle that does not have the right-of-way. The second role is the other vehicle in the crash, i.e., the struck vehicle in a rear-end crash and the vehicle with the right-of-way in intersection/cross-paths crashes.

Thus, we define a set of crashes that are especially relevant to braking. This does not imply that braking is not relevant to other crash types. For example, there are cases of trucks in the LTCCS which were unable, because of defective brakes, to slow sufficiently for a curve, so the truck entered a curve too fast, ran off the road, and rolled over. However, it is believed that in BR crash types, braking is clearly the primary issue. In these crash types, the relationship of mechanical condition to the crash is particularly clean. There is a solid physical connection between the crash type and the mechanical system.

BR crashes also nicely supply their own control group, in that in one role in the crash, braking is highly implicated, while in the other role in the same crash, braking is either irrelevant or of much reduced salience. This leads to defining two groups for comparison to test the effect of vehicle mechanical condition, especially systems related to stopping or slowing the vehicle. The first group is trucks involved in BR crashes, where stopping is central to the crash role. In rear-end crashes, the striking vehicle, and in intersection/cross-paths crashes, the vehicle that did not have the right-of-way. This is essentially the case group. The control group is the complementary set of vehicles in BR crashes. The control group thus includes trucks that were the struck vehicle in a rear-end crash and trucks that had the right-of-way in intersection/cross paths crashes. Note that the “cases” and “controls” so defined do not necessarily come from the same crashes. They are vehicles involved in a rear-end crash in which they were the striking vehicle, or as the struck vehicle, and so on. In most of the crashes, the other vehicles involved are primarily light vehicles.

The table shows the definition of the two groups. The variables used to identify the groups are found in the CrashAssessment table. The CrashCode field was used to identify rear-end and intersecting paths crashes. ACRRightofWay was used to determine which vehicle had the right-of-way.

Variable level	Definition
BR=1	Striking vehicle in rear-end crash, and vehicle without right-of-way in intersection/cross-paths crashes
BR=0	Struck vehicle in rear-end crashes and vehicle with right-of-way in intersection/cross-paths

It is hypothesized that brake violations and tire violations would be overrepresented in the BR=1 crash role. Suspension violations may also be overrepresented in BR=1. The hypothesis is that trucks with diminished braking capacity would have longer stopping distances and so would be less likely to avoid slower or stopped traffic ahead, or less likely to be able to stop in time at intersections. In fact, drivers who know their brakes are defective may be more likely to run a red light or enter a signal-controlled intersection on the yellow phase, simply because they know they could not stop in time. Anecdotally, there are cases in the LTCCS in which the driver admitted as much.

No other systems should have a strong association with BR=1 crash role. However, light violations may have an association with BR=0 crash role, that is, the struck vehicle in rear-end crashes or the vehicle with the right-of-way in intersecting paths crashes. Previous work using Michigan FACT crash data showed that trucks struck in the rear had a higher incidence of rear signal and marking lights in violation, particularly at night.[3] The interpretation is that the reduced conspicuity of the truck due to the light violations contributed to being struck in the rear.

The first step in determining whether the items covered in the inspection data are associated with BR crash roles is to determine if the items are overrepresented in one role or the other. The inspection data includes information on driver violations and general carrier violations. In addition, we include light condition and roadway surface condition as they may also be associated with BR crash role. Trucks may be more likely to be struck in the rear at night. And lower roadway surface friction, as when the road is wet or snowy, may also be associated.

Table 21 shows the set of vehicle, driver, carrier, and environmental factors and their relationship to brake-relevant crash roles. In the table, the column labeled “cases w/condition” provides a count of the number of trucks that had the relevant condition. For example, 127 inspections found one or more driver violations, 14 inspections found one or more carrier violations, and 141 found one or more brake violations. The table also shows the percent of trucks with the given condition that were in a brake-relevant (BR) crash role and the percent of trucks in a BR crash role without the condition. The table also provides the p-value from a t-test of the significance of the difference in proportions.

The set of factors is primarily drawn from the inspection data, but also includes three other environmental or vehicle factors that can be hypothesized to be associated with BR crash involvements. Those three factors are daylight, road surface condition, and cargo loading. The daylight variable is categorized as daylight or all other light conditions, primarily dark. In the table, for daylight the condition is daylight. Road surface condition is classified as dry or any other condition, primarily wet. And load is split between trucks loaded to over 50 percent of capacity or less than 50 percent of capacity.

The analysis that developed the Load variable showed that the distribution of cargoes was strongly bimodal (split into two groups). The mean percentage of capacity occupied by the cargo for the loaded group (Load=1) was 91.4 percent, standard deviation (SD)=11.8, while the mean percentage of capacity for the lightly-loaded group (Load=0) was 10.2 percent, SD=17.1.

Table 21 Inspection and Other Factors,
Association with Brake-relevant Crash Involvements

Measure (violations or condition)	Cases w/condition	% BR given condition	%BR w/o condition	T-test of difference
Any violation	256	56.3	40.2	0.00*
Any mechanical system	218	56.0	44.4	0.03*
Driver	127	60.6	46.2	0.01*
Carrier	14	64.3	50.6	0.31
Any brake violation	141	61.7	44.7	0.00*
Cab	33	45.5	51.6	0.50
Coupling system	4	50.0	51.1	0.97
Electrical system	4	75.0	50.8	0.34
Frame	11	54.6	51.0	0.81
Fuel system	8	37.5	51.4	0.44
Load securement	19	52.6	51.0	0.89
Light system	91	51.7	50.9	0.90
Steering	14	71.4	50.3	0.12
Suspension	14	35.7	51.7	0.24
Tires	56	53.6	50.6	0.68
Wheels	12	75.0	50.3	0.09
Windshield	12	75.0	50.3	0.09
HOS	17	70.6	50.1	0.10
Log (driver)	57	57.9	49.8	0.26
Daylight (day vs. not day)	284	54.2	41.5	0.03*
Surface (dry vs. not dry)	338	51.8	45.0	0.42
Load (>50% capacity)	169	49.1	53.6	0.42

* significant <0.05 level

The table shows the association of the various inspection (and other) factors with BR crash role. Most of the systems show no association with BR crash role. In the case of cab, coupling, frame, load securement, tires, and driver log measures, the proportion of BR crash role is very similar for cases both with and without the condition. For other measures, such as electrical, fuel, steering, suspension, wheels, and windshield, BR crash role proportions are different, in some cases substantially so, but the number of cases with the condition is too small for the difference to be significant.

For most of the systems, there is no obvious physical mechanism for how a defect in the system could contribute to involvement in a BR crash as BR=1 in comparison with BR=0. That is, a fuel system violation should not be more likely as a pre-crash condition whether the vehicle is striking or struck. Similarly, load securement or frame violations should play no obvious physical role in generating the crashes.

On the other hand, it is noteworthy that two of the systems that may have been associated with BR crash roles were not found to be so in these data. No statistically significant association was found for suspensions or for tires. Trucks with tire violations were slightly more likely to be BR=1, but the difference was small. Trucks with suspension violations were substantially more likely to be BR=0, but there were only 14 cases with suspension violations, too few for this result to be reliable.

However, a significant association was found for the following measures: Any violation; any mechanical system violation; any driver violation; and any brake violation. For each of those measures, trucks in a BR crash with the measure were significantly more likely to be BR=1 than trucks without the condition.

7.4.1 Brake-relevant crashes

Three models are presented to explore the relationship of mechanical violations to the BR=1 crash role as opposed to the BR=0 crash role. The three different models are used to show that brake condition is strongly associated with crashes in which the truck's brakes are critical. But the brake regulations encompass a variety of items relating to the braking system. The work described above with the measurement data (section 6.2) that determines the status of brake adjustment permits us to isolate relatively clearly brake adjustment as a factor. The different models show that within brake violations, brake adjustment violations are most strongly associated with BR=1 crashes. This is consistent with the hypothesized physical mechanism, as adjustment is the most influential factor in braking power.

