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Large Truck Crash Causation Study Analysis Series

Federal Motor Carrier Safety Administration

Using LTCCS Data for Statistical Analyses of Crash Risk

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Summary

The Large Truck Crash Causation Study (LTCCS) was undertaken jointly by the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA). The LTCCS is based on a nationally representative sample of nearly 1,000 injury and fatal crashes involving large trucks that occurred between April 2001 and December 2003. The data collected provide a detailed description of the physical events of each crash, along with an unprecedented amount of information about all the vehicles and drivers, weather and roadway conditions, and trucking companies involved in the crashes.

This analysis brief discusses how statistical analyses of the LTCCS database can be used to investigate crash causes and contributing factors. It defines 10 critical issues for large truck safety, outlines the information needed to address each, assesses how well the LTCCS database fills those needs, and briefly discusses other data that could be used for questions where LTCCS data are not adequate. Analytic techniques that could be applied to the LTCCS data are illustrated by examples using data from an earlier study of fatal commercial motor vehicle crashes in Michigan.

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The Large Truck Crash Causation Study:
Using LTCCS Data for Statistical Analyses of Crash Risk

[continued from front]

The principal conclusions:

- The LTCCS is a general-purpose data file designed primarily for problem identification. It contains more than 1,000 data variables describing all aspects of the drivers, vehicles, and environment in large truck crashes. Because it is based on a representative sample of large truck crashes, it can be used to estimate unbiased national frequencies.
- The LTCCS database can be used to investigate crash risk using relative risk methods. With the LTCCS database, these methods apply to many vehicle features, some driver features, and few environmental features. Their usefulness depends on whether there is a suitable control group of crashes in which the feature being examined has no effect.
- The 963-case sample size limits some statistical conclusions from the LTCCS data. Analyses and national estimates of relatively infrequent situations will have large uncertainties and will be able to distinguish only large differences.
- Data accuracy and completeness may limit some conclusions from the data. Directly observable variables are likely to be quite accurate and complete. Variables that depend on interviews may be less accurate and complete, even if investigators have checked other sources to confirm the interview reports.
- While LTCCS is designed as a statistical data file, its individual case reports will be useful for investigative analyses based on in-depth crash reconstructions.
- Additional data from experimental settings almost certainly will be needed to develop specific interventions for reducing the risks of large truck crashes.

Contents

Introduction and Purpose

The Motor Carrier Safety Improvement Act of 1999 (Public Law 106-159), which established the FMCSA, requires the Agency to "conduct a comprehensive study to determine the causes of, and contributing factors to, crashes that involve commercial motor vehicles." To fulfill that requirement, FMCSA joined with NHTSA to design and operate the LTCCS. The study investigated a nationally representative sample of 963 large truck crashes at 24 data collection sites within NHTSA's National Automotive Sampling System (NASS). Trained NASS crash investigators and State truck inspectors collected more than 1,000 individual data elements for each crash. After pilot testing, full data collection began in April 2001 and concluded in December 2003. The final LTCCS data file will be released to the public in 2006.

In the first report of this LTCCS Analysis Series, Blower and Campbell discussed the LTCCS methodology in some detail [*1*]. They described two basic uses of the LTCCS data file: (1) "investigative" or "clinical" analyses, in which crash reconstruction experts can review individual crash reports to investigate factors that may have influenced or could have prevented specific crashes; and (2) statistical analyses of the full database, in which investigators can examine the frequencies of various factors and their associations with crash risks.

This report discusses in greater detail how the LTCCS data can be used for statistical analyses to explore crash risk and measures to prevent or reduce crashes. It begins with a general discussion of the data file's strengths and weaknesses for statistical analyses. It then lists 10 critical issues related to the safety of large trucks, outlines the specific information that ideally would be available to address each issue, and assesses how well the LTCCS database fills those information needs. Where appropriate, it discusses how other data sources could be used to complement the LTCCS data. Finally, it gives two examples of the types of analyses that the LTCCS will support, using similar data from a file of fatal truck crashes in Michigan.

