

INSURANCE INSTITUTE FOR HIGHWAY SAFETY

March 6, 2008

The Honorable John H. Hill
Administrator
Federal Motor Carrier Safety Administration
400 Seventh Street SW
Nassif Building, Room PL-401
Washington, DC 20590-0001

Hours of Service of Drivers, 49 CFR Parts 385 and 395; Interim Final Rule, Request for Comments Docket No. FMCSA-2004-19608

Dear Administrator Hill:

The Federal Motor Carrier Safety Administration (FMCSA) has requested comments on its interim final hours-of-service rule that took effect on December 27, 2007. To justify this rule, FMCSA has added some analyses but left intact the same provisions, and the same problems, that undermined the 2003 and 2005 rules, which were struck down by the US Court of Appeals for the District of Columbia (Circuit, No. 06-1035). These rules were struck down for good reasons, which FMCSA still has not adequately addressed. Therefore, the interim rule persists in failing to meet the agency's obligation to safeguard truck drivers and others on the road.

There are two main problems. The interim rule still allows truckers to drive 11 hours at a stretch instead of 10, despite overwhelming evidence that this compromises safety, and it retains a provision that effectively extends maximum driving hours to 77 in 7 days or 88 in 8 days. The court told the agency it had failed to explain the basis for these provisions, but instead of explaining this time around, FMCSA continues to rely on flawed evidence and to ignore the body of sound research on the risks of driving more than 8 hours at a stretch. The agency does report some new studies to support its provisions, but these studies are riddled with the same kinds of inaccuracies and omissions that plagued the previous ones on which the agency relied. The result is another flawed rule, as detailed below.

FMCSA's claim that driving 11 hours at a stretch is no more hazardous than driving 10 hours is not based on sound scientific evidence

Justification for permitting 11 hours of driving is based primarily on counts of fatigue-related fatal crashes per fatal crash involvement, by hours driven, available in the Trucks Involved in Fatal Accidents (TIFA) database. In testimony before Congress on December 19, 2007, FMCSA claimed this is "the only comprehensive data source that tracks fatal large truck crashes by hour of driving," adding that "between 1991 and 2002 only 9 large trucks were involved in fatigue-related crashes in the 11th hour of driving. More recent TIFA data reveal that there was one such involvement in 2003, none in 2004, and only one in 2005" (Hill, 2007).

The problem is that TIFA data on driving hours are not reliable because they are based on self-reports from drivers and motor carriers. Nor can these data reliably indicate fatigue-related crashes. TIFA data are drawn from police-reported data in the Fatality Analysis Reporting System (FARS) and, as a TIFA researcher told FMCSA, "the incidence of fatigue in the FARS file underestimates the true incidence of fatigue in fatal crashes" (Campbell, 2005).

There is no physical evidence at crash scenes that can establish the contribution of fatigue. Nor is there a biological marker for fatigue. A driver might be quite alert when police arrive. Drivers would be unlikely to report being sleepy or falling asleep, and some might even be unaware of the degree of their sleepiness (Moller et al., 2006). There are no uniform criteria among states for coding a crash as fatigue-related. Making this determination is up to individual officers, so reporting varies (Blower and Campbell, 2002). FMCSA itself has acknowledged that police reports underestimate the contribution of fatigue to crashes (Office of the Federal Register, 2000).

To bolster its findings based on TIFA data, FMCSA uses data from the Large Truck Crash Causation Study, which also are flawed for numerous reasons detailed in attached critiques from Dr. Ezra Hauer (2003), the Centers for Disease Control and Prevention (2005), and the Committee for Review of FMCSA's Large Truck Crash Causation Study (2000-03). Among the flaws are an absence of a comparison group of large trucks not involved in crashes, small sample size, missing data, lack of control for confounding factors, reliance on deficient sources for driving hours, and the inherent uncertainties in labeling a crash fatigue-related.

FMCSA also relies on the findings of instrumented driving studies by Hanowski et al. (2007a, 2007b) to buttress the claim of no difference in risk between the 11th and 10th hours of driving. However, the drivers were using experimental warning systems intended to alert them when signs of drowsiness were detected. This makes it impossible to isolate the effects of an additional hour of driving or to generalize to the population of large truck drivers.

Recognizing this, Hanowski (2007b) restricted some analyses to periods when the warning system was not activated. Then analysis of all critical incidents in which a trucker was judged at-fault revealed a higher risk in the 11th versus 10th hour (Analysis 1.4; odds-ratio = 1.90; 95 percent confidence interval = 0.88, 4.12). Hanowski dismissed this difference because it was not statistically significant. However, statistical significance is not the sole criterion for determining whether effects are real (it is a tool to help quantify evidence for or against a hypothesis; Vaughan, 2007). The findings should have been described as a nonsignificant increase in risk because the increase was so substantial. Although not statistically significant, the best estimate from Hanowski's study is that risk of an at-fault incident nearly doubles between the 10th and 11th hours of driving.

One of the most striking findings of Hanowski's studies was the observation of highest risk during the first hour of driving. Most of the drivers began their shifts at night, such that the 11th hour would have occurred almost exclusively during daylight, making it impossible to disentangle the effect of driving long hours from the effects of time of day. Other problems with Hanowski's studies include the following:

1. In some analyses, critical incidents were deleted if a driver had more than one per hour. This ignored the fact that fatigue can result in multiple driving errors.
2. Some drivers did not complete the 11th hour of driving, but their rates of critical incidents (crashes, near-crashes, and conflicts) were calculated as if they had. This resulted in overestimations of driving time and systematic underestimations of critical incident risk during the 11th hour. The researchers should have used partial driving hours as the denominators in calculating rates for truckers who quit driving before the end of the 11th hour.
3. Some analyses were restricted to drivers who drove 11 consecutive hours, excluding drivers involved in crashes during earlier hours who would not have kept on driving. Near-crashes and other critical incidents also could have led to early termination of driving trips.

4. It is questionable whether travel conditions during the 10th and 11th hours were similar. Time of day, traffic congestion, roadway type, and other factors affect crash risk. Breaks, off-duty time, number of consecutive shifts, and daylight conditions were not controlled.
5. Although the researchers mentioned drowsiness that preceded critical incidents, they did not report driver drowsiness observed by staff during the 11th versus 10th hour of driving.

By relying on flawed studies such as these, FMCSA overlooks numerous scientific studies indicating that crash risk does increase after driving more than 8-10 hours (e.g., summarized by the Insurance Institute for Highway Safety (IIHS), 2000, 2005). The agency ignores such studies as well as a newer research finding that each additional hour of work per day increases by about one-quarter the odds that truck drivers will experience fatigue (Friswell and Williamson, 2008). Such omissions invalidate the agency's conclusion that driving 11 hours at a stretch is as safe as driving 10. The burden of proof is on FMCSA to produce scientific evidence that this policy is not endangering truck drivers and others on the road, but the agency has failed to provide such evidence.

FMCSA's rationale for retaining the 34-hour restart provision ignores not only sound data on the effects of driver fatigue but also real-world data indicating that fatigue among truckers increased after the restart provision took effect

The restart provision in the interim rule allows truckers to increase their work time by 26 percent per week for a total of up to 88 hours in 8 days. In allowing this increase in driving time from a previous maximum of 70 hours in 8 days, the agency ignored a National Institute for Occupational Safety and Health (2000, 2005) finding that long work hours have adverse effects on truck drivers' health, increasing the risk of chronic disease and injury due to fatigue and exposure to toxic agents and other environmental and occupational hazards. Knowing of this finding, the agency convened its own panel for review, and the panel pointed to decrements in driving performance related to working long hours. Still the agency has retained the restart provision (Orris et al., 2005).

IIHS (2005) already has cited the absence of scientific evidence to justify this provision and the wealth of research about the adverse health and safety effects of driving long hours. What we primarily want to address here are two of FMCSA's arguments. One is that compliance with work-hour rules has improved since this provision has been in effect. The other is that few truckers drive the maximum allowed under the restart provision. The agency is wrong on both counts, and it fails to explain why it ignored survey evidence to the contrary. The agency already had some of these survey results (McCartt et al., 2005) when it began work on the interim rule in response to the court. Results of a newer survey by McCartt et al. (2008) are attached to this submission.

McCartt (2005) details the responses of long-haul truck drivers interviewed in November-December 2003 and 2004 about their work schedules before and after the restart provision took effect. The surveys were conducted anonymously so drivers would be willing to report violations of work rules without fear of legal or other repercussions. Using the same methodology, McCartt (2008) repeated the survey in November-December 2005.

A total of 1,921 drivers were questioned at two inspection sites on interstate highways with heavy volumes of east-west truck traffic in western Pennsylvania and northwestern Oregon. About 80 percent of drivers in 2005 reported regular use of the 34-hour restart. More than 90 percent reported using it at least once. These are higher percentages than FMCSA estimates.

Almost 20 percent of drivers surveyed in 2005 said they drove more hours per shift than before the 2003 rule change. About 30 percent reported driving more than 10 hours but fewer than 11 hours per shift. About 6 percent said they routinely drove more than 11 hours per shift. Yet the agency assumes that a smaller proportion (i.e., smaller than about 36 percent) of truckers drive during the 11th hour.

FMCSA says compliance with work-hour rules has increased since 2003, based on what drivers report in their official logbooks. However, these logbooks are notoriously inaccurate, and FMCSA has refused to require electronic recorders in trucks that would, among other things, keep accurate counts of driving hours. The agency proposed to require recorders in 2000 but backed off, leaving this provision out of the final rule it issued in 2003. Despite the appeals court telling FMCSA in 2004 that its justification for bypassing a requirement reflected “questionable rationality,” the agency again left such a requirement out of its final rule in 2005.

In the absence of recorder data, the most credible source of accurate information about truckers’ driving hours and violations is the McCartt (2008) survey results, according to which violations during a single month among Pennsylvania truckers went up from 25 percent in 2003 to 29 percent in 2005. Compliance did improve in Oregon, from 30 percent of drivers reporting violations in 2003 to 24 percent in 2005. These differences are not large and, in any case, the findings indicate continued violations.

The most important survey finding is an increase in trucker fatigue, measured according to whether drivers had fallen asleep at the wheel during the month before being surveyed. In Pennsylvania 19 percent admitted dozing at the wheel in 2005, up from 13 percent in 2003. The proportions in Oregon were 21 percent in 2005 compared with 12 percent in 2003.

Drivers also were asked about driving while sleepy “at least once” during the past week. Forty-one percent in Oregon reported such behavior in 2005, up from 36 percent in 2003. In Pennsylvania the proportion in both 2003 and 2005 was 43 percent.

FMCSA fails in other ways to justify retention of the 34-hour restart provision. For example, the agency assumes that 34 hours off duty will permit full recovery from cumulative sleep debt by permitting two 8-hour sleep periods. This contradicts findings of a study conducted for FMCSA indicating that even 36 hours off are not enough (Wylie et al., 1997). Some truckers (13 percent of those surveyed in Pennsylvania and 9 percent in Oregon) reported they do not even take the required 34 hours.

FMCSA does not require the 34-hour off-duty period to span two consecutive nights, which is a problem because fatigue literature already in the docket indicates that nighttime sleep is the best to manage or mitigate fatigue (Orris et al., 2005). Two 8-hour daytime sleep periods are not equivalent to two 8-hour sleep periods at night, even assuming that drivers could manage to sleep 8 full hours during the day.

Such evidence of the detrimental safety effects of the restart provision undercuts FMCSA’s retention of it in the interim rule. Retaining it is especially egregious given survey evidence that truckers use this provision week after week to increase their driving time.

The statistical models FMCSA used are not credible

In striking down FMCSA’s 2005 work-hour rule, the court noted the rule’s basis on a model for which “an important aspect of its methodology was wholly unexplained.” In issuing the interim rule, FMCSA supplied an explanation, which reveals the inadequacies of the model. In particular, the model is based on TIFA data, which are unreliable (see above, p.2). Statistical manipulations and model adjustment cannot compensate for the data deficiencies. Additional flaws in the model include the following:

1. The model assumes that fatigue contributes to 7 percent of large truck crashes. In 2000 FMCSA estimated fatigue-related crashes at 15 percent and then changed this estimate, without a strong basis, to 8 percent in 2003. Its current 7 percent estimate contradicts Gander et al. (2006), who compared crash reports of fatigue contributing to large truck crashes in New Zealand with other indicators of fatigue likelihood, estimating that fatigue contributed to almost 18 percent of large truck crashes compared with 5 percent on official crash reports. Other researchers also have reported estimates far higher than 7 percent (see summary in Saltzman and Belzer, 2007).
2. Relying on TIFA data, FMCSA ignores numerous studies that associate longer driving hours with increased overall crash risk, even after controlling for time of day. Driving-hour data from Lin et al. (1993; 1994), Park et al. (2005), and Jovanis et al. (2005) are more likely to be accurate than TIFA data because they were supplied by unionized carriers with fixed routes and schedules who are less likely to have hours-of-service violations. FMCSA's statistical models should have used these and other strong studies of crash risk (e.g., Jones and Stein, 1987). One of these studies is by Hall and Mukherjee (2008, attached), who conclude that the benefit of changing the driving hour limit from 11 to 10 would be a 2 percent reduction in crashes.
3. The models predicting performance or alertness rely heavily on SAFTE/FAST data, developed in a laboratory. Such data can be used to understand effects of sleep deprivation, but real-world crash data should have been given more weight.

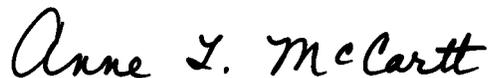
Summary

FMCSA's justification for its final rule is flawed in three important ways. The agency selectively omits important evidence that contradicts the assumptions and positions that underlie the rule. The evidence the agency does rely on is flawed. Its statistical models lack credibility.

It is true, as FMCSA says, that restoring the 10-hour driving limit and removing the 34-hour restart option would disrupt, to some extent, trucking industry operations and enforcement methods. But these disruptions can be accommodated in a way that is economically feasible for motor carriers, as indicated by Hall and Mukherjee (2008). Therefore, FMCSA should heed the "S" in its acronym and do what is best to safeguard both truckers and everybody else on the road instead of seeming to look first to serve the economic interests of the motor carriers it regulates.

Doing what is best entails heeding the scientific evidence before the agency and restoring the driving hour limit to 10 instead of 11 per shift, as was the case prior to 2003. The agency also should remove the restart provision so that weekly work hours will be restored to 60 over 7 days and 70 over 8 days.

Sincerely,



Anne T. McCartt, PhD
Senior Vice President, Research

cc: Docket Clerk, Docket No. FMCSA-2004-19608

Acknowledgement

The Institute would like to acknowledge the contribution of Elisa R. Braver, Ph.D., Associate Professor, Epidemiology and Preventive Medicine, University of Maryland School of Medicine. Dr. Braver conducted a critical review of FMCSA's documentation in support of the interim final rule. This included the data and analyses conducted under FMCSA contract and independent studies cited in the docket for this rulemaking.

Attachments

Centers for Disease Control and Prevention. 2005. Evaluation of the Large Truck Crash Causation Study Design. Atlanta, GA.

Committee for Review of the Federal Motor Carrier Safety Administration's Large Truck Crash Causation Study. 2000-03. Letter Reports of: September 4, 2003; December 19, 2002; December 4, 2001; March 9, 2001; and November 15, 2000. Washington, DC: Transportation Research Board. Available: http://www.trb.org/news/blurb_detail.asp?id=6086.

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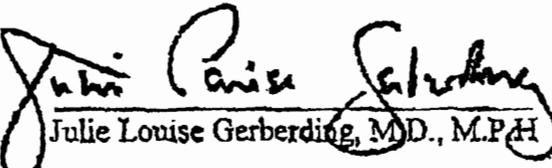
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Evaluation of the Large Truck Crash Causation Study Design

Centers for Disease Control and Prevention

Atlanta, Georgia

March 2005


Julie Louise Gerberding, M.D., M.P.H.