7.4.2 BR Model 1

The modeling work was initiated by testing all the different factors identified in Table 21 above. The fundamental hypothesis in this section is that brake violations are associated with the BR=1 crash role. However, the association of brake violations may be confounded by generally poor mechanical condition and generally poor operations of the carrier. That is, while there may be an association of brake violations with the BR=1 crash role, the brake violations may just be one manifestation of a generally poor operation, with violations in many systems. If that were the case, the physical link between brake violations (reduced stopping power) and the BR=1 crash role would not be demonstrated, because the braking problem would be just one among many other problems, few of which have any physical mechanism to link them to the crash type. If the whole range of vehicle violations were related to the BR=1 crash role, that would imply that the association is with poor operations reflected in poor maintenance, not poor brakes in and of themselves. On the other hand, if brake violations were primarily associated, and violations in other systems showed no consistent pattern of association, the result would support the link between brake violations and the BR=1 crash role.

Brake violations, driver violations, and the environmental light condition were strongly associated with BR=1 crash role. This is clearly indicated by examination of Table 21. The statistical modeling exercise confirmed the result. None of the other systems were significant statistically in any model. The only factors that were statistically significant are those (braking) for which there is a physical explanation.

The factors shown in Table 21 were used in the first model. The table also shows the response variable, BR. Each predictor variable had two levels. The brake variable was categorized as either no brake violation, or one or more brake violations. The driver variable included all driver violations, including qualifications, certification, moving violations, and hours-of-service (HOS) and log violations. The driver variable had two levels: Either zero driver violations or one or more driver violations. Finally, environmental light condition was partitioned into two groups: daylight or any condition other than daylight (primarily dark conditions).

Table 22 Factors and Definitions in BR Model 1

Factor	Definition
BR	0=Truck struck in rear, or has right-of-way in intersection/cross-paths crash 1=Truck striking in rear-end crash, or does not have right-of-way in intersection/cross-paths crash
Brakes	0=No brake violations 1=One or more brake violations
Driver	0=No driver violations 1=One or more driver violations
Daylight	0=Not daylight 1=Daylight

Logistic regression fits parameters relative to a baseline case. In this model, the baseline case is a truck with no brake violations, no driver violations, and not in daylight. The parameter estimates show the change in the odds that the vehicle is involved in a BR crash as BR=1 (in the brake-relevant role) in comparison to the baseline case. Positive values indicate that the factor increases the odds of involvement as BR=1 and negative values indicate that the factor decreases the odds, or is “protective.”

The baseline case for BR Model 1 was chosen to be the case with the following values for the predictor variables:

Brakes:	0=No brake violations
Driver	0=No driver violations
Daylight:	0=Not daylight

Table 23 shows the parameter estimates, standard errors of the estimates, Chi-square statistic, and statistical significance of the parameter for Model 1 of BR crashes. The parameters for Driver and Brakes are significant at better than the 0.05 level, which is the conventional threshold to identify a factor as “statistically significant.” The Pr (probability) value for the Driver parameter is 0.0229, while the Pr value for the Brakes parameter is 0.0074. Both indicate a probability less than 5 percent that the results are due to chance alone. The Daylight parameter has a Pr value slightly over 0.05. The value is 0.0532 for that parameter. The value thus somewhat exceeds the conventional rule for significance, although it rounds to 0.05. It is retained in the model because the size of the effect is relatively large and informative.

Table 23 Parameter Estimates, Standard Errors, and Significance
Logistic Regression Model 1 of BR Crashes

Parameter	DF	Coefficient	Standard Error	Chi-square	Pr > ChiSq
Intercept	1	-0.7058	0.2357	8.9641	0.0028
Driver	1	0.5154	0.2266	5.1727	0.0229
Brakes	1	0.5928	0.2213	7.1769	0.0074
Daylight	1	0.4759	0.2462	3.7382	0.0532

Table 24 shows the odds ratios for each parameter in Model 1, along with the 95 percent confidence intervals for each parameter. The odds ratios in the table are calculated by exponentiating the parameter coefficients in Table 23. For example, the coefficient for the Driver parameter in the model is 0.5154. The odds ratio for the parameter is computed by raising *e* to the power 0.5154, equaling 1.674. In equation form, $e^{0.5154}$=1.674. The interpretation of the odds ratio for the Driver variable is that the odds of involvement as BR=1 for drivers with one or more violations is about 1.7 times higher than drivers without a driver violation. The 95 percent confidence interval for the estimate ranges from 1.1 to 2.6.

Table 24 Odds Ratios and 95% Confidence Intervals
for Parameters of Model 1 of BR Crashes

Effect	Ratio	Odds ratio	95% confidence interval	
			Lower bound	Upper bound
Driver	1 vs 0	1.674	1.074	2.610
Brakes	1 vs 0	1.809	1.172	2.791
Daylight	1 vs 0	1.610	0.993	2.608

The odds ratio for the Brakes variable is 1.809, with a 95 percent confidence interval from 1.172 to 2.791. This means that one or more brake violations increases the odds of involvement in a BR crash as BR=1 by 1.81 times. Trucks involved in brake-relevant crashes that have brake violations are 1.81 times more likely to be involved as the striking vehicle in a rear-end crash or the vehicle violating the right-of-way in a crossing-paths intersection crash.

The odds ratio for the Daylight variable is 1.61, indicating that the odds of being in the BR=1 crash role is 1.61 times higher in day light than at other times (chiefly dark, unlighted conditions). The 95 percent confidence interval for the odds ratio includes 1, so this factor just barely fails the 0.05 significance test but only by a very small margin.

What is the interpretation of this result? In daylight, trucks are more likely to be the striking vehicle in a rear-end crash, while at night, they are more likely to be struck. That they are more likely to be struck at night suggests that conspicuity may be an issue, which points to the lighting system. No significant effect for Lights was observed. However, the Light variable includes all light system violations, all around the vehicle. Light system violations were not recorded in a way that permitted the location of the light violation on the vehicle to be determined for a large proportion of the violations, so it was not possible to test front light violations or rear light violations in the model.

Overall, the model fits the data very well. Table 25 shows the results of the Hosmer Lemeshow test, which partitions the data into a number of mutually exclusive groups and compares how well the model predicts the observed results. In this case, the groups are determined by the cross-classification of the variables in the model. For each group, the test uses the model to predict the number of cases expected to be BR=1 and the number expected to be BR=0. The closer the number expected is to the number actually observed, the better the model fits. The Chi-square statistic is used to test for differences. The result here is that there is no significant difference between the distribution of observed and expected frequencies. One use of the Hosmer Lemeshow test is to identify groups for which the model fits the data less well, but in this case, model fit is quite good for each group.

Table 25 Test of Goodness-of-Fit Model 2 (Hosmer Lemeshow Test)

		BR=1		BR=0	
Group	Total N	Observed	Expected	Observed	Expected
1	47	15	15.5	32	31.5
2	123	54	54.5	69	68.5
3	34	16	15.7	18	18.3
4	48	26	27.4	22	20.6
5	66	42	38.9	24	27.1
6	60	40	41.0	20	19.0

Chi-square=0.8832; p=0.9270

Figure 6 shows the predicted conditional probability (conditional on involvement in a BR crash) of BR=1 for all combinations of the factors in the model. The figure provides a visual description of the implications of the model. (Note that the figure displays *probabilities* associated with the factors, not odds ratios.) The factor combinations are ordered in terms of the probability, with the probability of the baseline case first. Daylight, driver violations, and brake violations all increase the probability relative to the baseline case by about the same amount, from about 0.33 to about 0.44 to 0.47. Each of the pair-wise combinations of the factors has a predicted probability of the BR=1 case of about 0.57 to 0.60. Of vehicles with all three factors—at least one driver and brake violation, in daylight—the probability of the BR=1 crash role is over 0.70. Driver, brake, and environmental factors all play a significant role in this crash type.