Throughout this report, the terms "truck" or "large truck" refer to all vehicles within the LTCCS scope—that is, trucks with a gross vehicle weight rating (GVWR) greater than 10,000 pounds. The term "passenger vehicle" refers to all other vehicles (cars, pickup trucks, vans, and sport utility vehicles). An "intervention" is any measure intended to prevent or reduce crashes (other authors may use the terms "countermeasure" or "treatment"). Finally, as discussed below, the term "cause" is used broadly to refer to any factor that may increase the risk of a crash occurrence. To emphasize this point, the phrase "cause or contributing factor" is also used.

Strengths and Weaknesses of the LTCSS Database

As discussed by Blower and Campbell [*1*], the "cause" of a crash can be defined in two ways: as a "necessary factor" (had the factor not been present in the crash sequence, the crash would not have occurred); or as a "risk-increasing factor" (the factor increases the risk, or probability, of a crash). This report uses the second definition.

Using the risk-increasing factor definition of a crash cause has several important consequences. First, it recognizes that a crash does not have a single cause but is influenced by many factors. Second, it renders the concept of "fault" irrelevant. Third, the factors considered are those that can be described by the LTCCS field data. They do not depend on inferences made after the fact by crash reconstruction experts—that is the role of investigative analysis, as discussed in detail by McKnight [*2*].

Finally, the whole question of crash cause in a sense misses the main point: the fundamental objective is to prevent crashes, and so the true goal of the LTCSS is to serve as a database for exploring possible interventions that could reduce the risk of truck crashes. One way to accomplish that goal is by looking for factors that increase crash risk. Another is by examining conditions that are common to many crashes and considering whether changes in those conditions could reduce crash risk.

Statistical and investigative analyses complement each other. Statistical analyses of the full LTCCS database and investigative analyses of individual LTCCS cases serve different and complementary roles. Statistical analyses can determine that specific factors increase crash risk and can estimate how often the factors occur on a national level. Investigative analyses can dig further into specific causal mechanisms and suggest interventions. Statistical analyses can then suggest ways of extrapolating potential interventions back to a national scale and estimating their costs and benefits.

Exposure data for large truck crashes are crude, and most crash risk analyses of the LTCCS database will require the use of induced exposure techniques. Crash risk is defined as crashes per some measure of exposure, or opportunity: typically crashes per mile of travel, or crashes per hour, in appropriate circumstances. For example, to examine the role of brake violations, one could compare crashes per mile of travel for trucks with brake violations against crashes per mile of travel for trucks without brake violations (or perhaps crashes per mile of travel on wet roads or in other circumstances for trucks with and without brake violations). Alternatively, one could use a case-control study design, in which vehicles that have crashed (the cases) are matched with vehicles that have not crashed but that are similar on a number of other variables (the controls—same vehicle type, driving on the same road, at the same time of day and day of week, etc.). Because the LTCCS did not use a case-control study design, other exposure data are required for case-control studies using the LTCCS database.

Exposure data on large truck travel are crude. Registration data are of little use, because the spread of annual miles traveled by different trucks is very large. The available data on vehicle miles of travel (VMT) are not especially accurate, and they make only gross distinctions among truck and road types. Data on such critical issues as driver fatigue and vehicle maintenance may be available from inspection stations, but they are difficult to extrapolate to travel estimates.

Induced exposure is a general technique that uses crash data to estimate relative exposure for a specific factor being examined. It is based on the assumption that the factor can affect only some crashes. The factor's presence in crashes that it cannot affect serves as a measure of its presence on the road (its exposure); the relative risk of the factor is the ratio of its presence in crashes that it may affect to its presence in crashes that it cannot affect (an example is given in the final section of this report). Induced exposure methods are standard techniques in crash data analyses and are appropriate for the LTCCS database.

Sample sizes will limit statistical conclusions from the LTCCS. The LTCSS data file contains 963 crashes. This is a large file for investigative analyses and should provide a wide variety of crash circumstances, but it is small for statistical analyses. As an everyday example, national single-issue polls (for example, to estimate support for two competing presidential candidates) typically use a sample of about 1,000 and have a possible error of about 3 percent. The error increases when the sample is not random or when responses may be biased in some way.

The LTCCS is a complex multi-stage sample. As a result, estimating variances is considerably more complicated than in a simple random sample. The complexity increases the variance. This means that if the LTCSS file is used to estimate the national incidence of any single parameter that is measured objectively for all crashes, such as the proportion of large truck crashes that occur during daylight hours, then the 95-percent confidence error will be greater than 3 percent.