Congressional Request to CDC Through the Federal Motor Carrier Safety Administration

The Centers for Disease Control and Prevention (CDC) was asked by Congress to evaluate the design of the Large Truck Crash Causation Study (Truck Study). The congressionally-mandated Truck Study was a joint effort of the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA), both within the U.S. Department of Transportation. The Truck Study was mandated by Congress via Public Law 106-159, dated December 9, 1999. An interagency agreement between FMCSA and NHTSA was established in August 1999, at which time planning for the Truck Study was initiated. Data collection began January 1, 2001 and continued through December 31, 2003.

Federal Motor Carrier Safety Administration fiscal year 2003 Conference Report language included a request for CDC's National Center for Injury Prevention and Control to evaluate the adequacy of the Truck Study research design.

FY 2003 Conference Report Language for the Large Truck Crash Causation Study

Conference Report (H.R. Conf. Rep No. 108-10) – Making Further Continuing Appropriations for Fiscal Year 2003, and for Other Purposes

Crash causation study.—The conference agreement includes language proposed by the Senate urging FMCSA to make available the preliminary results of the crash causation study as soon as a representative data set is analyzed and to submit a letter to the House and Senate Committees on Appropriations by May 15, 2003, indicating the study's progress, the response to and status of the Transportation Research Board's recommendations, and a time schedule for the release of the initial results. In addition, the conferees direct NHTSA to request that the Centers for Disease Control's National Center for Injury Prevention and Control evaluate the adequacy of the crash causation research design. CDC's evaluation is to be provided to the House and Senate Committees on Appropriations.

CDC received this request from NHTSA in June 2003.

The National Research Council (NRC) of the National Academy of Sciences conducted a previous review of the Truck Study. At the request of the Department of Transportation, the NRC convened a committee of experts to review the Truck Study and to provide guidance to FMCSA and NHTSA. The committee held the first of five meetings in September 2000 and the last in March 2003. The committee documented its findings in five "letter" reports issued between November 2000 and September 2003. CDC used these reports, interviews with FMCSA and NHTSA staff, reports from experts in the field, and materials from NHTSA describing the Truck Study to prepare its assessment.

Introduction

As described by NHTSA, the purpose of the Truck Study was to gain information about the causes of serious crashes (i.e., crashes that result in a death or serious injury) involving large trucks. Understanding the causes of these crashes may lead to the development of successful countermeasures to prevent them. To collect data on large truck crashes, the Truck Study took advantage of an ongoing data collection system, NHTSA's National Automotive Sampling System Crashworthiness Data System (NASS-CDS). The NASS-CDS uses trained personnel to conduct detailed investigations on crashes involving passenger cars, light trucks, and vans under 10,000 pounds in the United States. The investigations are conducted in 24 sites around the country and provide a nationally representative sample of these crashes. Employing the same methodology as the NASS-CDS, a sample of 1000 large truck crashes was selected for study.

CDC Review of the Truck Study Methodology

To assess the adequacy of any design, it is important to understand the purpose of the research. Although it was apparent that FMCSA and NHTSA sought to obtain information about factors associated with large truck crashes, it was not clear that a research plan with specific research questions had been developed for the study. Thus, it could not be determined whether the purpose of the study was to generate general questions for further research or to answer specific research questions. For example, one approach to investigate the causes of truck crashes might be to conduct a general, broad-based study designed to generate research questions for further study. Alternatively, if there is sufficient information about a particular area, then a more focused study designed to answer specific research questions may be a better approach,

Strengths and Limitations of the Design

The Truck Study has several strengths. By capitalizing on the infrastructure of the NASS-CDS, FMCSA and NHTSA were able to begin data collection fairly quickly. Moreover, a great deal of information was obtained on each truck crash (more than 1000 coded data elements per crash), which should be helpful to further studies. In addition, the sample was representative of large truck crashes throughout the nation, and the data will provide an estimate of the total burden of large truck crashes. Finally, when analyses of the data are complete, the study should yield information on the prevalence of certain types of large truck crashes.

Conversely, because the FMCSA/NHTSA Truck Study did not have a clearly defined research plan, there are important limitations. The major drawback is that the design was driving the study. For any study, the purpose of the research needs to be clearly defined and a design selected that is appropriate to answer the question(s) under study. Because the Truck Study did not begin with a well documented research plan, the design (including the size of the sample selected for study) limits the usefulness of the findings.

As an illustration, one might be interested in the causes of large truck crashes in which a flat tire or tire blow out (on the truck) was a contributor. However, since the size of the

study was limited to 1000 crashes (due to FMCSA/NHTSA funding), there may be only 10-15 crashes that had a flat tire or tire blow out. **Although** a description of these crashes is possible, a meaningful interpretation of such a small sub-sample is not.

A related issue is the ability of the 1000 crashes to provide for appropriate comparison groups within the sample. If there is an interest in crashes with driver fatigue as a contributing cause, crashes with this factor must be compared to similar crashes (e.g., crashes in similar types of trucks, similar weather conditions, similar road conditions, etc.) without this factor. It is likely that finding appropriate comparison groups of sufficient size within the total sample of 1000 will be difficult. **Consequently**, there must be an adequate number of crashes in each group to make comparisons valid,

An equally important challenge is translating what is learned about crash causation from the Truck Study into effective countermeasures to prevent future crashes. There was considerable effort in the Truck Study to identify the "critical event" and "critical reason" for the crash. The "critical event" is the event that made the crash unavoidable. The "critical reason" is the reason for the critical event. While there is nothing inherently wrong with defining these factors, relying too heavily on "critical event" and "critical reason" limits the scope of the search for effective countermeasures and should be avoided.

A countermeasure designed to prevent this crash based on the "critical event" and "critical reason" might be "improved braking inspections and maintenance." However, the "critical event" and "critical reason" limit the search for countermeasures to causes that are close in time to the crash. What can be missed by focusing only on "critical events" and "critical reason" are the causes that are farther away from the moment of impact, such as icy road conditions, obscured signage, the driver feeling ill, brake problems, driver fatigue, or hours of service violation (extra long shift). For example, disincentives for hours of service violations might have resulted in the driver being more alert and recognizing the need to slow down earlier. If the intent of the Truck Study is to ultimately prevent crashes, not only should the "critical event" and "critical reason" be considered, but also all alterable causes anywhere in the chain of events leading to the crash.

Future Studies

By the time the request to CDC came through NHTSA in June of 2003, the Truck Study was well underway and data collection had been ongoing for more than two years. This limited the usefulness of a "study design evaluation" for the Truck Study; however, lessons learned from the execution of the Truck Study may be useful for planning future studies.

Of utmost importance is to have a clear plan for the research, including selection of the design and methodology appropriate to answer the specific questions under study. When little is known about a particular area, broad exploratory studies may be useful to generate questions for further study. As more is learned, broad-based exploratory studies

become **less** productive **and** studies designed to address **specific** research questions (those questions **identified by a broad-based study**) become more **helpful**.

Recommendations

- 1. Begin with well defined study objectives, research questions, and plans for data analysis. Without a well documented research plan, it is impossible to know whether the study can meet its purpose.**
- 2. In terms of practical application, the Truck Study would have benefited had crash causes been linked to countermeasures. The development of countermeasures for future studies of this type will enhance their usefulness.**

September 4, 2003

Ms. Annette M. Sandberg
Administrator
Federal Motor Carrier Safety Administration
Room 8202
400 7th Street SW
Washington, DC 20590

Dear Ms. Sandberg:

The Committee for Review of the Federal Motor Carrier Safety Administration's (FMCSA's) Large Truck Crash Causation Study held its fifth and final meeting on March 23 and 24, 2003, in Washington, D.C. The enclosed meeting roster lists the Committee members, government staff, guests, and Transportation Research Board (TRB) staff in attendance.

TRB formed the Committee in 2000 at the request of FMCSA to provide advice on study methods. This is the Committee's fifth letter report. The others were submitted on November 15, 2000, March 9, 2001, December 4, 2001, and December 19, 2002.

On behalf of the Committee, I thank the staff members of FMCSA and the National Highway Traffic Safety Administration (NHTSA) for their cooperation throughout the term of our activities. As we have stated in our earlier letters, we recognize that the study is a landmark undertaking of great potential importance to highway safety.

At the meeting, the Committee discussed two background papers it had decided to commission at the preceding meeting. The topics of the papers are described in our December 2002 letter report. Both papers consider how the government could organize the data analysis of the Large Truck Crash Causation Study (LTCCS). The Committee used the papers as resources in formulating the recommendations presented in this letter report. In addition, the Committee heard presentations from FMCSA and NHTSA staff on study progress, including analysis of rates of missing data in the database. Before the meeting, the Committee received responses from FMCSA to the recommendations of the December 2002 letter report and also copies of the NHTSA interim report on the study (*Large Truck Crash Causation Study Interim Report*, NHTSA, September 2002). Since the reviews conducted in 2002 and described in our December 2002 letter report, the Committee has not reviewed any additional crash cases in the database.

Because not all high-priority questions on truck safety can be answered in the current study and because Congress has directed FMCSA to update the study in the future, the Committee also discussed data collection and analysis methods that might be appropriate for follow-up efforts, in particular, automated data collection, which may yield much more complete and accurate information on certain questions than the data obtained by traditional methods.

Following this letter report is a statement by Committee member Lawrence A. Shepp on the need for automated data collection and on other matters. The Committee majority agrees that onboard monitors could be valuable for the study of certain risk factors and shares Dr. Shepp's concern as to whether the study will permit inference of the role of certain factors, including fatigue, in increasing crash risk. However, we did not examine automatic data collection methods in sufficient depth to allow us to recommend specific research, and the Committee majority believes that the question of whether onboard recorders should be mandatory involves issues beyond the scope of the Committee's charge.

Because data collection is now at an advanced stage, the Committee majority has focused its recommendations in this letter on actions that will allow the Department of Transportation (DOT) to derive the greatest benefit from the effort that has been expended on the LTCCS. To this end, our conclusions and recommendations in the next two sections concern analysis of the LTCCS data and issues of data quality. The third section addresses issues for consideration in planning future crash causation studies and similar major safety studies. A summary of all our recommendations follows the sections on these three topics.

In our previous letter reports, we urged DOT to devote attention to detailed planning of how it would employ the information obtained in this study for the purposes Congress specified. We noted that planning would be needed for the analyses DOT will include in its report to Congress and that planning should also anticipate how the database will serve as a resource in support of DOT's continuing needs for analysis and research related to its safety programs.

Such planning should be the earliest stage of this or any study—at the point of designing the data collection. For the LTCCS this did not occur. DOT staff described to the Committee a number of their objectives or interests, including questions on the effectiveness and design of FMCSA regulations and management of enforcement resources; however, it seems that no formal process was in place at the beginning of the study for stating these objectives explicitly and then checking the ability of the planned data collection to fulfill them. A basic Committee recommendation, as explained in the third section below, is that DOT include such a formal planning process in any similar future crash causation studies.

ANALYSIS METHODS FOR THE LTCCS DATA

The congressional charge for the LTCCS in Section 224 of the Motor Carrier Safety Improvement Act of 1999 provides that “[t]he study shall be designed to yield information that will help the Department and the States identify activities and other measures likely to lead to significant

reductions in the frequency, severity, and rate per mile traveled of crashes involving commercial motor vehicles...."

To fulfill this charge, DOT is now developing methods to use the LTCCS data to improve performance and provide strategic guidance for its established safety programs. Our conclusions and recommendations in this section address two aspects of the required analyses:

- Clearly defining research objectives that are related to DOT's overall efforts to reduce truck crashes and that can be addressed with the LTCCS database, and
- Defining methods of analysis that can be used with the LTCCS data to meet these research objectives.

The Committee believes that such clear definition of LTCCS objectives and methods will allow DOT to identify enhancements to the LTCCS database that can be introduced in the near term and also to identify needs for alternative databases and methods to meet research objectives that cannot be met with the LTCCS database.

These two aspects of LTCCS analysis planning are discussed in the two subsections below. Our recommendations are supported by the background papers that we commissioned to illustrate approaches to analysis planning. The two papers, "Statistical Analysis of Large Truck Crash Causation Study Data," by James Hedlund, and "Investigative Analysis of Large Truck Accident Causation," by A. James McKnight, are enclosed with this letter. The judgments contained in these papers are solely those of their respective authors, and the Committee does not necessarily concur with all of them. The papers have not been reviewed by the National Research Council. However, we believe that the conclusions of these papers cited below provide worthwhile guidance. The papers are not presented as substitutes for DOT's own efforts but describe general methods the Committee believes would be constructive.

Defining Objectives That Can Be Addressed with the LTCCS Database

The Committee as well as DOT staff have struggled with the issue of what specific research objectives can be addressed with the LTCCS database and thus what analysis methods should be employed. Clearly, the longer-term use of the database by both DOT and external researchers will identify numerous research objectives and methods. However, the Committee's focus at this point is meeting the immediate need of DOT and Congress to identify measures that will reduce the harm caused by truck crashes. Our conclusion is that at a minimum, DOT can do the following:

1. Analyze the LTCCS database to better define and quantify the human, vehicle, and roadway and environmental factors that are present in a significant proportion of truck crashes and that are candidate causal factors. The Committee believes that the emphasis should be placed on the human factors in crashes.
2. For selected policy issues that are critical to FMCSA's role, use the LTCCS database to quantify the *relative risk* of certain human, vehicular, or roadway and environmental factors to estimate the relationship between the presence of relevant risk factors and the increase in the chance

of an accident, using the relative risk method outlined by Dr. Daniel Blower of the University of Michigan in presentations to the committee in 2001 and 2002.

Defining Research Methods to Meet the Objectives

Various research methods could be employed to meet each of these two objectives. The following two subsections, based on the findings of the two commissioned background papers, summarize the opportunities that we see for FMCSA and NHTSA to conduct two kinds of analysis in the remainder of the study, designated here as “investigative analysis” and “statistical analysis.” The experience of past studies suggests that investigative analysis is most successful in identifying the immediate and direct contributors to crashes and statistical analyses are successful in identifying underlying contributors. In the statistical approach, cause may be defined on the basis of statistical relationship; that is, one can say that a given factor was a causative factor to the extent that the presence of the factor affects the odds of occurrence of a crash. The third subsection presents recommendations concerning analyses in FMCSA’s report to Congress.

Investigative Analysis

The commissioned background paper, “Investigative Analysis of Large Truck Accident Causation” by A. James McKnight, examines methods and applications of causal assessment in crashes. The author was asked to consider how the variables in the database could be used to explore causes in a way that would be useful to DOT in developing programs to reduce crash frequency. He was also asked to consider whether modifications are needed in assessment methods or in the coding or presentation of data to support examination of crash causation. The paper includes a review of similar efforts in other fields.

Some form of investigative analysis underlies the identification of cause in almost all aspects of life. This is true whether the question is cause of death determined by a doctor’s observations or a post-mortem examination of the body, the cause of a major airline crash, or the cause of a truck crash. Currently, the primary variables related to the immediate cause of the LTCCS crash are the “critical event” and “critical reason,” as defined by DOT analysts. The specification of causal factors in these truck crashes will be based not on direct observation of the crash itself, but on data gathered from the scene and from interviews after the crash. Some of these factors will be patently obvious, but others may be inferred only with intensive investigation. In particular, more intensive investigation may be necessary to investigate human factors: operator behaviors and factors influencing these behaviors.