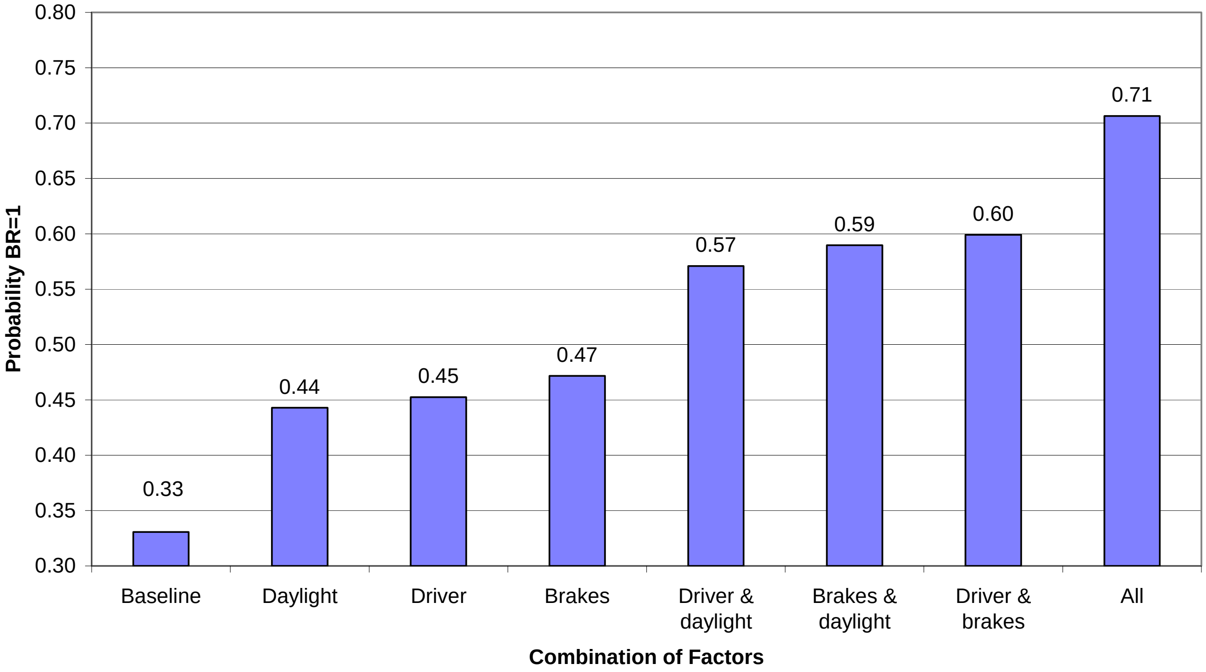

Figure 6 Probability of BR=1 Predicted for Model 1

7.4.3 BR Model 2

In the second model, the variable Brakes, which captures any brake violation, is replaced with BrakeLevel. BrakeLevel captures information about the brake adjustment status of the vehicle and has three levels. The three levels are: 0=all brakes correctly adjusted; 1=some brakes out of adjustment but not out-of-service; 2=sufficient brakes out of adjustment to put the vehicle out of service. BrakeLevel captures only brake adjustment and excludes any other brake violations. Thus, the BrakeLevel focuses directly on the factor that influences braking power the most.

The BrakeLevel variable is based on the brake adjustment data, which captures the actual adjustment of each brake on the vehicle. The method and results to generate this variable were described in more detail above. But it may be useful to repeat the most important points here. Brake chamber size, stroke type, and stroke length is recorded for each brake on a combination. The rules for determining brake adjustment status in the North American Uniform Out of Service Manual were applied to determine if a brake was out of adjustment, if the brake was out of service, and to count the number of brakes on a combination that were out of adjustment to determine if the vehicle should be placed out of service.

Table 26 shows the factors in BR crash type Model 2. They are the same as Model 1, with the exception that BrakeLevel replaces Brakes. As in the development of Model 1, initially all factors were tested in the model, with the exception that the Brakes variable was replaced by BrakeLevel, but only the factors in Table 26 were found significant.

Table 26 Factors and Definitions in BR Model 2

Factor	Definition
BrakeLevel	0=No brakes out of adjustment 1=Some brakes out of adjustment but not OOS 2=Vehicle OOS due to brake adjustment violations.
Driver	0=No driver violations 1=One or more driver violations
Daylight	0=Not daylight 1=Daylight

Substituting BrakeLevel for Brakes in the model produced parameter estimates quite similar to those in Model 1, but with the added insight from focusing on brake adjustment by itself, and showing three levels of adjustment. The parameter estimates, standard errors, Chi-square of the estimate, and significance test results for each parameter are given in Table 27. The magnitude of the parameters for the intercept, Driver, and Daylight factors are all very similar. The parameter estimate for Driver is significant at better than the 0.05 level, and, as in Model 1, the parameter for Daylight only just fails that test. The parameters for BrakeLevel1 (brakes out of adjustment but not out of service) is somewhat smaller than the parameter for BrakeLevel2 (vehicle OOS due to brake adjustment), though similar. The parameter for BrakeLevel1 is 0.59 and for BrakeLevel2 is 0.71. But the parameter for BrakeLevel1 fails that 0.05 test, while the parameter for BrakeLevel2 is highly significant.

Table 27 Parameter Estimates, Standard Errors, and Significance Logistic Regression Model 2 of BR Crashes

Parameter	DF	Coefficient	Standard Error	Chi-Square	Pr> ChiSq
Intercept	1	-0.7685	0.2581	8.8655	0.0029
Driver	1	0.5197	0.2441	4.5321	0.0333
BrakeLevel1	1	0.5889	0.3130	3.5395	0.0599
BrakeLevel2	1	0.7144	0.3066	5.4280	0.0198
Daylight	1	0.5072	0.2664	3.6249	0.0569

The estimated odds ratio for BrakeLevel2 is the largest among the different factors. A truck with an OOS condition due to brake adjustment has over twice the odds of BR=1 crash role, compared to the baseline case of a truck with fully adjusted brakes, no driver violations, and not in day light. The 95 percent confidence interval ranges from 1.1 times to 3.7 times. Trucks with some brakes out of adjustment, but not enough to qualify as OOS, have odds 1.8 times the baseline case of BR=1, with a 95 percent confidence interval from 0.98 times to 3.3 times. The two odds ratios are similar, and the range of their confidence intervals overlap considerably, but it is at least suggestive that the OOS due to brake adjustment condition has a greater effect on the odds of BR=1. Driver violations and the day light condition both increase the odds by about 1.6-

1.7 times. For both variables, the 95 percent confidence interval ranges from about 1 (no effect) to about 2.7.

Table 28 Odds Ratios and 95% Confidence Intervals for Parameters of Model 2 of BR Crashes

Effect	Ratio	Odds ratio	95% confidence interval Lower bound	95% confidence interval Upper bound
Driver	1 vs 0	1.681	1.042	2.713
BrakeLevel	1 vs 0	1.802	0.976	3.328
BrakeLevel	2 vs 0	2.043	1.120	3.726
Daylight	1 vs 0	1.661	0.985	2.799

As in the case of Model 1, the model fits the data very well. Table 29 shows the observed and expected results for seven groups in the data. The table shows that at each level the number expected (predicted by the model) is very close to the number actually observed in the data. A Chi-square test of association confirms that there is no statistically significant difference between the two distributions.