Many interesting and useful analytic questions will go beyond simple estimates of a single objectively recorded parameter. Some questions will apply only to a subset of the LTCCS crashes, such as questions about crashes involving multi-unit trucks. Other questions may involve more than one parameter: for example, does the proportion of crashes occurring in daylight hours differ for single-unit and multi-unit trucks? As the questions become more specific in either of these ways, the size of the possible error increases. Some questions must rely on more subjective data, such as a driver's report on his hours of sleep the previous night. The possibilities of inaccurate data are obvious.

The LTCCS file of 963 cases will serve to estimate first-order effects (the proportion of something in all crashes) fairly accurately (to within about 3 percent, assuming that the data themselves are accurate and complete). Comparisons of proportions in two types of crashes will not be able to distinguish differences smaller than about 10 percent. Any analysis of a relatively infrequent situation—something that occurred in fewer than 10 percent of the crashes (or fewer than 100 cases) in the LTCCS database—can distinguish only large differences, on the order of 30 percent or more (see Hedlund [*3*] for further examples).

Data accuracy and completeness will limit some conclusions from LTCCS analyses. Incomplete data both limit the size of the dataset for any analysis and also probably introduce bias, because data seldom are incomplete at random. Inaccurate data clearly bias the conclusions. The authors have not had the opportunity to examine data completeness and accuracy in the final LTCCS file. In general, it is expected that variables directly observed by LTCCS investigators will be quite accurate and complete, including most vehicle data and non-transitory environmental data. Variables for which the LTCCS investigators had to rely on second-hand information will be less accurate and complete. Sensitive variables, such as whether or not the truck driver was in violation of the FMCSA Hours-of-Service (HOS) rules, are likely to be both incomplete and highly biased. The following discussions illustrate these points.

Critical Issues Related to Large Truck Safety

To provide a structure for discussing LTCCS analyses, the authors selected 10 high-priority issues in large truck safety and policy, developed problem statements for each issue, and assessed how useful LTCCS data would be in addressing the problem statements. The issues were selected using the following criteria:

- Relevance (issues involved in enough truck crashes to be worthy of attention)
- Current interest and knowledge (issues actively being investigated)
- Opportunity for intervention (issues that may suggest measures to reduce crashes)
- Feasibility (the relative ease of potential interventions, including costs, time frames, and implementation requirements)
- Jurisdiction (issues that FMCSA may be able to influence)
- Political priority (issues that FMCSA cannot afford to ignore).

The 10 issues and specific problem statements associated with each are detailed below. The issues are listed in the approximate order of their priority and are followed by brief assessments of whether, and how well, the LTCCS data could be used to address them.

Issue 1. Problem Identification

Problem statement: *Identify factors involved in a substantial number of crashes and factors that significantly increase crash risk.* This information is critical for determining the most important targets to be searched in order to formulate large truck safety countermeasures and to estimate the potential benefits of such countermeasures.

Assessment: To address the issue, it will be necessary to estimate the number of crashes nationally that involve various factors, and how the factors increase crash risk. LTCCS data are well suited to assess both issues across a wide range of potential causal or contributing factors related to drivers, vehicles, the environment, and motor carrier companies. Driver factors include: data on fatigue (hours driving before the crash, time and length of last sleep period, possible causal links between driver fatigue and crashes); driver license status, including crash and violation history; driver experience and training; driver performance during the crash, including any performance errors; and driver working environment, including wages, pay basis, schedule, and company safety record. Vehicle factors include: maintenance status, including any defects in brakes, tires, steering, or other critical vehicle components; and vehicle size, weight, load, and design. (An example of examining brakes as a factor is presented in Table 4 in the last section of this report.) Environmental factors include: roadway geometry, surface conditions, lighting, and traffic controls. Motor carrier factors, in addition to those involving the driver, include: size and type of carrier, carrier operations, and carrier safety history.

The potential limitations are data completeness and accuracy, especially for subjective data on driver factors. Data file size should not be a limitation. If a factor occurs infrequently enough that it cannot be studied with LTCSS data, then it cannot affect a substantial number of large truck crashes and, almost by definition, is unlikely to be a major crash causation issue for large trucks from an absolute point of view (although it could be a major issue from a political, regulatory, or relative risk point of view).