Because of both the difficulty and importance of defining causal factors, particularly those related to human behaviors, the Committee recommends that DOT consider conducting a second, independent round of assessments of the cases, using different methods than were used in the first assessments. A small team of experts (working as consultants to DOT) would review cases and, according to a predefined scheme, identify multiple immediate causes or factors contributing to the occurrence of the crash. The experts would then combine all identified causes in a crash taxonomy, as described in the background paper by McKnight.

The following are the central elements of the method of assessment and classification outlined in the paper:

- In-depth analysis of crash cases to identify crash causes. This will require analysis of the cases by a multidisciplinary team of technical specialists in fields related to prevention of truck crashes—including automotive engineering, motor carrier operations, and human factors research—freed from the inferential constraints under which the LTCCS assessments are conducted.
- Identification of multiple causes or contributing factors. Typically, truck crashes are the consequence of the presence of multiple circumstances and events, the alteration of any one of which would have reduced or eliminated the possibility of the crash. To fully exploit the LTCCS cases, it will be necessary to document such chains of events and circumstances, because each failure suggests particular opportunities for intervention to reduce the risk of similar crashes.
- Aggregation of causes and contributing factors. Development of a taxonomy of causes or factors that groups causes into categories with similar preventive requirements would be a valuable step toward identifying priorities and improving crash prevention efforts.

The McKnight paper provides examples of assessments from past studies that could serve as models. The value of such judgments from experts has been demonstrated in the Indiana Tri-Level study, described in the paper, which is recognized as the most insightful investigation of crash causation ever conducted. Relevant approaches also have been demonstrated in recent studies of motorcycle safety and boating described in the paper. In light of the attention that the assessments coded in the database will likely receive, this additional round of assessments would serve as a worthwhile final quality control check.

We recommend that the main objective of the new assessments be to shed light on the role of human factors in precipitating crashes. The investigative analysis technique may reveal a wide variety of kinds of crash causes or contributory factors, but it is especially valuable for documenting factors that cannot readily be inferred from observations of physical conditions following a crash. An important such category is driver behavior that may contribute to crashes, such as lapses in vigilance, habits or patterns in operating the vehicle, or failures to take preventive action. We suspect that the relative significance of such human factors will not be evident in the LTCCS data as they are now coded; however, understanding these factors may be critical in the design of countermeasures. Past studies on crash causation have shown that such factors often can be identified in carefully conducted investigations and that they contribute to the occurrence of a significant number of crashes. As we have noted elsewhere, to develop countermeasures aimed at crashes arising from such driver behaviors it will be necessary to study factors like work schedule, work organization, and fatigue that may lead to driver errors and inattention. Of course, the investigative analysis may reveal vehicular and environmental factors as well as human factors.

Statistical Analysis

While investigative analyses will lead to better identification of causal factors in truck crashes, quantification of the association between the presence of certain factors and a subsequent crash is accomplished through statistical models, such as the relative risk method that DOT plans to use in analyzing the LTCCS data. The quantification of relative risk provides a basis for regulations or other treatments. FMCSA has initiated the planning of relative-risk analysis. In his paper and presentation to the Committee, Dr. Blower of the University of Michigan described the relative risk method that will be used and presented examples of policy issues or factors (e.g., truck brake failure) that can be successfully studied with this method. After hearing this presentation, we recommended in our December 2002 letter report that in planning and carrying out its statistical analysis of LTCCS data, FMCSA should adopt “a comprehensive and strategic perspective, rather than ... searching through the data being collected to seek analyses that are feasible. That is, FMCSA should identify a list of high-priority potential risk factors ... [and] then determine which of these can be assessed using the database and the planned statistical analysis method ... and which would require other approaches.”

The commissioned paper by James Hedlund illustrates an approach that incorporates such a comprehensive and strategic perspective in planning the statistical (relative risk) analyses. As requested by the Committee, the author defined and ranked critical policy questions related to truck safety. (The author consulted with the Committee in selecting policy questions.) Then the author considered which of these questions can be expressed as hypotheses that can be tested by the relative risk method FMCSA plans to employ and with LTCCS data.

The analysis in the Hedlund paper follows these four steps:

1. A list of critical policy questions or issues related to truck safety is developed, derived from DOT regulatory responsibilities related to truck safety. These critical policy questions are grouped into priority categories, based on such factors as the potential for reduction in crash losses and the probability of successful treatment.
2. For each policy question the information that ideally would be available to the safety regulatory agency is defined. This information would in general include three elements: measures of the significance of the question, scientific understanding of the physical and behavioral phenomena involved, and evaluations of the effectiveness of treatments or interventions.
3. The extent to which the crash causation study data can contribute to filling each critical information need is assessed. For those questions to which the data may be applicable, the author examined whether the relative risk statistical method proposed by FMCSA would be appropriate or whether an alternative analytical method would be needed.
4. For the information needs identified in Step 2 that cannot be fulfilled by the LTCCS data and the proposed analysis methodology, alternative data sources and research techniques are identified for assessing the significance of those policy questions, developing scientific understanding of the relevant phenomena, and evaluating effectiveness of interventions.

Within its limited scope, the paper could not fully carry out this analysis. In particular, in addressing Steps 3 and 4, the paper assumes reasonably complete and unbiased data, since the author could not assess the quality of the actual LTCCS data or the adequacy of sample sizes. The paper's purpose is to provide insight into potential critical issues and a sketch of a method for defining objectives and consequent information needs and determining whether alternative analytical techniques are needed.

The Committee is not recommending that DOT necessarily adopt the paper's conclusions about priority safety issues or whether the LTCCS data can be used to explore such priority issues. However, we do recommend that FMCSA follow a similar procedure in identifying priority safety issues before initiating relative risk analysis. We also recommend that the paper's conclusion on the LTCCS database's applicability be considered when DOT is identifying other potential data sources and analysis methods for filling gaps in the LTCCS coverage. Other existing data sources may help, but filling in the gaps will require new research. More importantly, we recommend that DOT adopt a statistical analysis planning strategy along the lines presented in the paper for (a) its report to Congress explaining how the study fulfills the congressionally specified objectives, (b) its analysis of the LTCCS data, and (c) the earliest planning stages of any future similar studies.

The analyses employing the relative risk method suggested in the Hedlund paper would require use of multivariate statistical techniques to control for the effects of all relevant variables. Such analyses should be designed by qualified statisticians.

Analyses in FMCSA's Report to Congress

Although DOT has not presented the Committee with an analysis plan for its report to Congress, we can anticipate, on the basis of the NHTSA interim report and DOT presentations, some problems DOT may encounter in presenting study results, especially in addressing Congress's question on the causes of truck crashes. In particular, we are concerned that misunderstandings will arise from use of the critical event and critical reason assessments. Discussions at the meeting showed that the DOT staff is aware of potential pitfalls in presenting these assessments. DOT cannot avoid these potential misunderstandings merely by avoiding the use of the word "cause." Any tabulations or discussions that highlight particular precipitating circumstances or occurrences (for example, the tabulation in the interim report of numbers of crashes by critical reason) will present the same problems of interpretation and will require the same careful explanation by DOT. Such tabulations are likely to be interpreted by many nonspecialist readers as indicating "cause" or "fault."

We recommend that to discourage misinterpretation, DOT emphasize the following considerations in its presentation of assessment results in its report to Congress:

- The report should make clear the categories of causes or factors influencing crash risk that the study is most suited to illuminating, and those categories for which it can be expected to provide less information. Accurately describing the limits of the study requires presenting the results within a context-setting discussion of the state of knowledge about the

determinants of crash risk and the means of reducing crash risks. This discussion could be organized according to the well-established framework that categorizes risk factors and interventions as relating to the vehicle, the driver, and the environment. The limitations on coverage arise from the study's basic design, the choices of data elements, the sample size, and difficulties encountered in obtaining accurate information for some data elements. Among the factors whose relations to crash risk the LTCCS data may not be able to reveal for one or more of these reasons are driver fatigue, driver inattention, driver collision avoidance actions, speed, roadway conditions, driver characteristics, and driver pay and work organization. (See the Hedlund paper for further details.) Explaining the study's limitations will be necessary, because Congress asked for a comprehensive study of the causes and contributory factors of truck crashes. Attempting to draw policy conclusions from the study without an understanding of its coverage limitations could lead to misplaced priorities.

- The report should make clear that the association of the critical event or critical reason in a set of crash cases with some element of the crash circumstances (for example, with driver behavior, road condition, or a vehicle characteristic) does not imply that countermeasures should necessarily be targeted to that element. In particular, the association of the critical event or critical reason with the car or car driver involved in a truck crash does not necessarily indicate that preventive measures aimed at cars or car drivers will be the most effective means to avoid similar future crashes, or that the case is irrelevant for assessing truck safety regulatory programs. For example, standards for truck reflective markings, under-ride guards, and braking are means to avoid or mitigate crashes in which critical reasons and events are likely to be associated with actions of car drivers.
- If the report contains conclusions about the implications of the study results for truck safety regulation, regulatory enforcement, or other safety programs, it should outline the additional quantitative research that would be necessary to translate each such observation into effective policy. This discussion will be necessary to ensure that nonspecialist readers understand that the LTCCS was not designed to function as the sole quantitative basis for regulatory decisions or for evaluation of the effectiveness of regulations. Any new safety measure suggested by the LTCCS results would require development and evaluation before full-scale implementation (for example, through pilot studies) and quantitative evaluation after implementation to demonstrate effectiveness.

DATA QUALITY

We reiterate our recommendation in the December 2002 letter report that DOT take all feasible measures to verify and enhance data accuracy and completeness. Efforts to improve data quality at this stage of the study can yield large dividends by increasing the database's power to identify ways to reduce the frequency of truck crashes. The DOT presentation at the March 2003 Committee meeting addressed some of the concerns with data quality that we expressed in the previous letter report. DOT staff presented tabulations of rates of missing data for 30 cases. These are all cases completed of the 588 initiated by January 22, 2003 (excluding the initial several dozen cases investigated, which DOT regards as a pilot study of the data collection method). Thus the summary statistics presented at the meeting on rates of completion refer only

to a special subset of cases—those that have been easiest to complete. We do not know if they are representative of the database, and there is reason to suspect that they will not be. Committee members have not examined any additional cases since the December 2002 letter report.

Data that DOT presented at the meeting indicate that at some data collections sites, notification rates—the percentage of crashes eligible for inclusion in the study of which the investigators are informed by local jurisdictions—remain low, at around 50 percent. Low notification rates probably introduce bias in the data, as reporting rates probably vary by site, severity of crash, and other factors. The Committee recommends that DOT continue to investigate the causes of failures to receive notification of crashes and the characteristics of eligible crashes that are not being reported.

We remain particularly concerned that the method of the present study is not well suited for obtaining reliable data on fatigue, driver inattention, and driver collision avoidance actions. In addition, the reliability of speed data may not be high and it appears unlikely that present study procedures will produce useful data on the topic of the relation of driver pay and work organization to crash risk.

We recommend that DOT commission an independent data quality evaluation of a random sample of cases by a multidisciplinary group of experts, as soon as an appreciable fraction of the entire sample has reached the last stages of editing. The evaluation could be similar to the reviews that a subcommittee of this Committee performed at DOT in 2002. However, it should follow a systematic and documented procedure and will require more time than the subcommittee devoted to the task to ensure that the evaluators are first familiarized with the database.

Once the extent of missing data and nonresponse problems is documented, NHTSA and FMCSA should assess the effects of these problems on parameter estimates and hypothesis tests in their statistical analyses.

It would be worthwhile for the data quality review to also serve as a review of the database's user-friendliness. Specifically, the review could test whether users tend to frequently misinterpret any of the data elements and whether they can extract data of interest with a reasonable effort. The review team also should test the new case overview form and comment on its effectiveness in guiding the researcher to pertinent data.

FUTURE STUDIES

The LTCCS began with very generally stated objectives provided by Congress. Indeed, Congress asked for “a comprehensive study to determine the causes” of truck crashes. DOT may be asked to undertake studies of similarly ambitious scope in the future. The congressional charge provides that “[t]he Secretary shall review the study at least once every 5 years and update the study and report as necessary.” In addition, if the present study is successful, Congress may ask DOT to conduct crash causation studies for other classes of vehicles.

We believe that DOT's experience with the present study has taught lessons that will improve the quality of updates and new causation studies or of other studies with similarly broadly conceived goals and substantial costs. Our observations over the past three years lead us to offer the recommendations presented below for future studies.

The starting point for the present study was a data collection methodology that involved use of NHTSA's National Accident Sampling System (NASS) data collection teams and sampling method. The important advantages to DOT of this strategy were that the NASS framework was in place (thus saving time and money) and was proven. However, the drawback of adopting a pre-existing data collection scheme in a new study is that the scheme probably will not be ideal for meeting all the goals of the study.

We recommend that, instead of allowing the data collection to drive the analyses, DOT begin any future similar studies by formulating precise statements of research objectives. If the study is to support NHTSA's and FMCSA's programs of safety regulation, then objectives should be stated in terms of critical policy issues and hypotheses about crash causes and risk factors that follow from the issues, along the lines proposed in the Hedlund paper. Then the researchers should design data collection methods to answer the questions of interest. This approach may entail focusing a future study on certain safety issues to the exclusion of others, or use of multiple data collection methods and research designs. If the study objectives include refining understanding of mechanisms of crash causation, then we recommend that consideration be given to the recommendations above and in the McKnight paper concerning methods and assessment team expertise.

In our conception, any large-scale safety study that DOT conducts should be designed to closely support the process of identifying opportunities to reduce the number of crashes (that is, points of intervention, such as for fatigued drivers or malfunctioning brakes), designing interventions (for example, regulations and regulatory enforcement programs), implementing the interventions, and measuring their effectiveness. Management of each step in this process requires data, analysis, and evaluation. The planning for a crash causation study ought to specify exactly where and how the study will contribute to these information needs.

We recommend that when DOT considers the need for updating LTCCS, it look for opportunities to fill gaps in the data that are revealed by analysis of the completed cases. We have predicted that gaps may include the relationships of fatigue and driver behavior to crash risk; however, DOT will be able to see the gaps clearly as analyses from the database proceed.

We recommend that, in planning for future crash causation studies, DOT consider including data collection by instrumented vehicles. Such techniques might be necessary to obtain reliable information on the roles of fatigue and driver behavior. Recent research using instrumented vehicles, described at the Committee's March 2003 meeting, demonstrated methods for obtaining reliable information on such factors. As we noted above, we did not examine automated data collection in sufficient depth to allow us to recommend a specific study design or program of research. We recommend that in evaluating proposals for mandatory onboard truck data systems, DOT give attention to the requirements of safety research and the potential benefits of improved safety information.

In general, DOT should seek a variety of alternative or supplementary data collection methods for consideration in planning future studies. One way to generate the needed variety of approaches would be to advertise a request for proposals with generally stated study criteria and allow potential contractors to propose data collection and analysis methods. We therefore recommend that data collection and analysis for future crash causation studies be competitively awarded.

We recommend that any future major crash causation study incorporate a methodology study as a distinct phase, with its own budget, schedule, and published product. Similarly, we recommend that any future major study incorporate a true pilot study. The pilot study would be large enough to clearly indicate whether planned data collection and analysis methods could meet the declared objectives of the study. The pilot study would end with revisions in the methodology and with a published report. The schedule and budget for the overall study would permit significant revisions after the pilot, if revisions were found necessary.

If DOT undertakes a similar crash causation study focusing on small vehicles, we recommend that crashes involving large trucks not be excluded from the survey population. Inclusion of these crashes will be necessary for developing a comprehensive understanding of the causation of small vehicle crashes.