Table 29 Test of Goodness-of-Fit Model 2 (Hosmer Lemeshow Test)

		BR=1		BR=0	
Group	Total N	Observed	Expected	Observed	Expected
1	39	12	12.4	27	26.7
2	104	46	45.2	58	58.8
3	31	13	14.0	18	17.0
4	46	25	26.0	21	20.1
5	32	20	18.6	12	13.4
6	34	22	20.8	12	13.2
7	35	24	25.0	11	10.0

Chi-square=0.8192; p=0.9758

Figure 7 shows the predicted conditional probability that a truck is BR=1 for the baseline case and for all combinations of factor levels in the model. The figure illustrates the effect of each factor and all combinations of factors on the conditional probability that a truck is BR=1. Daylight, Driver, and BrakeLevel1 all have similar probabilities, from 0.44 to 0.46, but BrakeLevel2 raises the probability to 0.49, compared with the baseline probability of 0.32. Trucks with two risk factors (i.e., driver violation in daylight; BrakeLevel1 and daylight; Brakelevel1 and drive violation; etc.) increase the BR=1 probability to 0.56 to 0.61. The highest probability of the BR=1 condition is trucks that are OOS due to brake adjustment, at least one driver violation, and daylight. That combination of risk factors raises the probability of BR=1 to 0.73, compared to 0.32 for the baseline case. In other words, a vehicle with all the risk factors in the model—out-of-service brakes, driver violations, and in day light—would have a 73 percent chance of being in the BR=1 crash role, while a truck with none of the risk factors has only a 32 percent chance of being in that role.

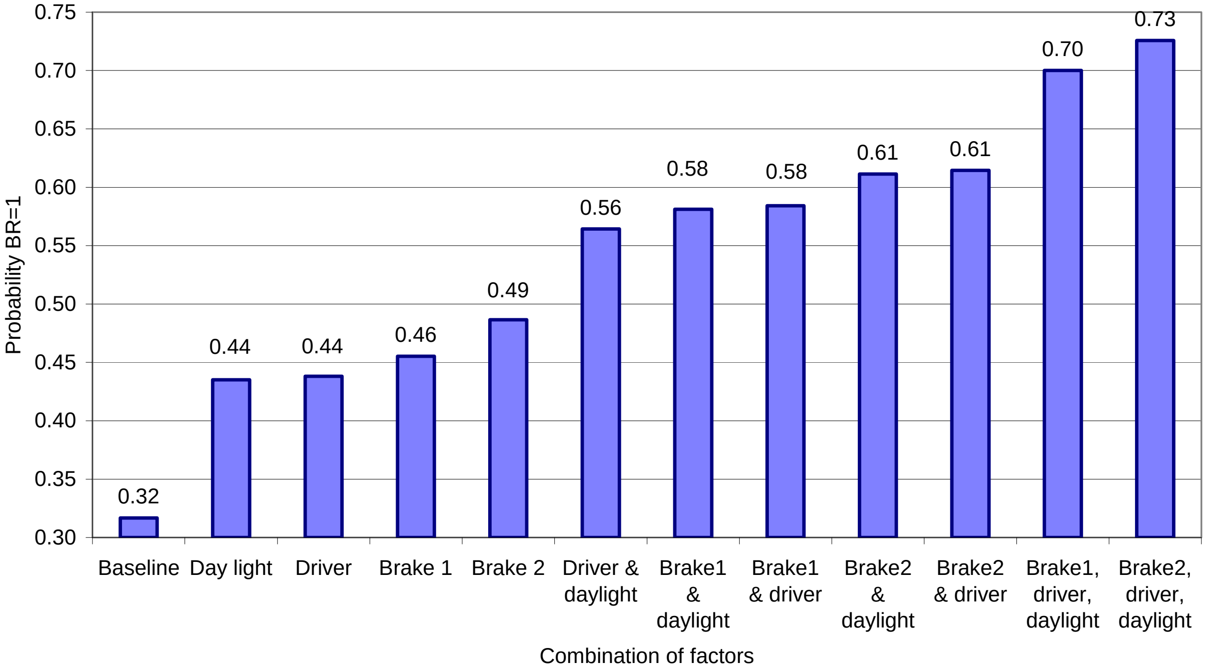

Figure 7 Probability of BR=1 Predicted for Model 2

7.4.4 BR Model 3

The third BR model focuses on brake adjustment in the context of other brake violations. In the first model, the Brake variable included all brake violations, those related to adjustment as well as all others, which can encompass a range of violations such as low brake line air pressure, kinked air hose, and defective parking brakes. The second model used just a measure of brake adjustment, and ignored other violations. In the third model, a BrakeProblem variable is incorporated, with three levels: 0=No brake violations or out of adjustment condition; 1=brake violations other than adjustment; and, 2=brake adjustment violations. Cases in BrakeProblem=1 level have only non-adjustment violations. Their brakes are fully adjusted. Cases in the BrakeProblem=2 level have one or more brakes out of adjustment. There may be other brake violations in addition, but all have adjustment violations. The other variables in the model are the same as in the previous two models. Table 30 shows the list of factors included in the BR Model 3.

Table 30 Factors and Definitions in BR Model 3

Factor	Definition
BrakeProblem	0=No brake violations/out-of-adjustment. 1=Brake violations other than brake adjustment. 2=Brake adjustment violations.
Driver	0=No driver violations 1=One or more driver violations
Daylight	0=Not daylight 1=Daylight

The parameter estimates for Driver and Daylight in BR Model 3 are quite similar to those in BR Model 1 and BR Model 2, but the parameters for the two levels of BrakeProblem are striking. In BR Model 2, the effect of brakes was captured in a variable that measured only adjustment, and in three levels: fully adjusted, out of adjustment but not out of service, and out of service. The parameter estimate for brake adjustment OOS was somewhat higher than that for the out of adjustment condition, but not dramatically so. However, in BR Model 3, the parameters for the levels of the variable that captures brake condition are quite different. In Table 31, BrakeProb1 is the parameter for BrakeProblem=1, i.e., brake violation other than brake adjustment. The parameter is small, negative (meaning that the effect is to reduce the probability of BR=1 crash role) and not statistically significant. However, the parameter for BrakeProb2 (BrakeProblem=2, i.e., at least one brake out of adjustment) is large relative to the other parameters in the table, positive, and statistically significant. In BR Model 3, brake adjustment violations are differentiated from other brake violations, and their effect is large and statistically significant.

Table 31 Parameter Estimates, Standard Errors, and Significance Logistic Regression Model 3 of BR Crashes

Parameter	DF	Estimate	Error	Chi-Square	Pr > ChiSq
Intercept	1	-0.7428	0.2616	8.0640	0.0045
Driver	1	0.5293	0.2447	4.6813	0.0305
BrakeProb1	1	-0.2179	0.3700	0.3468	0.5559
BrakeProb2	1	0.6125	0.2510	5.9531	0.0147
Daylight	1	0.5228	0.2677	3.8144	0.0508

Table 32 shows the odds ratios along with the 95 percent confidence intervals for the parameters. Brake adjustment violations increase the odds of the BR=1 crash role by 1.8 times, with the 95 percent confidence interval ranging from 1.1 to 3.0 times. In contrast, other brake violations have no statistically significant effect on the probability of the BR=1 crash role. In terms of brake violations, adjustment is the key. The effects for driver violations and daylight are very similar to the other models. Daylight just barely fails the 0.05 test of significance, but is retained because the size of the effect is practically significant.

Table 32 Odds Ratios and 95% Confidence Intervals for Parameters of Model 3 of BR Crashes

Effect	Ratio	Odds ratio	95% Confidence Interval Lower bound	Upper bound
Driver	1 vs 0	1.698	1.051	2.742
BrakeProb1	1 vs 0	0.804	0.389	1.661
BrakeProb2	2 vs 0	1.845	1.128	3.018
Daylight	1 vs 0	1.687	0.998	2.850

Comparison of the number of cases predicted by the model and the number actually observed in the data for different levels shows that the model fits the data well. Table 33 shows the results of the Hosmer Lemeshow test for BR Model 3, along with the Chi-square test of association. The observations are aggregated into distinct groups and then within each, the number of BR=1 cases are predicted for each group and then compared with the number BR=1 actually observed in the group. The table shows that for each group, the number predicted is very close to the number actually observed.