Issue 2. Driver Fatigue and Hours of Service

Problem statement: *Determine effective regulatory methods to reduce driver fatigue and increase alertness.* Driver fatigue has been identified as an important crash cause. It is known that many drivers drive while fatigued, but accurate estimates are not available.

HOS regulations that attempt to reduce fatigue are highly controversial and widely violated.

Assessment: The necessary data to investigate the role of fatigue and alertness in crashes include objective measures of the driver's hours of driving before the crash, his immediately previous hours of rest and sleep, and his longer-term sleep and driving schedule. Ideally there would be a measure of the driver's fatigue and alertness before the crash. This would require in-vehicle real-time monitoring of eye movements, brain function, or the like, which would be impossible without instrumenting all trucks. Next, data are needed on HOS compliance, both reported and actual, in order to determine the size of the problem. To determine crash risk, similar data are needed either for truck drivers not involved in crashes or, using relative risk methods, for drivers in crashes not involving fatigue or alertness. Then, data are needed on the roles of fatigue and alertness in causing or contributing to the crash: Did the driver fail to recognize or interpret a dangerous situation? Did he fail to take appropriate action that he might have taken if he had been more alert?

LTCCS collects the proper data on driver sleep history, driving hours, and fatigue and also on crash event variables that relate to driver alertness, such as inattention and distraction. Most of the data come from driver interviews, however, and it is likely that they will be considered suspect unless they can be confirmed by other evidence. Additional driver data are collected during Level 1 inspections of vehicles and drivers. If the data are accurate they can be analyzed to address the key issues of driver fatigue and hours of service.

Issue 3. Vehicle Maintenance and Inspections

Problem statement: *Evaluate the role of vehicle maintenance and defects in crash causation and the value of the FMCSA Motor Carrier Safety Assistance Program (MCSAP) truck inspection efforts in reducing defects.* Defective brakes and other components are frequently cited as crash causes and contributing factors. FMCSA spends more than $100 million annually on MCSAP-funded truck and bus inspections.

Assessment: Data are needed on the status of major vehicle components at the time of the crash, measured against inspection standards. Components should include brakes, tires, and steering. To estimate relative crash risk, similar data are needed for trucks in crashes that do not involve these components. Next, data are needed on the role that these components played in the crash. The effectiveness of the MCSAP truck inspection program can be approached in several ways. For example, maintenance issues or defects shown to increase crash risk could be compared with MCSAP inspection procedures to see whether the inspections are looking at the right things, and to see how frequently the maintenance defects that cause or contribute to crashes are observed in inspections.

LTCCS data include the results of a North American Standard Level 1 inspection, the most rigorous inspection in the MCSAP program. The data should serve well to examine the role of vehicle maintenance issues in crashes. Detailed study of MCSAP effectiveness will also require data from MCSAP.

Issue 4. Relative Roles of Cars and Large Trucks

Problem statement: *Estimate how many large truck crashes result from actions by passenger vehicles (cars or light trucks) and how many large truck crashes are unlikely to be affected by measures directed at large trucks and their drivers.* This information will help FMCSA and NHTSA explore whether interventions directed at passenger vehicles are needed to reduce large truck crashes.

Assessment: Statistical analyses of LTCCS data cannot determine a single crash cause or assign a crash cause to one vehicle or another. Statistical analyses can determine contributing factors, assign them to large trucks or to other vehicles, and estimate how they increase crash risk. The question is really one of problem identification and relative risk, a special case of Issue 1. As with Issue 1, the potential limitations are data completeness and accuracy and the size of the LTCCS data file. Because the LTCCS protocol collects the same data on all vehicles in a crash, it is well suited to identifying risk factors for passenger vehicles involved in serious crashes with large trucks.

Issue 5. Driver Working Environment

Problem statement: *Determine the influence of driver working conditions (wages, work schedule, company structure) on large truck crashes.* This information is needed to investigate whether working conditions should be monitored or regulated to improve safety.

Assessment: The key variables describing driver working conditions are wages, pay method (by mile, hour, or job), schedule, and employer type, as well as the data describing fatigue (see Issue 2, above). LTCCS collects the relevant data, largely through driver interviews. If the data are reasonably complete and accurate, then LTCCS can be used for simple comparisons of working environment variables, such as wage structure and driver scheduling practices.