Finally, we recommend that any future major studies of crash causation or truck safety, that is, studies of the scale and complexity of the LTCCS, have the advantage of independent expert review from their earliest planning stages. DOT should seek funding for establishment of an independent scientific advisory group for each such study. To ensure timely input and efficiency, the advisory group should be named at the initiation of the project so that it can review the issues proposed for study, the choice of methodology, and the data to be collected. The products of future major studies should undergo peer review before publication or release.

SUMMARY OF RECOMMENDATIONS

The Committee's recommendations, extracted from the sections above, are repeated below.

Analysis Methods for the LTCCS Data

- In its report to Congress, in its analysis of the LTCCS data, and in the earliest stages of planning any future similar studies, DOT should adopt a strategy of identifying specific critical policy questions and defining the consequent needs for information and analysis. Then the functions of the LTCCS and other research and data programs in fulfilling these needs should be determined.
- DOT should conduct a new, independent round of investigative analyses of the cases, with different methods than were used in the first assessments, and add the results of this independent round of analyses to the LTCCS database. An expert team should identify causes or factors contributing to the occurrence of crashes according to a predefined scheme

and combine the causes or factors into a crash taxonomy. The necessary elements of the new investigative analyses and examples of studies employing relevant methods are described in the McKnight paper.

- DOT should consider the conclusions in the Hedlund paper on policy questions that will not be illuminated by analysis of the LTCCS data. DOT should identify other data sources and analysis methods for filling gaps in the coverage of LTCCS related to the critical policy questions DOT identifies.
- The DOT report to Congress should (a) identify gaps and limitations in the study's coverage of the kinds of crash risk factors, (b) explain how cases in which the critical events or critical reasons are associated with cars and car drivers are relevant for assessing truck safety regulatory programs, and (c) outline the additional quantitative research required in order for the conclusions and observations drawn from the study on potentially promising safety initiatives to be translated into effective policy.

Data Quality

- DOT should continue to take all feasible measures to verify and enhance data accuracy and completeness. Efforts to improve data quality can yield large dividends by increasing the power of the database to identify ways to reduce the frequency of truck crashes.
- DOT should investigate the causes of failures to receive notification of crashes eligible for inclusion in the study at the data collection sites and the characteristics of eligible crashes that go unreported.
- DOT should commission an independent data quality evaluation of a random sample of cases by a small, multidisciplinary group of experts, as soon as an appreciable fraction of the entire sample has reached the last stages of editing.

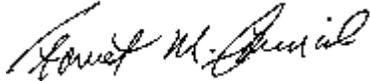
Future Studies

- Any future major safety studies should start with precise statements of research objectives in terms of critical policy issues and hypotheses about crash causes or risk factors that follow from the issues. Then data collection methods should be designed to answer the questions of interest.
- When DOT considers the need for updating the truck crash causation study, it should look for opportunities to fill in data gaps in the current study. These gaps may include the relationships of fatigue, driver behavior, driver characteristics, and driver pay and work organization to crash risk. However, as analyses using the database proceed, DOT will be able to see clearly where gaps lie.
- In planning for future crash causation studies, DOT should consider including data collection with instrumented vehicles. Such techniques might be necessary to obtain reliable information on the roles of fatigue and driver behavior. In evaluating regulatory proposals

for mandatory onboard truck data systems, DOT should give attention to the requirements of safety research and the potential benefits of improved safety information.

- Data collection and analysis for future major studies should be conducted through competitively awarded contracts.
- Any future major study should incorporate a methodology study as a distinct phase, with its own budget, schedule, and published product.
- Any future major study should incorporate a true pilot study, large enough to prove the suitability of data collection and analysis methods. The pilot study should produce a published report and recommendations for revisions in the methodology.
- If DOT undertakes a similar crash causation study focusing on small vehicles, crashes involving large trucks should not be excluded from the survey population.
- Any future major studies should have the advantage of independent expert review from the earliest planning stages. The products of future major studies should undergo peer review before publication.

Sincerely,



Forrest Council
Chairman
Committee for Review of the Federal Motor Carrier
Safety Administration's Truck Crash Causation Study

Enclosures

MEETING ATTENDANCE

March 23 and 24, 2003

Committee Members

Forrest M. Council, Chair
Michael H. Belzer
John R. Billing
Kenneth L. Campbell
James W. Dally
Anne T. McCartt
Hugh W. McGee
A. James McKnight
Jack Stuster
Steven J. Vaughn
Frank R. Wilson

TRB Staff and Consultant

Joseph Morris
Stephen Godwin
James Hedlund

Government Staff and Contractors

Terry Shelton, FMCSA
Ralph Craft, FMCSA
Richard Gruberg, FMCSA
Joseph Carra, NHTSA
Chip Chidester, NHTSA
Gary Toth, NHTSA
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Nancy Bondy, NHTSA
Barbara Rhea, NHTSA
Seymour Stern, NHTSA
Jim Page, Veridian Corporation
Don Hendricks, Veridian Corporation
Richard Ketterer, KLD Associates
Dan Blower, UMTRI
Richard Reed, Accident Research and Analysis

Minority opinion of Lawrence Shepp (National Academy of Sciences, Institute of Medicine, and Professor of Statistics, Rutgers University), to be appended to the majority report to FMCSA by the Committee for Review of the Federal Motor Carrier Safety Administration's Truck Crash Causation Study.

In my professional opinion the planned study will not produce definitive data, because the sample size of examples of truck crashes is much too small to produce statistically accurate results since the number of possible causations grossly exceeds the number of accident examples to be obtained. There are other sources of statistical bias as well in the planned study, including the choice of accidents to be studied, the biases of the interviewers on the scene, and the deceptions of the drivers who may be at fault, especially if they are the only survivors. Thus this study will likely lead to many inconclusive or erroneous conclusions.

Instead, there is a simple inexpensive method that should be considered: law should be enacted that would require a black box as in commercial airplanes, or a video camera as in police cars, to be placed in every commercial truck. This would give a far more accurate method to obtain not only the statistics of causes, but would likely lead to definitive determination of cause in every case of truck accident and would, in passing, lead to better performance of trucks on the road.

Lawrence A. Shepp
Rutgers University

Statistical Analyses of Large Truck Crash Causation Study Data

A Report to the Committee for Review of the Federal Motor Carrier Safety Administration
Truck Crash Causation Study, Transportation Research Board

J. Hedlund
Highway Safety North
April 8, 2003

EXECUTIVE SUMMARY

The paper discusses how the Large Truck Crash Causation Study (LTCCS) database can be used to investigate crash causes and contributing factors. It defines ten critical truck safety questions, outlines the specific information needed to address each, assesses how well the LTCCS database fills these needs, and briefly discusses other data that could be used for questions where LTCCS data are not adequate.

The principal conclusions:

- The LTCCS is a general-purpose data file designed primarily for problem identification. It collects over 1,000 data variables describing all aspects of a crash's drivers, vehicles, and environment. It can be used to estimate unbiased national frequencies since it is based on the NASS-CDS sampling protocol.
- 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 where the feature being examined has no effect.
- The 1,000-case sample size will limit statistical conclusions from the data. Analyses and national estimates of relatively infrequent situations will have large uncertainties and will only be able to distinguish large differences.
- Data accuracy and completeness may limit many conclusions from the data. Directly observable variables likely will be quite accurate and complete. Variables that depend on interviews may be less accurate and complete even if investigators check all possible sources to confirm the interview reports.
- While LTCCS is designed as a statistical data file, its individual case reports will be useful investigative analyses based on in-depth crash reconstructions.
- Additional data from experimental settings almost certainly will be needed to develop specific interventions.

INTRODUCTION AND PURPOSE

In the Motor Carrier Safety Improvement Act of 1999 that established the Federal Motor Carrier Safety Administration (FMCSA), Congress required FMCSA to “conduct a comprehensive study to determine the causes of, and contributing factors to, crashes that involve commercial motor vehicles” [Public Law 106-159]. To fulfill this requirement, FMCSA joined with the National Highway Traffic Safety Administration (NHTSA) to design and operate the Large Truck Crash Causation Study (LTCCS). The study is investigating a nationally representative sample of 1,000 large truck crashes at 24 data collection sites within NHTSA’s National Automotive Sampling System (NASS). Trained crash investigators from NASS and FMCSA collect over 1,000 individual data elements for each crash. After pilot testing, full data collection began in July 2001 and will conclude in 2003.

The Transportation Research Board Committee for Review of the Federal Motor Carrier Safety Administration’s Truck Crash Causation Study (the Committee) was formed to provide advice and oversight to FMCSA and NHTSA in designing and operating the LTCCS. Unfortunately, the Committee was convened only after the study design was complete and the pilot test was beginning (LTCCS Committee, 2001, Appendix A). This meant that several fundamental decisions had been made without Committee input: the use of NASS sites, sampling procedures, and crash investigation methods; the amount of data to be collected for each crash; the selection and definitions of most variables; the use of the Perchonok method of determining critical events that immediately precipitate a crash; and the number of crashes to be investigated.

At the first Committee meeting, some Committee members took issue with the basic LTCCS design. In particular, they believed that FMCSA placed the cart before the horse by building the study on a data collection methodology rather than an analysis plan. NASS is a highly respected, smooth-functioning, nationally representative data collection system, but NASS was designed to study the crashworthiness properties of passenger vehicles, not the causes of commercial motor vehicle crashes. The Committee expressed this view to FMCSA repeatedly in the Committee’s letter reports, most recently in December 2002 (LTCCS Committee, 2002):

“It is the Committee’s view that, although FMCSA now has taken some sound initial steps in the development of its analysis plan, the study is still behind schedule in this fundamental task. In our first letter report two years ago, we concluded that ‘there is a clear need for a thorough analysis plan that documents agency plans for interim and final analyses for the study.... Regardless of methodology, data collection must be based on the research questions being addressed and the analysis to be undertaken.’ We offered similar advice in subsequent letters. Although the study is no longer in the preliminary stage, there would still be benefits from developing a thorough plan now, before data collection is complete. It is not evident that a sufficient level of effort has yet been devoted to this task. Therefore, we recommend that FMCSA consider whether a reallocation of resources is necessary among the tasks of data collection, data base design, and analysis planning.”

The Committee decided to prepare two papers to communicate its views to FMCSA more clearly and in more detail than was possible in its brief letter reports. The two papers discuss how the

LTCCS database can be used to explore crash causation, crash risk, and measures to prevent or reduce crashes through, respectively, “investigative” analyses, in which crash reconstruction experts review individual crash reports to investigate factors that may have influenced or could have prevented these specific crashes, and “statistical” analyses of the full database, which can examine the frequencies and crash risks associated with various factors. See McKnight (2003) for the first paper.

This is the second paper. Its goal is to discuss how statistical analyses of the LTCCS database and other databases can be used to investigate crash frequencies and risks in the presence or absence of various driver, vehicular, or environmental characteristics and to assist in identifying, developing, and evaluating methods to decrease large truck crashes. More specifically, the paper addresses the following six points specified by the Committee.

1. List critical policy questions or issues related to truck safety. The list should be derived from present FMCSA and DOT regulatory responsibilities related to truck safety, from policy proposals and concerns of highway safety groups and the trucking and highway industries, and from past research results.
2. Attempt to group the questions into two or three priority categories. Explain the basis for the categorization. This discussion should make a credible argument that these questions are worthy of the attention of regulators, industry, and researchers, possibly to the exclusion of other questions.
3. For each of the policy questions identified, outline the specific information that ideally would be available to a safety regulatory agency responsible for addressing the issue, or to a truck operator who wished to control truck crash losses. Such information would in general include three elements: measures of the significance of the question, scientific understanding of the physical and behavioral phenomena involved (for the purpose of designing interventions), and evaluations of the effectiveness of interventions.
4. For each of the highest priority policy questions, assess whether the LTCCS database may be able to contribute to filling any of the critical information needs.
5. For some of the policy questions, the LTCCS database might be directly applicable to quantitatively estimating the relationship between the presence of relevant risk factors and the increase in the chance of an accident, using the relative risk method outlined by Blower (2001). Examine each of the highest priority policy questions and judge whether the relative risk methodology can be applied to the LTCCS database. For policy questions where the relative risk method does not appear applicable, outline any other methods that could be used with the data and that would be useful in examining the questions.
6. For some of the policy questions, neither the relative risk methodology nor other analysis methodologies may be applicable to or useful with the LTCSS database. For two to five of the most important such questions, suggest alternative databases and techniques for assessing

the significance of the question, developing scientific understanding of the relevant phenomena, and evaluating the effectiveness of interventions.

AUDIENCE, ASSUMPTIONS, AND APOLOGIES

This paper is written for the Committee and for interested persons in FMCSA and NHTSA involved with the LTCCS. It assumes a working knowledge of LTCSS design and data collection, including data collection forms and coding practices, as presented in NHTSA's LTCCS Interim Report of September 2002 (NHTSA, 2002b). It also assumes a general working understanding of methods used to analyze crash data. It attempts to address the Committee's six points honestly and directly. I've written it somewhat informally, in an attempt to communicate clearly and accurately.

I made two important assumptions and decisions in writing the paper.

- Crash causation: since the LTCCS's main purpose is to study crash causation, I've excluded issues that have little or no relation to crash causation. Underride guards, seat belts, and hazmat spill cleanup do not appear.
- Data accuracy and completeness: as this paper is written, in February 2003, LTCCS data collection is in full swing. Crashes will continue to be selected through the end of 2003. Many investigations of selected crashes are not yet complete. Also, NHTSA has not analyzed the accuracy and completeness of the data collected so far, and I have not conducted my own analyses. This means that I cannot assess how accurate and complete the data in the final LTCSS file will be. Unless otherwise noted, I assume that the data will be reasonably accurate and complete. I point out some places where this assumption may be doubtful.

I approach this paper with some trepidation and considerable humility. I know very little about large truck crash causation. Many members of the Committee and many persons in FMCSA and NHTSA know far more. I ask their indulgence for my errors of fact and interpretation. I consulted with some Committee members and some staff at FMCSA and NHTSA for background information and perspectives on the paper's issues. Several Committee members provided valuable comments on a draft. The paper's policy questions, priorities, assessments of LTCCS usefulness, and all other opinions and conclusions are my own.

Several terms are used throughout the paper. "Truck" or "large truck" refers to those vehicles within the LTCCS scope: vehicles over 10,000 lbs. "Car" or "light vehicle" refers to all other vehicles. An "intervention" is any measure intended to prevent or reduce crashes; other authors use the terms "countermeasure" or "treatment." Finally, "cause" should be understood broadly as any factor that may increase crash risk, as discussed in the following section. Occasionally I use "cause or contributing factor" to emphasize this point.

CRASH DATA AND CRASH CAUSATION -- CONTEXT OF THE LTCCS

What's meant by crash causation? The two best-known interpretations are the “necessary factor” definition used in the Indiana Tri-Level study (had the factor not been present in the crash sequence, the crash would not have occurred) and the “increased risk” definition (the factor increases the risk, or probability, of a crash). Blower (2001) discusses these more fully. This paper, by its charge, concentrates on the “crash risk” interpretation.

This definition of crash cause has several important consequences. First, a crash does not have a single cause, but rather may have been influenced by many factors. Second, the concept of fault is not relevant. 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's the role of investigative analysis (McKnight, 2003).

Finally, the whole question of crash cause in a sense misses the main point. At the end of the day, the goal is to prevent or reduce crashes. So the true goal of the LTCCS is to serve as a database for exploring possible interventions, as stated in the Committee's requirement #3 for this paper. One way to explore interventions is to look for factors that increase crash risk, but that's not the only way. Another way is to examine characteristics common to many crashes and consider whether changes in these conditions may reduce crash risk. This paper considers LTCCS's usefulness in these two ways.

Which comes first, data collection design or analysis plan? To set a context for the LTCCS, consider two extreme situations.