Table 33 Test of Goodness-of-Fit BR Model 3 (Hosmer Lemeshow Test)

Group	Total	BR=1 Observed	BR=1 Expected	BR=0 Observed	BR=0 Expected
1	39	12	12.4	27	26.6
2	24	10	9.4	14	14.6
3	83	37	37.0	46	46.1
4	28	12	12.8	16	15.2
5	46	25	25.9	21	20.1
6	55	34	32.8	21	22.2
7	46	32	31.6	14	14.4

Chi-square=0.3694; p=0.996

Finally, as for the other models, we include a chart that shows the predicted conditional probability (conditional on involvement in a BR crash) of BR=1 for each factor in the model, and all the different combinations of factor levels. The different combinations of factors are ordered by probability of the BR=1 crash role for the factor. This use of this figure is to give a visual representation of the relative effect of the different factors and combinations of factors.

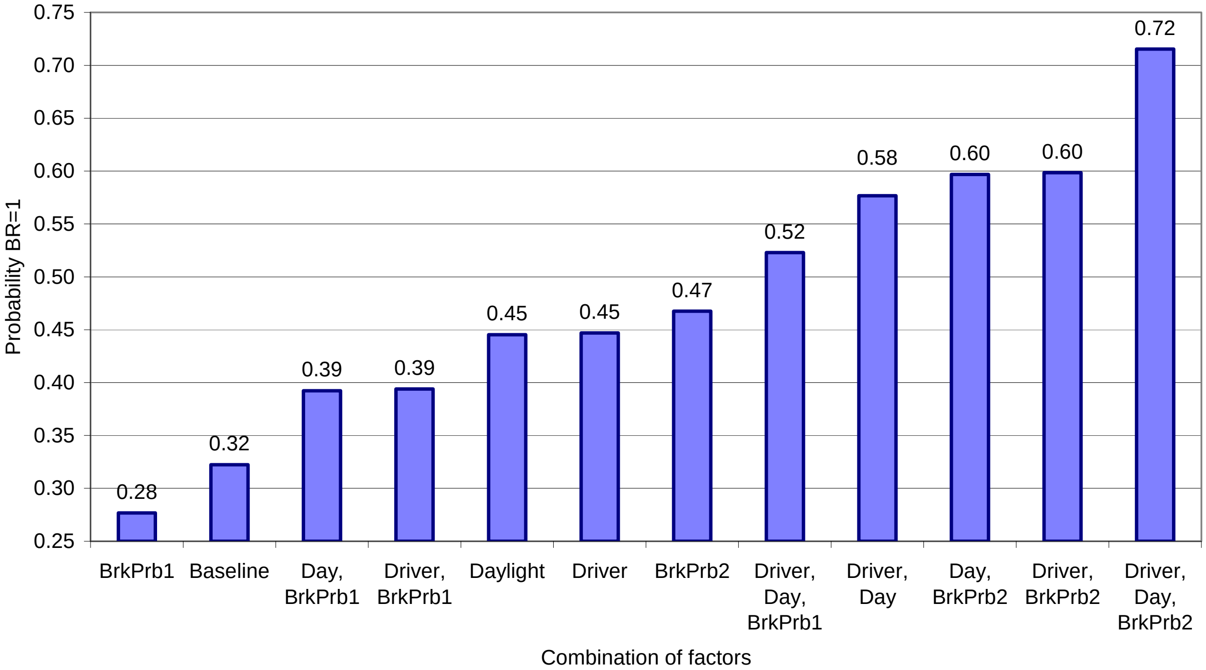

Figure 8 Probability of BR=1 Predicted for Model 3

Note that the baseline case actually does not have the lowest probability of the BR=1 crash role. This is because the parameter for the BrakeProblem=1 level is negative, so it decreases the probability of BR=1 relative to the baseline case. But the parameter is not statistically significant and so has no meaningful interpretation. Therefore, it can be ignored safely and is included in the figure only for the sake of completeness. Note that Daylight and Driver each have about the same effect on the probability relative to the base line case, while BrakeProblem=2 (brake adjustment violation) substantially increases the probability of the BR=1 crash role. Trucks with all three primary risk factors—driver violation, daylight, and at least one brake out of adjustment—have a probability of the BR=1 crash role over twice the size of the baseline case. Driver and day light contribute, but the most influential factor in the model is brake adjustment.

8 Summary and discussion

Post crash inspections showed that the condition of the trucks in the LTCCS is poor. Almost 55 percent of vehicles had one or more mechanical violations. Almost 30 percent had at least one out of service condition, meaning they would have been parked and not allowed to operate until the condition was corrected, if they had been inspected prior to the crash.

Drivers also had high rates of violations and OOS conditions, though lower than the trucks themselves. Almost 35 percent of the truck drivers involved in an LTCCS crash had one or more violations, and about 12 percent had an OOS condition that would have prevented them from operating, had it been discovered prior to the crash. Most of the driver violations related to the log and driver qualifications. Many were moving violations, however. About four percent were hours of service violations, and 1.8 percent had an OOS related to hours of service.

Among mechanical systems, violations in the brake and lighting system were the most frequent. Over 36 percent of the vehicles had a violation in some component of the brake system, and almost 20 percent of the trucks had an OOS condition in the brake system. Almost 20 percent of the trucks had a violation in some aspect of the light system, though the proportion that constituted an OOS condition was much lower, only 4.4 percent. General inspection and maintenance violations were the next most frequent at 14.7 percent, with tire violations at 12.1 percent of trucks inspected, and cab and equipment violations found in 8.3 percent of the trucks. Violations in the other systems were recorded at lower rates, ranging from load securement violations in 5.0 percent of the trucks, to wheel violations in 2.6 percent, down to violations of the rear-impact standards in 0.4 percent. But overall, almost 55 percent of the trucks had a violation, and almost 30 percent had an out of service condition.

There were few significant differences between truck configurations in terms of vehicle condition. Tractor-semitrailers had a slightly higher OOS rate, and bobtail tractors, somewhat lower. But there was not much difference in terms of violations overall. Tractor-semitrailers had somewhat higher rates on driver items, but not large enough to make a practical difference. Doubles configurations had lower rates on driver items, and the amount of difference is both statistically significant and of practical significance. But the incidence of vehicle, brake, and light violations is about the same for doubles as other configurations. In general, there were no statistically significant differences among truck configurations in terms of brake or light system violations. And specifically on brake adjustment, doubles have a lower percentage of adjustment OOS conditions. Overall, though, the most noteworthy finding related to truck configuration is that there were few significant differences among them.

Two fundamental approaches were explored to examine the association of vehicle condition with truck crashes. The first, and more general, examined the association of vehicle condition with the assignment of the “critical reason” in the crash. The critical reason for the crash is assigned to the vehicle (including driver and environmental factors, as well as vehicle failures) that precipitated the crash. In the second, the association of defects is examined through specific causal mechanisms that link the defect with the role of the truck in the crash.

The assignment of critical reason was mostly associated with driver problems, and much less so with mechanical problems. Driver violations in general, and especially log violations, increased the probability of being assigned the CR in crashes. Among the mechanical systems, only brakes showed up as statistically associated with the CR. One might expect that if mechanical condition contributes to truck crashes generally, one would find an association with the assignment of CR. Since critical reason identifies the vehicle that precipitated the crash, then, if truck defects were a big contributor, then one would expect an overrepresentation among trucks assigned the CR.