Because of LTCCS sample size limitations and issues of data completeness and accuracy, more detailed analyses will require other data sources, probably at the motor carrier level. For example, comparing the crash records of drivers from motor carriers of similar types, pay methods, and scheduling practices but different wage levels would yield immediate information on whether wage levels by themselves influence crash risk.

Issue 6. Role of Environmental Factors

Problem statement: *Investigate whether changes in roadway environmental design or operation, such as exit ramp designs, truck-free lanes, or different speed limits for trucks, would improve large truck safety.*

Assessment: The LTCCS database is less useful for investigating environmental issues than for driver or vehicle issues. Many if not most environmental issues are best analyzed from a road section point of view, while the LTCCS data are suited to a truck or driver point of view. For example, an investigation of the effects of truck lane restrictions would compare crash risk between otherwise similar roads with and without truck lane restrictions or compare crash rates before and after lane restrictions were introduced. The data needed include traffic volumes for both large trucks and passenger vehicles in the lane restriction and unrestricted roads, which are not available in LTCCS. More detailed study requires substantial engineering data, such as lane widths and analyses of how large truck and passenger vehicle traffic enters and exits the roadway. The best that LTCCS can do for most environmental issues is estimate overall frequencies of crashes involving specific environmental conditions and provide individual cases for investigative analysis.

Issue 7. Truck Driver Performance

Problem statement: *Determine the role of truck driver performance in crashes, as measured by features such as truck speed, danger recognition, and driver actions, and identify areas where reasonable improvements in driver performance could reduce the risk of large truck crashes.*

Assessment: Driver performance is inherently more difficult to assess than are the other issues discussed in this report. Without in-vehicle data recorders or video cameras, driver performance in crash situations must be inferred after the fact from interview data, crash reconstructions, and expert judgment. The LTCCS collects information on the driver's attention, vision, judgments, and actions during the crash sequence both from interviews and from crash reconstructions. The data should provide an initial estimate of the overall contribution of driver performance errors to crashes, begin to distinguish the relative importance of different types of errors, and link specific crash types to specific errors. Other data sources will be needed to address how driver performance could be improved.

Issue 8. Vehicle Design and Load

Problem statement: *Determine the number and types of crashes in which truck design and/or load features are contributing factors.* Typical features include truck conspicuity, truck driver blind spots, and load shifts. This information could be used to explore potential interventions.

Assessment: The LTCCS data describe truck design and load features in great detail. The data are objective, can be observed at the crash site, and should be recorded completely and accurately. These data can be used to address many truck design and load issues quite well, up to the limits imposed by the LTCCS sample size.

Issue 9. Truck Driver Licensing and Monitoring

Problem statement: *Determine the contribution of improperly licensed or problem truck drivers to crash causation.* This information could be used to explore voluntary or regulatory measures to improve licensing and monitoring of drivers.

Assessment: The LTCSS data include driver license status and driver history data from interviews, police accident reports, and Motor Vehicle Department files. If the data are accurate, they can be used to estimate the contribution of improperly licensed or problem drivers to crashes and may suggest specific crash circumstances where these drivers are especially involved. Additional data sources will be required to explore interventions.

10. Truck Driver Training and Experience

Problem statement: *Evaluate the effects of truck driver training and experience in reducing crashes.* This information could be useful in considering methods to improve training or increase experience if appropriate.

Assessment: The LTCCS data record only the number of years driving a truck, the number of years driving the class of vehicle involved in the crash, and the date and type of driver training. These data will support only crude comparisons of crash rates and crash types for drivers at different experience levels or who received different types of training. Detailed data on training and driving experience will be needed for any further investigations.

Examples

The following examples of analytical techniques that could be used successfully with the LTCCS data are based on a similar data collection. From 1996 to 2001, the Michigan State Police Motor Carrier Enforcement Division (MCD) sponsored the Fatal Accident Complaint Team (FACT) program to collect data on fatal commercial motor vehicle (CMV) crashes in Michigan. The FACT approach was similar to that of the LTCCS, with some important differences. First, because the MCD has primary responsibility for enforcement of CMV regulations, the FACT program focused on truck data and collected relatively little data on other vehicles in the crashes. Second, although the crash type and critical event variables in the FACT database are similar to those in the LTCCS, critical reason was not coded. Third, the LTCCS data provide significantly more information on associated factors. Finally, the FACT program was restricted to traffic crashes in which at least one fatality occurred. Despite the differences, the FACT data provide useful examples of the range of analyses that LTCCS data can support.