- A tightly-focused research question for which new data are needed. The researcher prepares a study and analysis plan, then designs data collection to address the specific question. The data typically aren't useful for a broad range of other questions. As a recent example, see Hanowski et al (2003), which studied fatigue in short-haul truck drivers. The study investigated 42 drivers using instruments on their trucks, wrist activity monitors, and questionnaires. The data are useful only for studying short-haul truckers, and they won't say much about issues not related to fatigue.
- A set of administrative data available for analysis. The researcher attempts to use the data to investigate the questions of interest but may well find the data lacking because useful information was not collected, or the data file size is too small, or other reasons. As an example, NHTSA's FARS (Fatality Analysis Reporting System) collects data from official sources -- police accident reports, driver license files, coroner's reports, etc. -- on all fatal traffic crashes. FARS data show clearly the number of heavy trucks involved in fatal crashes and can be disaggregated by roadway type, weather conditions, and the like. But FARS data can say little about issues such as driver fatigue because the only on-site data collected are those in a standard police accident report.

The LTCCS lies somewhere in between these extremes. On the one hand, its goal is to examine the causes of large truck crashes. So it's limited to crashes involving large trucks and should concentrate on data relevant to crash causation (though not exclusively, as Congress also asked

for information on crash severity). It also is able to design and collect its own data. But it's to be comprehensive -- all causes, not just the top ten; all questions and issues related to crash causation, not just those that are most politically sensitive at the moment.

This means that the basic LTCCS "analysis plan" must be to investigate "all" potential causes and contributing factors of large truck crashes. FMCSA and NHTSA explicitly designed the LTCCS to collect "all" reasonable data that in their judgment might be relevant to crash causation and intervention development. They explicitly did not start with a list of top priority issues, as does this paper; rather, they assumed that the LTCCS data would in fact address most or all of the high priority questions. This paper thus tests whether that assumption is correct, at least for the ten priority questions I have identified.

Two other points support the FMCSA and NHTSA decision to start with a very broad analytic objective and design data collection to support that objective rather than starting with a detailed analysis plan. First, analysis objectives are seldom fixed in time but frequently evolve and change to adapt to new circumstances and information. As researchers well know, studies frequently raise more questions than they answer. (The old saw that the standard conclusion of a research study is "More research is needed" is often quite accurate.) As the national study of truck crash causation, LTCCS must be capable of addressing many different issues -- "all reasonable issues" is in fact an appropriate goal. Second, data collection systems have substantial inertia -- once established, they change only slowly, at considerable expense. LTCCS cannot afford to ignore major areas that may affect crash causation on the grounds that "if a new issue comes up, we can add the data to address it" -- as far as possible, LTCCS must collect the right data from the start.

Statistical and investigative analyses work together and complement each other. It's useful to think of the two analysis methods -- statistical analyses of the full LTCCS database and investigative analyses of individual LTCCS cases -- together rather than separately. For example, statistical analyses can suggest that a specific feature increases crash risk and can estimate how often this feature occurs on a national level. Investigative analyses can dig further into specific causal mechanisms and suggest interventions. Statistical analyses can suggest how to extrapolate these potential interventions back to a national scale and how to estimate costs and benefits.

Note in particular that investigative analyses have limited usefulness without the national context provided by statistical analyses. By itself, all an individual investigative analysis can say is "I found the following causes and contributing factors for this crash; here are various measures that may have prevented it." This may suffice in situations where zero defects are truly expected, such as aircraft or space shuttles. For a variety of reasons, we are unlikely to achieve or even seek zero highway crashes. Even if zero crashes are the ultimate goal, sound policy demands that we concentrate on the most important issues first. Investigative analyses cannot say which issues are more important -- which occur the most frequently and which affect crash risk the most -- unless all relevant crashes on the LTCCS database are analyzed individually using the same well-defined investigative protocol. Statistical analyses can determine frequency easily, as long as the issue can be defined by LTCCS variables, and can determine crash risk in many instances.

The LTCCS data must be useful for both investigative and statistical analyses of large truck crash causation. NHTSA's NASS CDS (Crashworthiness Data System) has fulfilled these dual roles for light vehicle crashworthiness issues. By using the NASS CDS field structure, basic sampling design, and data collection protocols, and by building on NASS field data collection variables and experience, LTCCS should do the same.

Exposure data for large truck crashes are crude, so most crash risk analyses of the LTCCS database must use induced exposure techniques. **As Blower (2001) explains, a key strategy in statistical analyses of crash causation is to examine how various factors change crash risk. 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 we'd like to compare crashes per mile of travel for trucks with brake violations to crashes per mile of travel for trucks without brake violations; perhaps even crashes per mile of travel on wet roads or in other circumstances. Alternatively, we 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 (same vehicle type, driving on the same road at the same time of day and day of week, etc. -- the controls). The LTCCS did not use a case-control study design, so other exposure data must be used.**

Exposure data on large truck travel are crude. Registration data aren't much use since the spread of annual miles traveled by different trucks is very large. Miles of travel (VMT) data are not especially accurate and distinguish only gross truck and road types. Data on critical issues such as driver fatigue and vehicle maintenance may be available from inspection stations, but these will be hard to extrapolate to travel estimates.

Induced exposure is a general technique that uses crash data themselves to estimate relative exposure for a specific factor being examined. It's based on the presumption that the factor can affect only some crashes. The presence of the factor 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. Again, see Blower (2001) for a more thorough discussion and an example.

Induced exposure and relative risk methods are standard techniques in crash data analyses and will be appropriate for the LTCCS database.

Sample sizes will limit statistical conclusions from the LTCCS. The complete LTCCS data file will have 1,000 cases. This is a large file for investigative analyses and should provide a wide variety of crash circumstances. But it's 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%.

(Precisely, if the true proportion of people in the nation that plan to vote for presidential candidate John Smith is about 50%, then a simple random sample of 1,000 will have standard deviation of 1.58%, so that the usual 95% confidence interval will have a potential error of 1.96 standard deviations, or 3.1%. If 480 people in the sample say they will vote for Smith -- 48% of the total -- then the 95% confidence interval of the estimated national support for Smith is 48% plus or minus 3.1%, or 44.9% to 51.1%. The true possible error undoubtedly will be larger than this. The sample may not be truly random: if it's conducted by telephone, then it excludes persons without a telephone, as was the case in the famous prediction that Dewey would defeat Truman in 1948. Some persons may refuse to participate, and the refusers may have different preferences for Smith than the participants. Some persons may not answer honestly. These and other ways in which the responses differ from a true and accurate random sample all increase the possible error.)

The LTCCS is a complex multi-stage sample, so estimating variances is considerably more complicated than this simple binomial example. The complexity increases the variance. This means that if the LTCCS 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% confidence error will be greater than 3%.

Many, perhaps most, interesting and useful analytic questions go beyond simple estimates of a single objectively-recorded parameter. Some questions only apply to a subset of the LTCCS crashes: for example, questions regarding multi-unit truck crashes (about two-thirds of the LTCCS crashes selected to date (Craft, 2003)). Other questions may involve more than one parameter: for example, does the proportion of daylight hour crashes 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.

Here's an example of the effect of sampling error on relative risk comparisons, based on Blower's data from Michigan (2001, page B-13, Table 4). The question is to determine whether truck brake violations increase the risk of crashes. Blower divided crashes into those where the truck brake condition was likely to be relevant to the crash (the truck struck another vehicle in the rear or the truck went through a traffic control) and those where truck brakes were likely not relevant (for example, the truck was struck in the rear while stopped at a traffic signal). In the

Michigan data, truck brakes were relevant (“critical,” in Blower’s terminology) about 30% of the time. Next, research suggests that as many as 40% of truck brakes may be in violation of inspection standards (Jones and Stein, 1989).

Suppose that, as in the Michigan data, truck brakes are not critical in 70% of the 1,000 LTCCS cases, or 700. So these 700 should have about the same brake violation proportion as trucks on the road. Using the Jones and Stein findings, this would be 40% of the 700, or 280. We thus have the following partial table.

Brake violations	truck brake critical	truck brake not critical	total
yes		280	
no		420	
total	300	700	1,000

How large a difference in brake violations in the truck brake critical crashes can a sample of 1,000 detect? If brake violations occur in 50% of these crashes -- that’s 1.25 times the 40% observed in the other, control, crashes, or 25% more frequently -- will this be statistically significant? If they do, the full table is:

Brake violations	truck brake critical	truck brake not critical	total
yes	150	280	430
no	150	420	570
total	300	700	1,000

The Chi-square test for independence gives $\chi^2 = 8.56$, $p < 0.005$ -- yes, the difference is highly significant. But if brake violations occur in 45% of these crashes -- 1.125 times the 40% observed in the control crashes, or 12.5% more, then we have:

Brake violations	truck brake critical	truck brake not critical	total
yes	135	280	415
no	165	420	585
total	300	700	1,000

Now $\chi^2 = 2.16$, $p > 0.10$ -- no, the difference is not significant. Conclusion: our sample of 1,000 can distinguish differences only of about 20% in this highly idealized example.

In fact, most relative risk analyses of the LTCCS database won’t be able to distinguish differences this small. Not all crashes will be relevant for every analysis: we may wish to examine braking only for combination trucks, or only on wet road surfaces. If only half are relevant, then every cell in our examples will be only half as large. The Chi-square statistic then

is only half as large as well: we still can distinguish a 50% rate from a 40% rate, but now only at the level of $p < 0.05$. If the size of the relevant crash population shrinks further, the ability to distinguish differences becomes worse -- differences must be larger to be statistically significant. If some cases contain incomplete or inaccurate data, the distinguishable differences must be even larger.

These simple examples illustrate the basic point. The LTCCS file of 1,000 cases will serve to estimate first-order effects (the proportion of something in all crashes) fairly accurately (to within about 3 percentage points, assuming 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%. Any analyses of relatively infrequent situations -- say something restricted to less than 10% of the crashes, or fewer than 100 cases in the LTCCS database -- can only distinguish large differences, on the order of 30% or larger. For example, doubles are involved in about 4 % of truck crashes and triples in fewer than 1% (FMCSA, 2000a). The LTCCS file may thus have about 40 doubles in crashes -- only enough for the most crude statistical analyses -- and fewer than 10 triples -- statistical analyses won't be able to say anything about triples.

CRITICAL ISSUES IN LARGE TRUCK SAFETY

Crash causation topic outline. The paper's first two tasks are to list critical large truck safety issues and policy questions, group them into categories, and assess the relative priorities of each. I approached these tasks by starting with a comprehensive list of large truck crash causation topics, grouping these into priority categories, and finally developing specific questions.

To produce the comprehensive list I reviewed the priority issues raised by the committee (Council, 2002), the current FMCSA and NHTSA regulatory agendas (FMCSA, 2002b and NHTSA, 2002a), the subjects addressed by current FMCSA research as presented in the January 2003 FMCSA Research and Technology Forum (FMCSA, 2003), and the issues in the Large Truck and Bus Safety Symposia of 1997, 1999, and 2002 (Jones and Donahue, 1997 and 1999; Zacharia, 2002). From these and my own general experience I produced a first draft of a comprehensive outline of potential large truck crash causation topics. My goal was to begin with an outline of all potential areas that may contribute to crash causation or provide opportunities for interventions, without regard to relative priorities. I shared the outline with Ralph Craft and Terry Shelton of FMCSA; Forrest Council and Anne McCartt of the Committee; Joe Morris of TRB; and Elisa Braver of IIHS. After receiving their comments I revised the outline. The final outline follows.

Table 1. Large truck crash causation topics

I. Driver topics

IA. Long-term driver conditions -- before the crash day

physical conditions

age

medical conditions (including sleep apnea)

general health

technical qualifications

training and skills

experience

licensing and crash history

high-risk drivers, driver assessment

working environment and employment structure

scheduling (route structure, work and rest schedule, inc. hours of service)

employment and wage structure (employee or independent; wage basis and

amount)

specific driving environment (truck and cargo type, sleeper berth, team driving)

IB. Short-term driver conditions -- before the crash sequence

physical conditions

alcohol

drugs

health, medications

fatigue (including recent sleep-work history)

vision or hearing problems (e.g. night vision)

mental conditions

emotional state

alertness

environmental conditions

familiarity with road, vehicle

internal distractions (radio, phone, computer, rider, etc.)

IC. Driver actions -- immediately before and within the crash sequence

driver interaction with vehicle and environment before crash sequence

driver attention demands

ITS

dynamic warning systems

driving behavior leading into crash sequence

speed

- traffic rules -- traffic controls, following distance, signaling, etc.
- other potentially unsafe driving actions
- driver performance within crash sequence
- recognition (inattention, evaluation)
- decision

- performance (handling, braking)

II. Vehicular topics

- size, weight, truck type
- stability, load shifting

- handling

- defects, other specific component issues
- brakes (ABS, slack adjusters)

- tires

- role of inspections

- interaction with light vehicles
- underride

- forgiving (non-aggressive)

- visibility (blind spots)
- conspicuity (retroreflectivity, lighting)
- specific vehicular behaviors
 - rollover (speed, stability, handling, road design, driver alertness)
 - jackknife

III. Environmental topics

- features that may affect trucks differentially
- freeway exit ramps (see rollover)
- other road geometry and design
- construction zones

- road surface
- features applying specifically to trucks
- designated truck lanes

- truck exclusions from specific roads or lanes
- differential speed limits
- transitory features

weather

congestion

roadside features

truck stops and rest areas

IV. Other topics

role of light vehicles in car-truck crashes

company performance record

The outline follows the familiar Haddon matrix organization of driver, vehicular, and environmental topics, with a final section for two crosscutting topics. The driver section is further divided into long-term topics that apply before the crash day, short-term topics that affect the driver on the crash day, and driver actions immediately before and during the crash sequence.

The outline is quite comprehensive at the first two levels, almost by definition. At the third level it includes only those topics mentioned in the source documents or that I believed important. For example, the specific environmental transitory features included are weather and congestion, not light conditions or road surface condition.

The outline has some inevitable overlap between categories. For example, hours of service considerations are included under long-term driver working environment, short-term driver physical conditions, and perhaps even company performance record under other factors. Overall, though, I believe the outline provides a good basis from which to consider which crash causation issues are critical and what policy questions should be framed for the critical issues. Note finally that two topics under the driver interaction section of driver actions -- ITS and dynamic warning systems -- refer to technology that's not yet common in the vehicle fleet. LTCCS crash investigations will not be able to shed any light on them, so they will not be considered further.

Critical large truck crash causation policy areas. Next I winnowed this list down to what I believe to be the most critical and high-priority areas. To do this I used six criteria.

- relevance -- the topic must be involved in enough truck crashes to be worthy of attention;
- current interest and knowledge -- the topic is actively being investigated, and additional information is needed;
- opportunity for intervention -- the possibility of doing something useful to affect the topic;
- feasibility -- the relative ease of potential interventions, including costs, time frame, and implementation requirements;
- jurisdiction -- FMCSA has an opportunity to affect the topic; and
- political priority -- topics where FMCSA cannot afford ignorance.

I also combined some topics that appeared to fit together naturally. Finally, I added the very broad question #0 on problem identification. The result is a list of nine priority areas in five

major categories (four categories if the first and last are combined into a general category). The following list gives the categories, the priority areas, a brief description of the area, and some specific issues that fall under each area. The areas are listed in the same order as the topic list of Table 1. The justification for each area is provided subsequently in the discussion of the specific questions

Table 2. Large truck crash causation priority areas and questions

0. Problem identification

0.1 What factors cause or contribute to heavy truck crashes.

Specific issues: everything--driver, vehicle, environment, other road users, trucking industry.