In terms of the general condition of the truck, that is not the case. The strongest association was with driver factors, especially log violations and OOS conditions. Defective truck equipment overall, as measured by violations, showed no strong association. However, some individual systems, especially brakes, show up as significant, statistically so. And both steering and tire defects were overrepresented in the group assigned the CR by an amount that is significant in practice, but the overrepresentation was not statistically significant because of too few cases. In a data set with more cases, the result may be more significant.

Statistical modeling validated this result. A logistic regression model was developed to predict CR, including both driver violations, HOS and log (OOS), and brake OOS. Brakes were the only vehicle factor included in the model. A brake OOS condition increased the odds of the truck being assigned the CR by 1.8 times. Both HOS violations and log OOS increased by a larger amount—2.0 and 2.2 times respectively. Brake OOS condition and cargo loading were also shown to interact, such that a truck whose brakes are OOS and that is loaded increases the odds that the truck will be assigned the CR in a crash by 3.5 times, much higher than for brake OOS alone.

These results show the impact of driver factors in the crash, but also point up the importance of vehicle factors, in that some vehicle factors were important terms in the model. One interpretation is that the driver factors influence the driver's response to a critical situation and the vehicle factors limit the effectiveness of his response.

Trucks with brake defects are more likely to be the vehicle in the crash that precipitated the crash. But this association of truck condition with the assignment of CR just suggests that there is a physical mechanism here, that the defect in some sense caused the crash. The test is just whether the vehicle defects are associated with being the contributing vehicle in the crash. There is a suggestion that there is a physical link, but all types of crashes are included in this comparison, so the physical link—i.e., crashes in which brakes are the critical element in crash avoidance—is not tested.

Accordingly, a second set of tests was developed. In this one, we developed crash types that were directly related to the type of mechanical defect. These are defined as "brake-related" crashes, crashes in which brakes are the primary means of crash avoidance. Brake-related (BR) crashes include rear-end crashes in which the truck is the striking vehicle, and crossing-paths crashes, in which the truck did not have the right-of-way. The control group included rear-end crashes in which the truck was struck and crossing-paths crashes in which the truck had the right-of-way.

A series of statistical models were developed that show that the condition of the brake system is strongly associated with BR crashes. The models included variables for driver, brake system, and light condition. The light condition variable may be a surrogate for truck conspicuity, since trucks were more likely to be struck in dark conditions, but this possibility could not be explored in more detail because of limitations in the way light system defects were recorded. But in terms of the results for driver and brake system variables, the results were quite informative.

In each of the models of BR crashes, the effect of driver violations was about the same, and associated with an increase in the odds of a BR crash of about 1.7 times. That is, a driver with one or more violations was 1.7 times more likely to have contributed to the crash than drivers with no violations. So the role of drivers is clear. The series of models also increasingly focused on brake adjustment.

In the first model, brake condition was incorporated as any brake violation. Trucks with any brake violation were 1.8 times more likely to in be in the BR case group as in the control group. The second model included a variable that classified the level of brake adjustment into three groups: Fully-adjusted brakes, some brakes out of adjustment but not OOS, and brakes OOS due to adjustment. In this model, the OOS condition due to brake adjustment had the highest odds ratio of being in the BR case group at over two, but the odds ratio for out of adjustment but not OOS was 1.8 times, not that different from the OOS condition. So brake adjustment is clearly significant, and the level of adjustment is significant.

In the final model, brake status was captured as related to brake adjustment or not. Trucks were classified into three groups: No brake violations, violations other than brake adjustment, and brake-adjustment violations. In this model, the results show that brake adjustment per se is the critical factor in the crashes. The parameter for brake violations other than adjustment was small and not significant, indicating that brake violations other than adjustment do not contribute to this crash type significantly, at least in these data. However, the parameter for brake adjustment violations was large and highly significant, associated with an increase in the odds by about 1.8 times.

Just as tellingly, no other vehicle system defects were significantly related to the crashes, in any of the models. Brake adjustment, which most directly bears on the stopping power of the truck, was the factor most significantly related to the crash role and had the largest effect in the model.

9 Conclusion

Clearly, driver and other factors are important in truck crashes. This study was not designed to provide a full accounting of the factors that contribute to truck crashes, but instead to exploit the rich detail available in the inspection data on the condition of the vehicle and the compliance of the driver with FMCSR requirements. In all of the analyses, the salience of driver factors was clear. Even without looking at specific driver actions in the crashes, it is clear that driver condition is clearly associated with crash risk.

Yet the condition of the truck also plays a large role. If driver condition, training, and experience shape and limits the driver's contribution to crashes and the actions that cause crashes, the condition of the vehicle certainly shape and limit the driver's ability to respond effectively in avoiding crashes. Thus, FMCSA's role in supporting roadside inspections and enforcing the regulations governing vehicle condition is critical. Research such as the present study could be used to identify the systems on trucks most important to crash reduction and to drive improvements in those systems from the present level.

Finally, it is noteworthy that two recent surveys of safety practices among motor carriers both highlighted vehicle condition in reducing crashes. In a survey of safety managers of the "safest" motor carriers, 90 percent "agree[d] that deploying a defect-free fleet is the most important thing they do to ensure highway safety." [4, page 8] In another survey of effective safety management techniques, safety managers at motor carriers ranked at-risk driver behaviors (e.g. speeding or tailgating) as the top *problem* area. High risk drivers is number two. But in identifying *solutions* to safety issues, safety managers ranked regularly scheduled vehicle inspection programs as the number one solution, with hiring of safe drivers based on criteria relating to driver crash, violation, or incident history as number two.[15]

The LTCCS is the most richly detailed source of crash data currently available. The contrast just in terms of the inspection data alone in the LTCCS and what is available from conventional sources such as FARS, TIFA, and GES, clearly illustrates the value of the LTCCS project. The depth of analysis possible, down to the level of brake adjustment, is well beyond what has been hitherto possible. This is not to say that the LTCCS is without flaw. The way some of the data were collected, e.g., violations in the light system, limited the scope of analysis here, because the location of the lights in violation could not be determined for a large number of trucks. A more serious limitation is in the number of cases. Some suggestive associations could not be pursued because there were too few cases in the data set. But overall, the value of the comprehensive approach to crash data collection has been abundantly demonstrated. Follow-on projects, applying the lessons learned from the LTCCS, could provide great guidance to realizing FMCSA's mission to significantly reduce truck crashes in the US.

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Appendix

This Appendix shows how specific violations were grouped into higher levels. The Category column shows the general category into which the violations are grouped. Subcategory is a more specific grouping, identifying particular mechanical systems or aspects of the driver regulations. Section and label gives the specific section of the Code of Federal Regulations, along with a brief description of the content. The N column shows the number of violations among the inspected trucks.

This appendix should be used to get an idea of the specific defects that are captured as Brake, Driver, Carrier, and so on.