Distributions of events and factors. Table 1 summarizes the vehicle inspection data from FACT. There are records for 503 trucks in the FACT data, and inspections were completed on 407. Just as in the LTCCS, each truck was subject to a North American Standard Level 1 inspection by an FMCSA-trained inspector. The FACT inspection data are much more thorough and reliable than the vehicle condition data in virtually any other crash file. Inspectors recorded the condition of the vehicle before the crash, to the extent that it could be determined, excluding crash damage.

Table 1

FACT Data: Inspection Results for 407 Large Trucks

Inspection Item	Percent of Large Trucks with Pre-Crash Violations
All log violations	12.3%
All hours-of-service (HOS) violations	2.2%
All other driver violations	16.2%
All brake problems	32.7%
All light/marker/signal violations	23.1%
All air pressure/hose violations	9.6%
All tire violations	14.5%
All steering axle violations, including brakes	14.0%
All suspension violations	9.6%
Any violation	**66.1%**
Any out-of-service (OOS) item	**35.1%**

Source: Michigan State Police, FACT data (1996–2001).

As shown in Table 1, more than one-third of the 407 trucks inspected by the Michigan FACT team had maintenance defects that would have placed them out-of-service (OOS) if they had been inspected before the crash. Brake problems were found in 32.7 percent of the trucks, and violations of light/marker/signal regulations were found in 23.1 percent. Brake-related inspection items are aggregated here; the FACT file contains more detail about the nature of the violation and the unit of the combination truck for which the violation was noted.

Table 2 shows the prevalence in the FACT data of several driver factors that have been identified as risk factors in large truck crashes. The LTCCS data provide national estimates of these and other factors that are, at least for items like fatigue, substantially better than any currently available data.

Table 2

FACT Data: Driver Factors Recorded

Driver Factor	Percent of Large Truck Drivers with Factor Recorded
Alcohol	1.0%
Illegal Drugs	1.8%
Fatigue	2.6%
Unfamiliar with area	3.4%
Driver Inexperience	2.2%

Source: Michigan State Police, FACT data (1996-2001).

It has been hypothesized that truckload carriers, at least small truckload carriers, have a relatively high incidence of fatigue-related crashes because of their irregular and unpredictable operating schedules. The only crash databases currently available that record carrier type are FACT and LTCCS. Table 3 shows the distribution of carrier type in the FACT data. More than 42 percent of the motor carriers in FACT crashes were for-hire, truckload carriers. Only 6.4 percent were less-than-truckload (LTL) carriers.

Table 3

FACT Data: Crash Involvement and Driver Fatigue by Motor Carrier Type

Carrier Type	Percent of Total Crash Involvements	Percent of Drivers Fatigued
For hire, less-than-truckload	6.4%	14.4%
For hire, truckload	42.2%	3.6%
Private	40.1%	0.0%
Other	4.6%	0.0%
Unknown	6.7%	0.0%

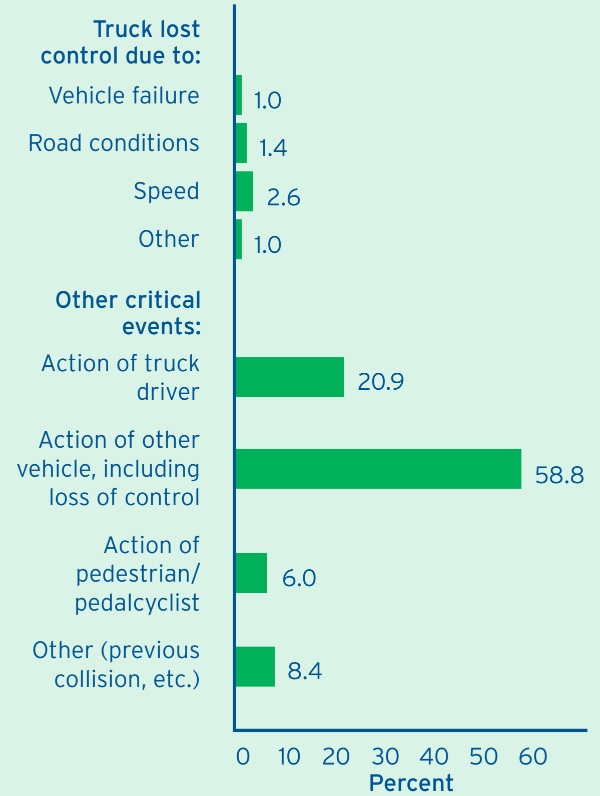
Source: Michigan State Police, FACT data (1996-2001).