1. Driver issues

1.1 Driver qualification, training, licensing, assessment

Specific issues: minimum and maximum age, health requirements (vision, physical condition), training and experience effects, licensing, relicensing, monitoring and assessment.

1.2. Driver employment structure and working environment

Specific issues: cargo and truck type, routes (geographic scope, schedule, regular or irregular), employment status (employee, independent), driver wage basis and amount, solo or team operations, company performance record.

1.3 Driver alertness and fatigue

Specific issues: scheduling, sleep and work cycle, sleep apnea, hours of service regulations.

1.4 Driver actions and performance in crash situations

Specific issues: pre-crash actions -- speed, handling, obeying traffic laws; crash event actions -- recognition, decision, performance.

2 Vehicular issues

2.1 Vehicle maintenance, defects, and inspections

Specific issues: brakes, tires, steering; role and effectiveness of inspections.

2.2. Vehicle design and load characteristics

Specific issues: size and weight (handling, interaction with road design, jackknife), load characteristics (load shifts, liquid cargo, exit ramps), conspicuity.

3. Environmental issues

3.1 Roadway design or operational modifications to accommodate large trucks

Specific issues: exit ramps, construction zones; designated truck lanes, differential speed limits.

4. Role of light vehicles in car-truck crashes

4.1 How many truck crashes, and what types of crashes, are caused by light vehicles
What are potential strategies to reduce these crashes?

Specific issues: proportion of crashes of different types.

It remains only to define specific questions for each of these nine areas and to set and justify my priorities. The following section does this. The questions are listed in my priority order. I divided area 1.1 into two parts, thus producing a final list of ten critical policy questions.

Critical large truck crash causation policy questions, in priority order.

1) Problem identification -- identify factors involved in a substantial number of crashes, or that increase crash risk substantially.

This question is fundamental. How often does a factor appear in crashes, and how does it affect crash risk; which factors appear often enough, or increase crash risk enough, that it's worth spending time and money to address them? FMCSA will use the results to determine how to direct and allocate FMCSA attention, funds, research, enforcement, and policy. It's a more general question than the rest on this list, so may not have been considered by some on the Committee. But FMCSA understands that it's the absolutely critical top priority for good management.

2) Fatigue and hours of service -- determine effective regulatory methods to reduce driver fatigue and increase alertness; include evaluation of the effectiveness of Hours of Service (HOS) regulations.

Driver fatigue, sometimes combined with driver inattention, was included by 8 of the 11 Committee members on their list of "top five" issues, nearly twice as many as the next highest issue. There's substantial research on driver fatigue, but many questions remain unanswered. The research does show that many drivers drive while fatigued. FMCSA has an extensive driver fatigue research program. FMCSA attempts to reduce fatigue through HOS regulations, driver logs, and inspections, but it's common knowledge that the regulations are widely ignored and driver logs are fabricated (Di Salvatore, 1988). Driver fatigue and HOS considerations constantly raise difficult policy and political issues for FMCSA.

3) Vehicle maintenance and inspections -- evaluate the role of vehicle maintenance and defects in crash causation; include evaluation of the effectiveness of FMCSA's inspection program in reducing defects and crashes.

Poorly maintained or defective vehicles are frequently cited as causes or contributing factors to crashes, but there also are many poorly maintained trucks on the road. For example, Jones and Stein (1989) found that 77% of combination trucks in crashes and 66% on the road had some defective equipment warranting a citation, while 41% in crashes and 31% on the road had a

serious enough defect to warrant being taken out of service. Brakes and steering defects were most common. FMCSA's MCSAP inspection program, designed to attempt to reduce these vehicle defects, costs over \$100 million annually. Five committee members included these issues on their priority lists. Again, the issue of vehicle maintenance is politically important and a crucial part of FMCSA's role. It's ranked below fatigue because more is known about vehicle maintenance than fatigue (largely since it's easier to acquire crash data on vehicle maintenance than on driver fatigue) and because there is less current research interest in vehicle maintenance issues than in driver fatigue.

4) Relative roles of cars and large trucks -- how many large truck crashes, and what types of crashes, are caused by cars? How many, and what crash types, are unlikely to be addressed by measures directed at large trucks and their drivers?

This question is politically sensitive for FMCSA. There's a tendency for the public to blame the large truck for any crash involving a large truck, whether or not the truck was in fact at fault. Research on fatal car/truck crashes by Blower (1998) indicates the car driver to be at fault in approximately 70% of the cases. Current work by Council, et al. (2003) indicates that "fault" is more equally divided when one examines the full distribution of crashes.

The important point is that interventions affecting only trucks and their drivers can affect only some large truck crashes. Knowing how many will allow FMCSA to define its crash prevention goals realistically. Knowing what crashes cannot be addressed by actions affecting only the truck will help FMCSA, NHTSA, and FHWA explore other interventions. Just as the other general question, #1 on problem identification, it's critical for FMCSA management decisions on all crash prevention issues, but less important than it or the more explicit issues of driver fatigue and vehicle maintenance. Three Committee members listed this issue as a priority.

5) Driver working environment -- determine the influence of driver working conditions (wage basis and amount, schedule, company structure) on crashes; is there a safety justification to explore methods to improve some drivers' working environments?

A driver's working environment is shaped by his employment structure and culture: how he is paid (by the hour, the mile, the job), how much he is paid, how and by whom his schedule is set, who maintains his vehicle, and the like (see McPhee (2003), Ouelett (1994), and Di Salvatore (1988) for background). Research is beginning to show that these factors influence crash risk (Belzer, Rodriguez, and Sedo, 2002). FMCSA attempts to affect some parts of this working environment through regulations, such as HOS. This of course raises the usual cost-benefit considerations. Three Committee members included these issues in their priority lists. Aside from HOS, this is a relatively new area for FMCSA to address, but an area with potential safety benefits, and an area in which additional research is sorely needed. Any proposed interventions will be politically sensitive because they will affect the trucking industry directly.

6) Environmental issues -- are roadway design or operational changes needed to accommodate large trucks? Design changes might be considered at exit ramps or construction zones.

Operational changes could exclude trucks from specified lanes or roads or could establish differential speed limits for large trucks.

Environmental issues enter the list as the sixth priority. I grouped them together because I believe that environmental issues are important but no individual question is high enough priority to crack the top 10 list. Four Committee members raised different environmental issues as priorities. Environmental issues are FHWA's jurisdiction, not FMCSA's. Environmental issues that require construction changes (freeway exit ramps; grade, curvature, or lane width specifications) will take decades to put into place except, perhaps, to address a specific dangerous feature in a specific location. Operational changes can be introduced short-term if conditions are appropriate (lane restrictions on multi-lane roads). Environmental issues also interact with and may be addressed by other issues on this list: rollover at exit ramps relates to speed (see #7), driver alertness (#2), and truck load shifts (#8). Overall, though, I rank environmental issues lower priority than the preceding driver, vehicle, and overall management issues.

7) Truck driver performance -- determine the role of driver performance (speed, other behavior, danger recognition, decision, actions) on crashes; identify any areas where reasonable improvements could reduce crashes.

Driver actions cause or contribute to the vast majority of crashes. Truck drivers are professionals; they are expected to be skilled and well-trained in the same way as commercial aircraft pilots or railroad engineers. Additionally, as professionals they are subject to control and regulation both from their employers and from government agencies. But they must operate in an environment dominated by poorly-trained and careless "4-wheel" drivers. While improving 4-wheel driver performance is unlikely, training and technology perhaps can improve truck driver performance with oversight from employers and government agencies. But we need to know what driver performance features contribute to crashes and what improvements might be useful. Five Committee members raised various driver performance issues, with travel speed the most frequent. Attempting to improve driver performance might involve driver training (see issue #10), licensing and monitoring (#9), or driver working environment (#5).

8) Vehicle design and load -- determine the number and types of crashes in which truck design or load contribute (conspicuity, no-zone visibility, load shifts); explore possible interventions.

Five Committee members raised different vehicle design and load issues -- load shifts, handling characteristics, ABS brakes, slack adjusters, conspicuity -- but no single issue stands out. This question holds a place on the list for these and other vehicle design and load issues. Problems or interventions involving vehicle design and load issues can be addressed by structural changes to the vehicles or by regulation. FMCSA has conducted an extensive public information campaign to inform light vehicle drivers about truck driver visibility issues in the "No Zone." There appears to be no specific issue that's critical at this time, but LTCCS should be able to address these and similar vehicle design and operation issues.

9) Truck driver licensing and monitoring -- determine the contribution of improperly licensed or problem drivers in crash causation; explore voluntary or regulatory measures to improve driver control.

Research shows that relatively few truck drivers -- the “problem drivers” -- are involved in more than their proportionate share of crashes. Who are these drivers? How can they be identified, both to potential employers and licensing agencies? Can closer monitoring, better training or more experience (see #10), or changes in the working environment (#5) affect their performance? If so, there’s a potential to reduce crashes substantially. Licensing and monitoring issues are always politically sensitive. Two Committee members raised this issue.

10) Truck driver training and experience -- evaluate the effect of driver training and experience in reducing crashes; should stiffer standards be considered?

This issue is closely related to #9, licensing and monitoring, but is listed separately because of differences in jurisdiction. Employers are responsible for setting standards for their drivers and providing training, while government is responsible for licensing and monitoring. The issue also is related to driver performance (#5).

The full list of 10 contains five driver issues (#2, 5, 7, 9, and 10), two vehicle issues (#3 and 8), one environmental issue (#6), and two general issues (#1 and 4). Driver issues dominate for several reasons. Data to address most driver questions (fatigue, working environment, performance during the crash, training and experience) are not captured on existing data sets, while some vehicle data and considerable environmental data are available. As a result, some driver issues have not been studied as extensively as vehicle or environmental issues. Drivers have the opportunity to intervene and prevent many crashes -- the usual observation that the majority of crashes involve driver error or could have been prevented by some driver actions holds for large truck crashes. Finally, FMCSA has the ability to address driver issues. Unlike car drivers, whose training is minimal and whose behavior is extremely difficult to control, commercial drivers can be trained and monitored.

ASSESSMENT OF EACH PRIORITY QUESTION

The remainder of this paper analyzes each of these ten questions in turn. For each, I discuss the information that ideally would be available to address it, examine the extent to which the LTCCS database will provide this information, discuss whether the relative risk methodology or other analyses methods are useful, and, if appropriate, discuss other data that might be needed to fill gaps. I don’t attempt to give a full study design; rather, I try to identify the key information needed. I’ve also taken a pragmatic approach in defining the “information that ideally would be available.” For example, while ideal information to address driver fatigue issues might include 24-hour real-time activity monitors for every truck driver, I don’t think this would be a realistic proposal.

Question #1: Problem identification. Identify factors involved in a substantial number of crashes, or that increase crash risk substantially.

1) Specific critical information needed to address the question. Problem identification requires estimating the size and the relative risk of a factor. For size, we need national estimates of the number and proportion of large truck crashes involving XXX, where XXX is a factor that may have contributed to a crash. Comprehensive problem identification requires data on “all” reasonable factors relating to the driver, the vehicles, and the environment, especially those factors that play a role in the other nine priority questions. For example, driver factors should include data on fatigue (hours driving before the crash, last sleep period time and length, an assessment of a causal link between driver fatigue and the crash); 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, company safety record. Vehicle factors should include maintenance status, including any defects in brakes, tires, steering, or other critical vehicle components; vehicle size, weight, load, design, and any causal links between these features and the crash. Environmental factors should include roadway geometry, surface conditions, lighting, and traffic controls.

As discussed previously, relative risk requires national estimates of the presence of XXX in crashes where XXX might be a contributing factor compared to the presence of XXX in crashes where it should not be a contributing factor.

2) LTCSS role in providing specific critical information. LTCSS is well-designed to provide both size and relative risk data. LTCSS is nationally representative. Its 1,000 data elements address most key factors at the level needed for initial problem identification. The relative importance of potential causal or contributing factors can be compared. The LTCSS data will allow useful breakouts of these issues: for example, faulty brakes in crashes on wet or icy roads, or in crashes with inexperienced drivers. The limitations will be data completeness, data accuracy, and sample size. Data completeness and accuracy issues are discussed subsequently for different driver, vehicle, and environmental factors. As noted previously, with 1,000 total crashes, few three-way comparisons are likely to yield anything useful (faulty brakes on wet or icy roads with inexperienced drivers). This is not a major 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 so almost by definition cannot be a major truck crash causation issue from an absolute point of view. (It could be a major issue from a political, regulatory, or relative risk point of view, though.)

3) Relative risk methodology. The relative risk methodology works well for problem identification, again limited only by data accuracy, data completeness, and sample size.

4) Alternative data. No alternative data are needed to estimate size. Exposure data -- miles of truck travel disaggregated by the presence or absence of the factor XXX -- would be needed to estimate absolute (as opposed to relative) risk, but relative risk and size suffice for basic problem identification. When intervention exploration begins, additional data likely will be needed, but those will be specific to the problem area and the interventions considered.

5) Summary. The LTCCS is well suited to problem identification across a wide range of potential causal or contributing factors. The LTCCS data elements appear to have no major gaps. The limitations are data completeness, data accuracy, and sample size. By the very nature of this question, data needed for the other elements of a question -- to understand the phenomena involved, to design interventions, and to evaluate effectiveness -- are not relevant to problem identification.

Question #2: Fatigue and hours of service. Determine effective regulatory methods to reduce driver fatigue and increase alertness; include evaluation of the effectiveness of Hours of Service (HOS) regulations.

1) Specific critical information needed to address the question. To understand the role of fatigue and alertness in crashes we first need objective measures of the driver's hours of driving prior to the crash, his immediately previous hours of rest and sleep, and his longer-term sleep and driving schedule. Ideally we would have a measure of the driver's fatigue and alertness prior to the crash. This would require in-vehicle real-time monitoring of eye movements, brain function, or the like, but this is impossible without instrumenting all trucks. Next, we need his HOS compliance, both reported and actual. These data will determine problem size. To determine risk we need either similar data for truck drivers not involved in crashes or, using relative risk, for drivers in crashes not involving fatigue or alertness. Then, we need an assessment of 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 were more alert? Exploring interventions can lead almost anywhere: for example, if we have data on the driver's scheduling, working conditions, and the like, we can investigate whether certain pay structures, wage levels, and management situations are associated with fewer crashes involving fatigue and alertness.

2) LTCSS role in providing specific critical information. The driver interview variables #49-65 give the driver's own account of the basic driver information on fatigue, sleep patterns, and the like, including the driver's self-report of his HOS compliance. Variables #69-76 do the same for information relating to distraction. Motor carrier form variables #30-32 and #38-40 give scheduling information for this trip and #41 gives the driver's hours on duty for the previous 7 days. Crash event variables #22-27 give the investigator's conclusions regarding fatigue information using data from all sources. Information recorded includes last sleep (start, end, length), last sleep greater than 4 hours (start, end, length), hours since last sleep, hours driving and hours on duty since last 8-hour break, factors influencing hours of sleep, previous 7-day sleep pattern, factors influencing previous 7-day sleep pattern, and previous 7-day work schedule. Critical event #37 gives the overall assessment of fatigue as a contributing factor (i.e., presence at the time of the crash). Crash event variables #41-48 measure factors that may relate to fatigue and alertness: #41 inattention, #42-44 distraction, and #45 inadequate surveillance. The exterior truck form records HOS log information (no log, log not current, false log, 10 hour rule, etc.) LTCCS does not record information from the driver's prior HOS records.

If these data are complete and accurate, they will provide exactly what's needed for problem identification and exploration of interventions -- national incidence estimates and second-level

analyses, up to the limits of sample size. They also will show the driver's actual HOS compliance, though they won't provide much data for comparing his actual and reported HOS compliance.