Category	Subcategory	Section and label	N
Carrier	Carrier	13901-Operating w/o proper motor carrier authority	1
Carrier	Carrier	13906-Oper w/o proper insurance or other securities	1
Carrier	Carrier	387.301A-No evidence of public liability and property damage insurance	3
Carrier	Carrier	387.303B4-No copy of certificate of registration	4
Carrier	Vehicle marking	390.21A-No DOT # marking and/or name/city/state	20
Carrier	Vehicle marking	390.21B-Carrier name and/or USDOT required; Not displayed	3
Carrier	Vehicle marking	390.21C-Improper marking, size, shape	2
Carrier subtotal			34
Driver	Driver licensing	383.23A2-Operating a CMV without a CDL	11
Driver	Driver licensing	383.51A-Driving a CMV (CDL) while disqualified	1
Driver	Driver licensing	383.93B3-No tank vehicle endorsement on CDL	1
Driver	Driver licensing	383.95A-Violating airbrake restriction	1
Driver	Driver qualification	391.11B2-Non-english speaking driver	1
Driver	Driver qualification	391.11B5-Not licensed for type vehicle being operated	1
Driver	Driver qualification	391.11B6-Operating CMV without corrective lenses	1
Driver	Driver qualification	391.11B7-No or invalid driver license CMV	4
Driver	Driver qualification	391.11-Driver qualification	4
Driver	Driver qualification	391.15A-Driving a CMV while disqualified	5
Driver	Driver qualification	391.41A-No medical certificate on drivers possession	35
Driver	Driver qualification	391.43G-Improper medical examiners certificate	4
Driver	Driver qualification	391.45B-Expired medical examiners certificate	17
Driver	Driver, general	396.11-Driver vehicle inspection report	2

Category	Subcategory	Section and label	N
Driver	Driver, general	396.13C-No reviewing drivers signature on DVIR	1
Driver	Driver, general	396.1-Must have knowledge of and comply with regulations	4
Driver	Driving violations (speed etc.)	392.16-Failing to use seat belt while operating CMV	30
Driver	Driving violations (speed etc.)	392.2C-Local laws/failure to obey traffic control device	3
Driver	Driving violations (speed etc.)	392.2FC-Local law/following too close	4
Driver	Driving violations (speed etc.)	392.2LC-Local law/improper lane change	3
Driver	Driving violations (speed etc.)	392.2-Local laws (general)	105
Driver	Driving violations (speed etc.)	392.2R-Local law/reckless driving	4
Driver	Driving violations (speed etc.)	392.2S-Local law/speeding	12
Driver	Driving violations (speed etc.)	392.2T-Local laws/improper turns	1
Driver	Driving violations (speed etc.)	392.2W-Local laws/size and weight	12
Driver	Driving violations (speed etc.)	392.2Y-Local laws/failure to yield right of way	1
Driver	Driving violations (speed etc.)	392.3-Operating a CMV while ill/fatigued	6
Driver	Driving violations (speed etc.)	392.4A-Driver uses or is in possession of drugs	5
Driver	Driving violations (speed etc.)	392.5A-Poss/use/under influence alcohol-4hrs prior duty	5
Driver	Driving violations (speed etc.)	392.5C2-Violating OOS order pursuant to 392.5(a)/(b)	1
Driver	Driving violations (speed etc.)	392.60A-Unauthorized passenger on board CMV	10
Driver	Driving violations (speed etc.)	392.6-Scheduling run to necessitate speeding	1
Driver	Driving violations (speed etc.)	392.71A-Using or equipping a CMV with radar detector	3
Driver	Driving violations (speed etc.)	392.7-No pre-trip inspection	7
Driver	Driving violations (speed etc.)	392.8-Failing to inspect/use emergency equipment	3
Driver	Driving violations (speed etc.)	392.9A2-Failing to secure vehicle equipment	3
Driver	Driving violations (speed etc.)	392.9A3-Drivers view/movement is obstructed	2
Driver	HOS	395.1I1-15,20,70/80 hours of service violations (AK)	1
Driver	HOS	395.3A1-10 hour rule violation	25
Driver	HOS	395.3A2-15 hour rule violation	10
Driver	HOS	395.3B-60/70 hour rule violation	8
Driver	HOS	398.6-Violation of hours of service reg-migrant	1
Driver	Log	395.8A-No drivers record of duty status	31
Driver	Log	395.8E-False report of drivers record of duty status	30
Driver	Log	395.8F1-Drivers record of duty status not current	85
Driver	Log	395.8K2-Driver failing to retain previous 7 days logs	22

Category	Subcategory	Section and label	N
Driver	Log	395.8-Log violation (general/form and manner)	50
Driver subtotal			577
Mechanical	Brakes	393.42-No brakes as required	2
Mechanical	Brakes	393.45A4-Brake hose/tubing chaffing and/or kinking	45
Mechanical	Brakes	393.45-Brake tubing and hose adequacy	18
Mechanical	Brakes	393.46B-Brake connections with leaks/constrictions	36
Mechanical	Brakes	393.46-Brake hose/tube connection	19
Mechanical	Brakes	393.47-Inadequate brake lining for safe stopping	44
Mechanical	Brakes	393.48A-Inoperative/defective brakes	65
Mechanical	Brakes	393.4-Inadequate brake system on a CMV	6
Mechanical	Brakes	393.50B-Failing to equip veh-prevent res air/vac leak	3
Mechanical	Brakes	393.53C-Brake adj ind cmv mfg >10/19/94 ext auto adj	1
Mechanical	Brakes	393.5-Inadequate reservoir for air/vacuum brakes	9
Mechanical	Brakes	396.3A1BA-Brake-out of adjustment	278
Mechanical	Brakes	396.3A1BC-Brake-air compressor violation	7
Mechanical	Brakes	396.3A1BD-Brake-defective brake drum	3
Mechanical	Brakes	396.3A1BL-Brake-reserve system pressure loss	5
Mechanical	Brakes	393.41-No or defective parking brake system on CMV	4
Mechanical	Brakes	393.43A-No/improper tractor protection valve	3
Mechanical	Brakes	393.43D-No or defective automatic trailer brake	1
Mechanical	Brakes	393.43-No/improper breakaway or emergency braking	3
Mechanical	Brakes	393.50C-No means to ensure operable check valve	1
Mechanical	Brakes	393.51-No or defective brake warning device	24
Mechanical	Brakes	393.55D1-ABS malf circ/signl mfg>2/97,sgl CMV mfg>2/98	1
Mechanical	Brakes	393.55E-ABS malfunct lamps towed CMV mfg>2/98mfg<2/09	1
Mechanical	Brakes	396.3A1B-Brakes (general)	69
		Brakes subtotal	648
Mechanical	Cab	393.203A-Cab door missing/broken	5
Mechanical	Cab	393.203B-Cab/body improperly secured to frame	6
Mechanical	Cab	393.203-Cab/body parts requirements violations	20
Mechanical	Cab	393.203C-Hood not securely fastened	17
Mechanical	Cab	393.203E-Cab front bumper missing/unsecured/protrude	16

Category	Subcategory	Section and label	N
Mechanical	Cab	393.76-Sleeper berth requirement violations	1
Mechanical	Cab	393.77-Defective and/or prohibited heaters	2
Mechanical	Cab	393.78-Windshield wipers inoperative/defective	15
Mechanical	Cab	393.79-Defroster inoperative	5
Mechanical	Cab	393.81-Horn inoperative	11
Mechanical	Cab	393.82-Speedometer inoperative	5
Mechanical	Cab	393.84-Inadequate floor condition	3
Mechanical	Cab	393.88-Improperly located tv receiver	1
Mechanical	Cab	393.8-No or defective rear-vision mirror	11
Mechanical	Cab	393.93B-Truck not equipped with seat belt	2
Mechanical	Cab	393.95A-No/discharged/unsecured fire extinguisher	64
Mechanical	Cab	393.95F-Emergency warning devices not as required	26
Mechanical	Cab	399.207-Vehicle access requirements violations	2
		Cab subtotal	212
Mechanical	Coupling	393.70A-Defective coupling device-improper tracking	3
Mechanical	Coupling	393.70B-Defective/improper fifth wheel assemblies	4
Mechanical	Coupling	393.70C-Defective coupling devices for full trailer	12
Mechanical	Coupling	393.70D-No/improper safety chains/cables for full trailer	2
Mechanical	Coupling	393.71H-Towbar requirement violations	3
Mechanical	Coupling	393.7-Fifth wheel	4
		Coupling subtotal	28
Mechanical	Electrical	393.28-Improper or no wiring protection as required	7
Mechanical	Electrical	393.32-Improper electrical connections	2
Mechanical	Electrical	393.33-Improper wiring installations	11
Mechanical	Electrical	393.3-Improper battery installation	6
		Electrical system subtotal	26
Mechanical	Exhaust	393.83A-Exhaust system location	2
Mechanical	Exhaust	393.83B-Exhaust discharge fuel tank/filler tube	1
Mechanical	Exhaust	393.83E-Improper exhaust discharge (not rear of cab)	1
Mechanical	Exhaust	393.83G-Exhaust leak under truck cab and/or sleeper	30
Mechanical	Exhaust	393.83H-Exhaust system not securely fastened	5
		Exhaust system subtotal	39
Mechanical	Frame	393.201A-Frame cracked/broken/bent/loose	36
Mechanical	Frame	393.201C-Frame rail flange improperly bent/cut/notched	3
Mechanical	Frame	393.201D-Frame accessories not bolted/riveted securely	5