Only about 2.6 percent of large truck drivers in the FACT data showed evidence of fatigue, but fatigued drivers were distributed unevenly across carrier types. No driver for private carriers and fewer than 4 percent of drivers for truckload carriers were judged to be fatigued at the time of the crash; but fatigue was recorded for 14.4 percent of the drivers for LTL firms involved in FACT crashes. The FACT sample size is too small to allow general conclusions on the relationship between carrier type and fatigue. Further study with more data, as the LTCCS provides, and ideally some measure of exposure, would be useful to explore the relationship between carrier type and fatigue.

Like the LTCCS, the FACT database includes data on "critical events." Figure 1 shows the distribution of broad critical event categories recorded in FACT. These descriptive statistics provide immediate insight and suggest where to look for countermeasures to reduce

Figure 1

FACT Data: Critical Events in Large Truck Fatal Crashes



Source: Michigan State Police, FACT data (1996-2001).

the incidence of truck crashes. For example, 58.8 percent of the critical events resulted from the action of another vehicle, 6.0 percent from the action of a pedestrian or pedalcyclist, 20.9 percent from the action of a truck driver, and 6.0 percent from loss of control of a large truck. These data directly address Issue 4, above.

Involvement ratios and relative risk. The most interesting use of the FACT and LTCCS data is for testing hypotheses using conditional probabilities. A primary goal of the LTCCS methodology is to establish a relatively detailed picture of what physically happened in the crash. By incorporating that detail into statistical analyses, it is possible to test hypotheses that certain factors are associated with increased risk. Most of the factors of interest operate through particular mechanisms. Thus, they are more likely to be found in some crash types than in others. Using the LTCCS data, one can calculate conditional probabilities to measure the relative risk of involvement of drivers or vehicles with certain factors in crashes where those factors may pose additional risks, as compared with other drivers or vehicles without those factors.

Take, for example, HOS violations. HOS violations themselves do not cause crashes, just as night or even excessive alcohol use does not cause crashes. Rather, we hypothesize that each increases the risk of crash involvement. The LTCCS data provide detail about what happened in a crash. Appropriately designed analyses can then test for over-involvement of HOS violations in that part of the crash population where they are expected.

The FACT data provide an example of a relative risk analysis of brake violations. To test for an association between brake violations and large truck crashes, specific crashes were identified in which the truck's brakes were the primary crash avoidance mechanism: rear-end crashes, crashes in which the vehicles were on intersecting paths, and crashes in which one or more of the vehicles involved were changing trafficways (that is, intersection crashes where the vehicles were on different roadways or one was turning onto a different roadway) and the other vehicle had the right-of-way. Braking is the primary collision-avoidance method at intersections, just as it is in rear-end crashes.

In Table 4, truck crashes from the FACT database are divided into two categories: (1) those in which the truck's brakes were critical to avoiding the crash (the truck was the striking vehicle in a rear-end crash or went through a traffic light or stop sign in an intersection crash); and (2) those in which the truck's brakes were not critical. For the cases in which the other vehicle needed to brake to avoid the crash (for

Table 4

FACT Data: Large Truck Brake Violations in Braking-Critical Crashes

Brake Violations	Truck Braking Critical	Truck Braking Not Critical	Total
	Number of Fatal Crashes		
None	42	82	124
One or more	35	35	70
Total	**77**	**117**	**194**
	Percent of Total Crashes		
None	54.5%	70.1%	63.9%
One or more	45.5%	29.9%	36.1%
Total	**100.0%**	**100.0%**	**100.0%**

Note: The results of a standard Chi-square test for association of the variables in the table (Chi-square = 4.86, 1 degree of freedom, probability = 0.027) indicates only a 2.7-percent chance that there is no association between truck brake violations and involvement in fatal crashes where the truck's braking is critical. That is, trucks with brake violations are much more likely to be involved in braking-critical crashes than trucks without brake violations.