The issue will be data accuracy. The Committee's July 2002 Task Force review of selected LTCCS cases suggests that the data may not be accurate: "drivers report 8, 10, or 12 hours sleep every night; these are red flags for lies; investigators do not seem to be using [other] sources [such as MCSAP records, interviews or records from carriers, shippers, and receivers] to verify/determine data" (LTCCS, 2002a). If this is true for a reasonable portion of the cases, especially if the cases with accurate data cannot be distinguished from cases with inaccurate data, then the file will produce little useful information.

3) Relative risk methodology. The relative risk methodology again works well, up to sample size. Crashes in which the truck was not moving (stopped at a traffic control device), or more generally crashes in which truck braking and handling and driver alertness are not relevant, can serve as a control to investigate the relative risk of driver fatigue or inattention. If there are few of these crashes in the LTCCS database, then the relative risk methodology won't yield much useful information.

4) Alternative data. If the data collected are accurate and complete, no alternative data are needed at this level. Exploring interventions may require quite detailed data from small experimental fleets -- for example, instrumentation on trucks and/or drivers to record driver activity and alertness as in Hanowski et al (2003).

5) Summary. LTCCS collects the right data, as long as they are accurate and complete. Self-reported data on a driver's fatigue, alertness, sleep patterns, HOS compliance, and the like will be suspect unless supported by other evidence. Sample size may limit relative risk conclusions.

Question #3: Vehicle maintenance and inspections. Evaluate the role of vehicle maintenance and defects in crash causation; include evaluation of the MCSAP inspection program in reducing defects and crashes.

1) Specific critical information needed to address the question. First, we need data 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 risk we need either similar data for trucks on the road or, using relative risk, for trucks in crashes that do not involve these components. Next, we need an assessment of the role that these components played in causing or contributing to the crash. The effectiveness of the MCSAP inspection program can be approached in several ways, such as:

- 1) Compare maintenance issues or defects shown to be causes or contributing factors with MCSAP inspection procedures -- are inspections looking at the right things?
- 2) Examine MCSAP inspection records -- how frequently are the maintenance defects that cause or contribute to crashes observed in inspections? Compare the defect's rate in inspections and in crashes. If the defect rate is high in inspections and higher still in crashes, then the inspections aren't serving their purpose.

- 3) Examine the inspection records of defective trucks in crashes. When was the truck last inspected? Did it comply? How quickly do compliant trucks become defective?
- 4) Examine the relation between maintenance defects and company type.

2) LTCCS role in providing specific critical information. **The exterior truck form Level 1 inspection (p. 10) gives both violation and out-of-service status for all reasonable vehicle systems and individual components that might be considered contributing factors, including a complete brake inspection. (p. 12). Vehicle form #17 records violations charged as a result of this crash for lights, brakes, and general equipment violations. Crash event #66 gives vehicle related malfunctions of tires, brakes, transmission, engine, and other components as related factors. There is no record of prior MCSAP inspection results. In addition, crash event #5 records loss of control due to tire failure and #6 gives failure of tires, brakes, steering, suspension, lights, and other as the critical reason for the crash. These can provide evidence on the frequency of major component failures.**

These data should serve quite well to estimate the presence, relative risk (see below), and specific crash role of the major vehicle components. Since LTCCS investigators will record objective data from their own inspections of the vehicles, the data should be both complete and accurate.

3) Relative risk methodology. The standard relative risk methodology applies well. Note that Blower (2001) uses brake violations as his example of how to apply relative risk methods. Crashes in which the truck was not moving (stopped at a traffic control device), or more generally crashes in which truck component maintenance is not relevant, can serve as a control to investigate the relative risk of component maintenance issues. As the questions become more specific -- for example, evaluating the role of brake violations for combination trucks -- sample sizes shrink and the ability to detect differences diminishes.

4) Alternative data. Data from MCSAP inspection records will be necessary to evaluate the effectiveness of these inspections, as discussed previously. Note that inspection records may give some useful information on the presence of maintenance defects in trucks on the road -- true exposure data that can be used for absolute risk estimates, which in turn can be compared with relative risk estimates.

5) Summary. The LTCCS database should serve well to investigate the role of vehicle maintenance issues in crashes. By itself, the LTCCS database can give some information on MCSAP inspection effectiveness. For example, is MCSAP inspecting the most important vehicle components? Do these components contribute to a substantial proportion of crashes despite MCSAP inspections? Serious study of MCSAP effectiveness will, of course, require data from MCSAP.

Question #4: Relative roles of cars and large trucks. How many large truck crashes, and what types of crashes, are caused by cars? How many, and what crash types, are unlikely to be addressed by measures directed at large trucks and their drivers?

1) Specific critical information needed to address the question. The first part of this question asks for “the cause,” or the fault, for each crash involving a light vehicle and a large truck to be assigned to one or the other. As discussed earlier, statistical analyses of LTCCS data can’t do this. But the second part is the important one. It asks for a full understanding of the factors that contributed to the crash, or that might have prevented the crash, so it requires data at several levels. Some crashes, including many single-vehicle crashes such as rollovers on a freeway ramp approached at a high speed, can be attributed easily to the truck alone. But even some single-vehicle crashes may involve other vehicles, for example if a truck loses control and leaves the roadway after braking suddenly to avoid striking a car that’s cut into the truck’s lane. Most crashes will require detailed information on potential interventions affecting the truck and its driver that could have prevented, reduced the likelihood, or reduced the severity of the crash. As an example, consider Pilot Study Case #2001-002-001, described in detail in the Interim Report (NHTSA, 2002b). A car stopped at a stop sign and then entered the intersection without noticing a straight truck approaching on the intersecting uncontrolled roadway. The truck braked and steered to the left but the car failed to brake, so the truck struck the car. The crash clearly was “caused” by the car because the truck had the right-of-way and the car failed to observe the truck. But was the truck’s speed too fast for conditions -- would a lower speed have allowed the truck to brake to a stop before crashing? Did the truck driver observe the car as it began to move toward the intersection? Were the truck’s brakes functioning properly? In short, this question requires data to identify and analyze the full range of crash causes and contributing factors.

2) LTCSS role in providing specific critical information. The first part of the question probably can’t be answered in anything other than a legal sense: what are the proportions and types of crashes where law enforcement found the truck, the car, or both to be at fault. It’s not a good answer, but it’s easily available from vehicle form #17. More detailed answers require either using information from the contentious crash event #5, the critical precrash event, or information from inferences made in investigative analyses.

The second part of the question can be viewed in at least two ways. The complicated view asks whether the truck could have avoided or prevented this crash and similar crashes. This leads to investigative analysis of the crash. Statistical analyses of the entire LTCCS database may help put the investigative analysis results into a national context by estimating the frequency of similar crash circumstances. The simple view is that the question is really one of problem identification and relative risk, perhaps defined more tightly than the general problem identification and relative risk question #1. For example, the truck may have been able to avoid the crash of the example case discussed above if it had been traveling more slowly. If so, this is just an instance of truck speed being a cause or contributing factor to crashes overall. More precise analyses may not be necessary, though it may be useful to exclude single-vehicle crashes to see if the influence of truck speed changes. In this simple view, the LTCCS database plays the same role that it does for question #1 -- if the data are complete and accurate, they will provide what’s needed.

3) Relative risk methodology. The relative risk methodology isn’t relevant to the first part of this question, as the question doesn’t involve crash risk. For the second part, the relative risk methodology applies just as it did in question #1.

4) Alternative data. Other data aren't necessary.

5) Summary. Statistical analyses can't answer the question of "who caused the crash?" Detailed investigation of interventions will involve either basic problem identification (question #1) or investigative analyses.

Question #5: Driver working environment. Determine the influence of driver working conditions (wages, pay base, schedule, company structure) on crashes; is there a safety justification for exploring methods to improve some drivers' working environments?

1) Specific critical information needed to address the question. 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 discussed in question #2. The goal is to compare crash rates across these variables: crash rates as a function of wage level, for example, controlling for other relevant variables. Crash rates require a denominator: crashes per hour, or per mile.

2) LTCCS role in providing specific critical information. Driver interview variable #38 records the pay method for this trip and #39 records special payments. #40 records whether the driver works a second job. #51 and 52 record driver views on over-scheduling. #105-107 record specific scheduling for this trip. Critical event variables #62-64 give the investigator's assessment of whether the driver was pressured or required to accept unscheduled loads, operate while fatigued, fill in for other drivers, etc. Motor carrier form #16 gives driver pay method in general and #33 gives the pay method for this trip. #30-32 and #38-40 give scheduling information for this trip and #41 gives the driver's hours on duty for the previous 7 days. #13-14 record who owns and maintains the power unit and #12 records the company's safety rating. Fatigue variables are discussed under question #2. LTCCS does not collect data on the driver's actual wages, either for this trip or longer-term.

Aside from actual wage data, the variables provide what's needed for crash rate numerators, under the usual assumption that the data are reasonably accurate and complete. As with the data for fatigue (question #2) and the other driver questions, these data depend on interviews and records. They are less objective and more difficult to acquire accurately and completely than data from observations of the crash vehicles or scene.

Lacking exposure data for a denominator, we must use relative risk methods. Suppose we wish to compare drivers paid by the mile to those paid by the hour (driver variable #38). Crashes in which the truck was stopped, or more generally crashes where the truck driver had no causal or contributory role, can serve as the control, as a relative measure of exposure. Calculate the ratio

crashes with critical event due to truck or driver / crashes where the truck was stopped

for drivers paid by the mile; compare it to the same ratio for drivers paid by the hour, and we have a measure of relative involvement rates. It may be necessary to refine this. Drivers paid by the mile and paid by the hour may drive trucks of different types, under different conditions. We

could, for example, restrict all the data to combination trucks to begin to account for these differences. Similar relative risk analyses can be applied to other working environment variables.

The inferences and conclusions from these relative risk analyses likely will be relatively crude. If there are few crashes in the control group (where the truck driver had no contributory role), then the analyses can detect only large differences, and controlling for other relevant variables, such as truck type, may be virtually impossible.

3) Relative risk methodology. See the previous discussion.

4) Alternative data. Detailed investigations of driver working environment effects require actual wage data as well as more details on long-term working conditions. It also would be very useful to have mileage and time data. This suggests a study at the motor carrier level, to follow drivers employed by different motor carriers under different pay structures, wage levels, scheduling and driving practices, and the like. See Belzer et al (2002) for examples.

5) Summary. If the LTCCS data are reasonably accurate and complete, they may give fairly crude relative risk estimates comparing different working environment variables such as pay structure, scheduling practices, and the like. They do not contain actual wage data. More detailed analyses will require other data sources, probably at the motor carrier level.

Question #6: Environmental issues. Are environmental design or operational changes needed to accommodate large trucks (specify designs at exit ramps or construction zones; exclude trucks from specified lanes or roadways; establish differential speed limits for trucks)?

1) Specific critical information needed to address the question. Consider three types of environmental and operational issues.

- a) Certain roadway features are inherently more hazardous for large trucks. Two good examples are exit ramps, where designs suitable for light vehicles may cause trucks traveling at the same speed to roll over, and construction zones, where width and speed requirements may differ.
- b) Some jurisdictions exclude trucks from specified roads or lanes in an attempt to reduce car-truck conflicts. Many multi-lane roads prohibit large trucks from the fastest lane and some roads prohibit trucks over a certain size or weight for safety reasons.
- c) Some jurisdictions establish lower speed limits for trucks, either throughout a roadway, on steep downgrades, at night, or in other circumstances.

For each of these, problem identification requires estimates of the number of truck crashes in these circumstances and some measure of risk, absolute or relative. Intervention investigations require considerably more detailed data.

- a) Consider exit ramps as a roadway feature example. We first need the number of crashes at exit ramps and the number in which the truck played some causal or contributory role. Risk is more difficult to define and evaluate. One measure is to classify exit ramps in

some way -- say by grade, radius of curvature, and speed limit -- and then compare truck crashes per truck trip through the exit ramp across the different ramp classes. This will show the relative risk of the different ramp classes for trucks. It requires truck trip counts at ramps. Similar data for light vehicles will show the relative risk of the ramp classes for trucks and light vehicles. To begin to investigate interventions we need detail on crash mechanisms -- the physics of truck size, speed, load, and ramp geometry, to consider how changes in each could affect truck stability -- and on truck driver behavior -- awareness of the ramp, signage, speed and other maneuvers.

- b) Consider truck lane restrictions. The basic problem identification issue can be phrased as an evaluation, either before-after or comparison: how does crash risk change after a truck lane restriction is introduced, all other things being equal; equivalently, compare crash risk between otherwise similar roads with and without truck lane restrictions. Since a lane restriction may affect traffic flow, we'd also wish to compare traffic flows as well as crash risk. The information needed includes traffic volumes for both trucks and light vehicles in the lane restriction and unrestricted roads. Ideally we'd have data by lane, to see whether trucks in fact obey the lane restrictions. More detailed study requires substantial engineering data, such as lane widths and analyses of how truck and light vehicle traffic enters and exits the roadway.
- c) Differential speed limits require information similar to that needed for lane restrictions. Investigating truck speed restrictions during nighttime hours, for example, requires crash rates for trucks and light vehicles during daytime and nighttime hours on similar roads with and without nighttime truck speed restrictions. Beyond this, we'd need information on actual travel speeds during daylight and nighttime hours, for trucks and cars (does the nighttime restriction in fact reduce truck speeds).

2) LTCCS role in providing specific critical information. The LTCCS can identify crashes occurring in some of these environmental circumstances. Crash event #6 identifies ramp curvature as a critical reason; #67 identifies ramp speed; #65 records construction zones. Lane restrictions and differential speed limits appear not to be coded, though they should be recorded on the crash diagram. These data will serve to provide basic estimates of problem size: how many truck crashes occur at exit ramps, or construction zones? But without appropriate exposure data they will not give crash rates. The LTCCS database can help explore potential interventions for some issues: is truck speed a contributing factor in exit ramp or construction zone crashes?

The LTCCS database should be quite useful for investigative analyses of some environmental issues. Detailed study of individual cases should show how truck geometry, speed, load characteristics, ramp design, ramp signage and speed limit, and the like all contributed to an exit ramp rollover.

3) Relative risk methodology. Relative risk estimates are not applicable to these and most other environmental issues. The reason is that to analyze environmental issues we must compare different roadways to each other; to analyze driver or vehicle issues we compare drivers and trucks. Relative risk analyses for driver or truck issues compare crashes with and without the feature of interest (faulty brakes, in the Blower (2001) example) in situations where the feature may have an effect (the experimental setting -- where truck braking may be critical) to situations

where it cannot (truck braking is irrelevant). We can make the same calculations for environmental issues, but we won't learn very much.

As an example, consider nighttime speed limits for trucks. The speed limit has an effect only at night, so nighttime and daytime crashes are situations where the feature may and cannot have an effect. Here's a hypothetical table, using the same layout as the introductory discussion of sample size effects.

<i>Night speed limit</i>	nighttime crashes	daytime crashes	total
yes	150	420	570
no	150	280	430
total	300	700	1,000

On nighttime speed limit roads, 26% of truck crashes occurred at night, while on other roads, 35% occurred at night. Does this mean that nighttime speed limits are effective? Perhaps -- but we don't know anything about traffic volumes. It may be that the nighttime speed limit roads have less nighttime truck traffic because they are inherently more dangerous at night (which is the reason why the nighttime speed limits were adopted). Or some nighttime traffic may have shifted to other roads after the nighttime speed limit was introduced, in order to travel faster. Without some travel data we do not know.