Category	Subcategory	Section and label	N
		Frame subtotal	44
Mechanical	Fuel system	393.65C-Improper securement of fuel tank	6
Mechanical	Fuel system	393.65F-Improper fuel line protection	1
Mechanical	Fuel system	393.65-Fuel system requirements	19
Mechanical	Fuel system	393.67C7-Fuel tank fill pipe cap missing	1
Mechanical	Fuel system	393.67-Fuel tank requirement violations	17
		Fuel system subtotal	44
Mechanical	Inspection/maintenance	396.17C-Operating a CMV without periodic inspection	84
Mechanical	Inspection/maintenance	396.3A1-Inspection/repair and maintenance	89
Mechanical	Inspection/maintenance	396.3A-Inspection, repair, and maintenance	36
Mechanical	Inspection/maintenance	396.5B-Oil and/or grease leak	13
Mechanical	Inspection/maintenance	396.5-Excessive oil leaks	10
Mechanical	Inspection/maintenance	396.7-Unsafe operations forbidden	6
Mechanical	Inspection/maintenance	396.9D2-Failure to correct defects noted on inspection	1
		Inspection/maintenance subtotal	239
Mechanical	Lights	393.11LR-Lwr rr retroreflct sht/reflx reflct mfg>12/93	1
Mechanical	Lights	393.11-No/defective lighting devices/ref/projected	62
Mechanical	Lights	393.11S-Side retroreflect sht/reflx reflect mfg>12/93	1
Mechanical	Lights	393.11TL-TT lwr rr mud flaps retro sht/reflex mfg>7/97	2
Mechanical	Lights	393.13A-No retroreflect sht/reflex reflect mfg <12/93	4
Mechanical	Lights	393.13C1-Side retroreflect sht/reflx reflect mfg<12/93	2
Mechanical	Lights	393.13C2-Lwr retroreflect sht/reflex reflect mfg<12/93	3
Mechanical	Lights	393.17B-No/defective side marker	26
Mechanical	Lights	393.19-No/defective turn/hazard lamp as required	121
Mechanical	Lights	393.24B-Non-compliance with headlamp requirements	19
Mechanical	Lights	393.25B-Lamps are not visible as required	1
Mechanical	Lights	393.25E-Lamp not steady burning	3
Mechanical	Lights	393.25F-Stop lamp violations	70
Mechanical	Lights	393.26-Requirements for reflectors	5
Mechanical	Lights	393.2-No/improper mounting of clearance lamps	30
Mechanical	Lights	393.9H-Inoperable head lamps	50
Mechanical	Lights	393.9-Inoperable lamp (other than head/tail)	98
Mechanical	Lights	393.9T-Inoperable tail lamp	36
		Lights subtotal	534
Mechanical	Load securement	392.9A-Failing to secure load	1
Mechanical	Load securement	392.9-Driver load secure	3
Mechanical	Load securement	393.100A-No or improper load securement	7

Category	Subcategory	Section and label	N
Mechanical	Load securement	393.102A-Improper securement system (tiedown assemblies)	8
Mechanical	Load securement	393.102-Improper securement system (tiedown assembly)	13
Mechanical	Load securement	393.104A-Improper blocking and/or bracing-longitudinal	3
Mechanical	Load securement	393.106A-No/improper front end structure/headerboard	4
Mechanical	Load securement	393.1-No or improper load securement	29
		Load securement subtotal	68
Mechanical	Steering	393.209A-Steering wheel not secured/broken	6
Mechanical	Steering	393.209B-Excessive steering wheel lash	3
Mechanical	Steering	393.209C-Loose steering column	6
Mechanical	Steering	393.209D-Steering system components worn/welded/missing	26
Mechanical	Steering	393.209E-Power steering violations	8
		steering subtotal	49
Mechanical	Suspension	393.207A-Axle positioning parts defective/missing	57
Mechanical	Suspension	393.207B-Adj axle locking pin missing/disengaged	1
Mechanical	Suspension	393.207C-Leaf spring assembly defective/missing	36
Mechanical	Suspension	393.207D-Coil spring cracked and/or broken	1
Mechanical	Suspension	393.207E-Torsion bar cracked and/or broken	6
Mechanical	Suspension	393.207F-Air suspension pressure loss	14
		Suspension subtotal	115
Mechanical	Tires	393.75A1-Tire-ply or belt material exposed	13
Mechanical	Tires	393.75A2-Tire-tread and/or sidewall separation	6
Mechanical	Tires	393.75A3-Tire-flat and/or audible air leak	13
Mechanical	Tires	393.75A4-Tire-cut exposing ply and/or belt material	11
Mechanical	Tires	393.75A-Flat tire or fabric exposed	51
Mechanical	Tires	393.75B-Tire-front tread depth less than 4/32 of inch	17
Mechanical	Tires	393.75C-Tire-other tread depth less than 2/32 of inch	68
Mechanical	Tires	393.75F1-Weight carried exceeds tire load limit	1
Mechanical	Tires	393.75F2-Tire under-inflated	17
Mechanical	Tires	393.75F-Tire-load weight rating/under inflated	5
Mechanical	Tires	396.3A1T-Tires (general)	13
		tires subtotal	215
Mechanical	Wheels	393.205A-Wheel/rim cracked or broken	22
Mechanical	Wheels	393.205B-Stud/bolt holes elongated on wheels	1
Mechanical	Wheels	393.205C-Wheel fasteners loose and/or	24

Category	Subcategory	Section and label	N
		missing	
		Wheels subtotal	47
Mechanical	Windshield	393.60B-Damaged or discolored windshield	60
Mechanical	Windshield	393.60C-Use of vision reducing matter on windows	1
Mechanical	Windshield	393.60D-Glazing permits < 70% of light	2
Mechanical	Windshield	393.61A-Inadequate or missing truck side windows	2
		Windshield subtotal	65
Mechanical subtotal			2373
Other	Hazmat	171.2B-Failed to comply with exemption	1
Other	Hazmat	172.200A-No shipping paper provided offeror	1
Other	Hazmat	172.332-ID# marking for (b) panel (c) placards	1
Other	Hazmat	172.502A1-Prohibited placarding	1
Other	Hazmat	172.516C6-Placard damaged, deteriorated, or obscured	1
Other	Hazmat	172.602A-ER info missing	1
Other	Hazmat	173.24B1-Release of HM from package	1
Other	Hazmat	177.817A-No shipping papers (carrier)	2
Other	Hazmat	177.817B-Shipper certification missing (when required)	1
Other	Impact guards	393.86A1-Rear Impact Guards all trailers/semitrailers mfg>1/26/98	1
Other	Impact guards	393.86A2-Impct guard width all trailers/semitrailers mfg>1/26/98	1
Other	Impact guards	393.86B1-Rear Impact Guards mv mfg >12/31/52 see excepts	1
Other	Impact guards	393.86-No or improper rearend protection	11
		Other subtotal	24