Source: Michigan State Police, FACT data (1996-2001).

example, where the truck was struck in the rear by the other vehicle), the condition of the truck's brakes would not have affected the crash outcome. In crashes where stopping the truck was the primary means of avoiding the crash (for example, where the truck struck another vehicle in the rear), the condition of the truck's brakes was critical.

The results of this relative risk analysis indicate that large trucks involved in a crash where the braking capacity of the truck was critical were 50 percent more likely to have a brake violation than were trucks involved in crashes where the truck's braking capacity was not critical. Of the trucks involved in brake-critical crashes, 45.5 percent had brake violations, compared with 29.9 percent of trucks involved in crashes of the same type but where their braking was not relevant.

One explanation for this result could be that the striking trucks are poorly operated and maintained, and therefore the association of brakes and the truck's role in the crashes reflects poor operations rather than the hypothesized mechanical association. However, there was no association with either overall violations or out-of-service condition. Nor did any other physical system on the truck, other than lights/markers, show a statistically significant association with violating the right-of-way in "brake-relevant" crashes. The association with lights/markers falls short of statistical significance at the 0.05 level, but it is in the opposite direction from that for brakes (trucks with light/marker violations are more likely to be the vehicle with the right-of-way), suggesting that conspicuity may play a role.

Brake violations are statistically associated with being the striking vehicle in crashes where braking is important. The association is statistically significant, of significant magnitude, and supported by a physical mechanism. The FACT data are the first data with which it is possible to examine statistically the link between vehicle condition and crashes for large trucks. The much richer LTCCS data support precisely this type of analysis. With about twice as many cases and much greater detail about all aspects of the crashes, it should be possible to examine many more plausible contributing factors with LTCCS data than can be done with the FACT data.

Conclusions

The LTCCS is a general-purpose data file designed primarily for problem identification: to estimate the number of large truck crashes involving a particular factor and the contribution of this factor to crash risk. Because it is nationally representative, it can estimate national frequencies. Because it collects more than 1,000 data variables describing all aspects of a crash's drivers, vehicles, and environment, its estimates will be quite comprehensive. In addition, while LTCCS is designed as a statistical data file, its individual case reports will be useful for investigative analyses.

The ability to use the LTCCS data to investigate crash risk is based on estimating relative risk using induced exposure techniques. These techniques will apply to many vehicle features, some driver features, and few environmental features. Their usefulness for vehicle and driver features depends on whether there is a suitable control group of crashes in which the feature being examined has no effect.

The main limitations on statistical analyses of the LTCCS database will be data accuracy and completeness and overall sample size. Variables that investigators observe directly, such as environmental features and vehicle inspection data, are likely to be quite accurate and complete. Variables that are more subjective, obtained from interviews or from secondary data sources, may well be less accurate and complete even if the investigators have checked other sources to confirm the data. The 963-crash sample size will limit the statistical conclusions. Analyses of relatively rare situations can distinguish only large differences.

By the very nature of its design, the LTCCS database will be most useful for identifying and estimating the significance of an issue and comparing different issues with each other. The data may help to describe the physical and behavioral phenomena involved that must be understood to investigate, develop, and test interventions for an issue, but data from experimental settings almost certainly will be needed as well. If an intervention is in place, the usefulness of the LTCCS data in evaluating its effectiveness will be similar to its usefulness in estimating the significance of the issue.

Large Truck Crash Causation Study Analysis Series

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Much of the material in this paper is derived from Blower [*4*] and Hedlund [*3*], working papers prepared for the Transportation Research Board's Committee for Review of the Federal Motor Carrier Safety Administration's Large Truck Crash Causation Study. The policy questions, priorities, assessments of LTCCS usefulness, and all other opinions and conclusions are those of the authors and do not necessarily reflect the views of their institutions or of the Federal Motor Carrier Safety Administration.

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The goal of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce the number and severity of large truck- and bus-involved crashes through more commercial motor vehicle and operator inspections and compliance reviews, stronger enforcement measures against violators, expedited completion of rulemaking proceedings, scientifically sound research, and effective CDL testing, recordkeeping, and sanctions.

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