Relative risk analyses for many environmental issues are similarly limited. Consider exit ramps. The basic relative risk question is whether exit ramps, or ramps with specific design features, are more risky for trucks than for cars. This requires crash data for light vehicles as well as trucks, which LTCCS does not collect. One possible method would be to compare the proportion of truck crashes at exit ramps from the LTCCS database with the proportion of light vehicle crashes at exit ramps from NASS. This would yield relative risks, but again the absence of exposure data would limit the conclusions. If trucks have a greater proportion of their travel on limited access highways than cars, then they also should have a greater proportion of crashes at exit ramps. We could restrict the analysis to crashes on limited access highways, but the sample sizes, at least for trucks, likely will be very small.

4) Alternative data. See the previous discussion. Many if not most environmental issues are best analyzed from a road section point of view rather than a truck-driver point of view. Travel volumes are necessary.

5) Summary. The LTCCS database is less useful for environmental than for driver or vehicle issues. The LTCCS database will produce overall frequencies -- crashes at exit ramps, for example -- and individual LTCCS cases can be used for investigative analyses to investigate contributing factors and potential interventions. But risk estimates will be limited.

Question #7: Truck driver performance. Determine the role of driver performance (speed, other behavior, danger recognition, decision, actions) on crashes; identify any areas where reasonable improvements could reduce crashes.

1) Specific critical information needed to address the question. This question asks for information on the role of truck driver performance in general, and on specific performance issues of recognition, decision, and action, as contributing factors to crashes. Some data, such as travel speed and vehicle maneuvers, are fairly objective. Other data, such as the driver's recognition of a potentially dangerous situation and his decisions regarding the situation, are more subjective.

2) LTCSS role in providing specific critical information. From the driver's point of view, driver interview variables #73-104 record information on his attention, vision, judgments, and actions during the crash sequence. Variables #41-46 of the crash event form provide the investigator's judgment of recognition factors and #47-54 do the same for decisions and actions combined. Other variables may help substantiate these judgments: for example, certain crash types are consistent with the performance error of traveling too fast for conditions.

Simple tabulations of these variables will show the proportion of crashes in which the truck driver's recognition, decision, or performance errors may have played a role and will divide these errors into about 15 specific and 3 general types. This identifies a baseline proportion of crashes that might be reduced or eliminated by improved truck driver performance and suggests what general performance features are most important to improve.

The deeper question is to examine if improved truck driver performance might prevent some crashes in which the critical event was not due to truck driver error. Crash event variables #41-54 may yield some useful information. For example, how frequently is inadequate surveillance, crash event #45, coded for these crashes? If frequently enough, then investigative analyses may suggest whether improved surveillance might have prevented some of these crashes.

Note that exposure data are not needed at this level of analysis but might be when the focus moves to examining interventions. If traveling too fast for conditions (crash event #47) is noted in 20% of all crashes, we don't need exposure data to conclude that slower truck speeds may prevent a substantial number of crashes, but we do need exposure data when we begin considering methods to induce truck drivers to slow down. If 40% of truck drivers are traveling too fast for conditions, then excessive speed isn't a risk factor and simple exhortations or laws probably won't have much effect in reducing truck speeds.

3) Relative risk methodology. Relative risk methods probably can't be applied to driver performance factors. For example, consider inadequate surveillance, crash even #45. We can in theory compare crashes where truck driver surveillance is relevant to those where it is not, and look at the ratio of crashes with and without inadequate surveillance for each. But an investigator is unlikely even to consider truck driver surveillance in a crash setting where surveillance is not relevant, say where the truck is stopped, so the comparison can't be made. Or consider traveling too fast for conditions. The control population would be crashes in which

truck speed is not relevant. This may include only crashes where the truck is stopped, for which traveling too fast for conditions clearly does not apply.

4) Alternative data. Alternative data will be needed to examine potential interventions. They likely will come from experimental settings. For example, the LTCCS database may suggest that inadequate surveillance is an important contributing factor and may indicate situations where inadequate surveillance is especially relevant. Experiments with instrumented drivers then can provide detailed data on surveillance patterns. Other experiments can explore training methods and evaluate their effect.

Exposure data for driver performance issues are simply impossible to obtain. One can't even define a decent exposure measure for inadequate surveillance.

5) Summary. The LTCCS database can provide an initial estimate of the overall contribution of driver performance errors to crashes, can begin to distinguish the relative importance of different types of errors, and may suggest specific crash circumstances where different types of errors are particularly relevant. Other data sources will be necessary to investigate interventions.

Question #8: Vehicle design and load. Determine the number and types of crashes in which truck design or load contribute (conspicuity, no-zone visibility, load shifts); explore possible interventions.

1) Specific critical information needed to address the question. Load issues include the specific question of whether load shifts contributed to truck instability and more generally whether loading contributed to truck handling problems. The information needed is similarly specific: load characteristics, contribution of load to the crash. Design issues are less well defined. One category is to evaluate the effects of specific components or designs such as ABS or reflective tape, for which information is needed on the component's presence and, if appropriate, function. Another is to examine whether trucks of certain configurations or designs are over-involved in crashes of certain types that may be related to these designs. Are tankers more likely to roll over? Are triples more likely to jackknife than doubles? For these questions we must be able to distinguish the design feature of interest.

2) LTCSS role in providing specific critical information. The LTCCS exterior truck form describes the truck in great detail, including configuration, cargo type, weight, and percent of cargo capacity used for each unit. ABS presence and function is recorded at each axle. Reflective tape data are coded in #80-111: presence, pattern, color, and condition for the sides and rear of each unit. Truck mirror data presence, position, and relation of blind spots to the crash are found in #112-114. Cargo shift information is recorded in crash event #17-21. Jackknife presence and details are found in #12-16. All of these data are objective and can be observed at the crash site so should be collected quite completely and accurately.

These data should address many truck design and load questions quite well. Up to the usual limitation imposed by the sample size, they will estimate the number of crashes, truck types, and roadway locations with truck load shifts. They can evaluate the effects of ABS, reflective tape,

and other specific components using the relative risk methodology in the same way that the methodology is used to investigate brake inspection violations (see question #3). Similarly, relative risk applies to compare the relative risks of different truck designs or configurations in different crash types: for example, compare jackknife to non-jackknife crashes for doubles and triples, perhaps controlling for roadway type.

3) Relative risk methodology. The relative risk methodology applies here, up to the limits of sample size.

4) Alternative data. After an issue has been identified, investigative analyses of LTCCS cases can start the process of exploring interventions. Further investigations likely will require experimental studies.

5) Summary. The LTCCS database should serve quite well for basic problem identification on vehicle design and load issues.

Question #9: Truck driver licensing and monitoring. Determine the contribution of improperly licensed or problem drivers in crash causation; explore voluntary or regulatory measures to improve driver control.

1) Specific critical information needed to address the question. For licensing we wish to compare the crash rates of properly and improperly licensed drivers. So we need accurate data on the license status of drivers in crashes, together with appropriate exposure data. For problem drivers, we first must create a definition, say as drivers with some number of crashes or violations in the past three years. Then the issue becomes the same: compare their crash rate to other drivers. For this we need driver record data on prior crashes and violations. To begin to investigate interventions we should explore the types of crashes in which these drivers are involved and the driver performance factors that may have contributed to these crashes.

2) LTCCS role in providing specific critical information. The question requires data from official records on driver license status and driver history. Driver form #27-32 record CDL license class, endorsements, status, and compliance. #33-37 record both CDL and non-CDL crashes and violations over the past five years. These data come from interviews, police accident report, and DMV files.

The data, if accurate, will give the number and proportion of crashes involving improperly licensed drivers or drivers with recent crashes or violations. Accuracy will depend on whether LTCCS investigators check DMV records for all drivers or only gather information from the driver interview. The LTCCS database also should shed some light on whether improperly licensed or problem drivers tend to be involved in certain types of crashes, both absolutely and in comparison with other drivers.

3) Relative risk methodology. The relative risk methodology can be used to estimate the relative crash involvement of improperly licensed or problem drivers: compare the ratio of crashes in which the driver may have contributed to crashes in which the driver played no role

(for example, crashes where the truck was stopped) for properly and improperly licensed drivers, or for drivers with prior violations or crashes and drivers with no prior violations or crashes. To the extent that properly and improperly licensed drivers (or problem and non-problem drivers) have different driving patterns, the methodology breaks down unless these differences can be controlled. For example, it may be the case that long-haul truckers have more stable employment relations and are more likely to be properly licensed than short-haul drivers. If so, the relative risk analysis must be conducted separately for long-haul and short-haul crashes. This will shrink the sample size further and reduce the ability to distinguish differences.

4) Alternative data. For basic problem identification, alternative data are not required unless LTCCS fails to obtain accurate driver license status and driver history data. Data needs for exploring interventions will depend on the interventions under consideration. For example, if interventions through the driver's working environment are suggested, then the issues raised under question #5 are relevant.

5) Summary. If LTCCS data are accurate and complete, they can estimate the overall contribution of improperly licensed or problem drivers to crashes and may suggest specific crash circumstances where these drivers are especially overinvolved. Intervention exploration undoubtedly will require additional data sources.

Question #10: Truck driver training and experience. Evaluate the effect of driver training and experience in reducing crashes; should stiffer standards be considered?

1) Specific critical information needed to address the question. The question requires data on driver training and experience, with enough detail on training to classify the training in a meaningful way and to analyze how different training affects driver performance. As in question #9, exploring interventions will require information on crash types and driver contributing factors.

2) LTCSS role in providing specific critical information. Driver form #22 records the number of years driving a truck and #23 records the number of years driving this class of vehicle. Driver form #24 records the source of the driver's training, if any, and #25 records the time since the completion of training. The information comes largely from the driver interview, but there is no reason to suspect that it will be biased.

3) Relative risk methodology. Both experience and training data can be used in relative risk calculations as were the licensing data in question #9. Compare the ratio of crashes in which the driver may have contributed to crashes in which the driver played no role for drivers with different experience, or different training. It's highly likely that driving patterns differ by driving experience, so the analyses must be restricted to crashes where driving patterns are similar.

4) Alternative data. LTCCS data on training are quite crude. They do not show training length, curriculum, or content. Any serious study must have this information. Such studies could be done at the driver or training institution level. For example, study all drivers who receive their initial CDL in a given year. Compare the crash and violation records in the

subsequent year for drivers receiving different types of training, controlling for the type and amount of commercial driving they do.

5) Summary. At best, the LTCCS database may be able to compare relative risk among drivers at different experience levels or who received training from different sources. Similarly, the LTCCS database can investigate crash types and driver contributing factors across these driver types.

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 feature and the contribution of this feature to crash risk. Because it is nationally representative, it can estimate national frequencies. Because it collects over 1,000 data variables describing all aspects of a crash's drivers, vehicles, and environment, its estimates will be quite comprehensive.

LTCCS's ability to investigate crash risk is based on estimating relative risk using induced exposure techniques (Blower, 2001). In general these 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 where the feature being examined has no effect.

The main limitations to these statistical analyses of the LTCCS database likely will be data accuracy and completeness and overall sample size. Variables that investigators observe directly, such as environmental features or vehicle inspection data, likely will be quite accurate and complete. Variables that are more subjective -- that come from interviews or that involve secondary data sources, such as information on a driver's sleep patterns in prior days or his crash and violation record in prior years -- may well be less accurate and complete even if the investigators check all possible sources to confirm the interview reports. The 1,000-case sample size will limit the statistical conclusions. Analyses of relatively rare situations can only distinguish large differences.

While LTCCS is designed as a statistical data file, its individual case reports will be useful for investigative analyses.

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 understand the physical and behavioral phenomena involved in an issue to investigate, develop, and test interventions, but data from experimental settings almost certainly will be needed as well. If an intervention is in place, LTCCS's usefulness in evaluating its effectiveness will be similar to its usefulness in estimating the issue's significance.

RECOMMENDATIONS

In its last year of data collection, with sampling procedures established, LTCCS can't do anything to increase its sample size. But it may be able to improve the other two potential limitations noted above: data accuracy and completeness. The more accurate and complete the data, the more useful they will be for both statistical and investigative analyses. LTCCS should try to make its data as accurate and complete as possible. In particular, LTCCS should:

- corroborate interview and other subjective data;
- quality control all questionable data (“I always get eight hours of sleep”);
- perhaps record the investigator's confidence in the accuracy of subjective data.

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INVESTIGATIVE ANALYSIS OF LARGE TRUCK ACCIDENT CAUSATION

Background Paper prepared for the Committee for Review of the Federal Motor Carrier Safety Administration Truck Crash Causation Study, Transportation Research Board

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The cost in damage, injury, and life resulting from accidents¹ has focused great attention within government, industry, and the public on means of preventing their occurrence and reducing their consequences. One logical step in accident prevention is discovering what causes them. The Federal Motor Carrier Safety Administration (FMCSA) Large Truck Crash Causation Study (LTCCS) represents just such an effort. Gathering information on 1,000 crashes involving large trucks is expected to yield information that can be applied to accident prevention.

The objective of this paper is to review the LTCCS program of data collection and analysis and to offer conclusions as to the need for continued study that will help ensure that the results of the current effort are of the greatest possible value in the prevention of large truck crashes.

LARGE TRUCK CRASH CAUSATION STUDY

Under the LTCCS program, National Automotive Sampling System (NASS) researchers, along with state truck inspectors, are collecting data at crash scenes through photographs and inspection of the truck as well as through interviews with the driver and witnesses. These are followed by off-site data collection from police accident reports, hospital records, and coroners and by additional interviews with representatives of motor carriers and others having crash-related information.

LTCCS Data

The elements of data being collected in the LTCCS can be viewed in the various data collection forms. These include (a) general descriptions and diagrams of the crash; (b) descriptions and sketches of the vehicles and damage involved; (c) assessments of nonmotorists (e.g., pedestrians and cyclists); (d) information gained from drivers concerning their characteristics, events surrounding the crash, and its consequences; and (e) information gathered from motor carriers concerning drivers, vehicles, the trip, and

¹ The term “accident” has been defined as “an unfortunate incident that happens unexpectedly and unintentionally,” in which sense it is generally used. Throughout this paper, “accident” will be used in reference to such incidents in general and “crash” for those involving motor vehicles specifically.

the carrier itself. The forms are sent to one of the two NASS zone centers, in Buffalo, New York, or San Antonio, Texas, where the data are coded and entered into a file.

The data gathered through the various forms are reviewed by the Veridian staff and summarized in a “Crash Event Assessment Form.” The central category of data is the “critical precrash event,” which is the event immediately preceding the crash, including something causing loss of control, motion of a vehicle, another vehicle in or encroaching on the same lane, pedestrians, pedalcyclists, other nonmotorists, animals, objects, or “other.” Underlying these are a host of “related factors,” including those involving characteristics of drivers, vehicles, and the environment. Although they are not specifically labeled causes, many of the factors appear to fall into that category (e.g., “failed to look far enough ahead,” “brakes failed,” “slick roads”).

The analysis being carried out with the LTCCS does not, and is not intended to, identify causes in a manner that will necessarily guide all forms of preventive activity. No one analysis can be expected to do that. It does provide a database from which professionals and technicians knowledgeable in various crash countermeasures can gain information that can help them prioritize various approaches according to the magnitude of the crash problem addressed by each approach. Those concerned with maintenance can focus on tests and inspections of parts and components whose failure is most important in crash causation. Training of drivers can focus on preventing those shortcomings that most frequently contribute to crashes. Testing of mental and physical abilities can focus on those showing the greatest relative crash risk. Procedures regulating hours, supervision, incentives, and other possible influences on driving can be addressed in terms of their importance to safety.

It is very early to reach conclusions as to the causes of truck crashes or the extent to which the LTCCS will be successful in revealing them. An interim report (FMCSA 2002) provides some initial tallies of crash causes but emphasizes their preliminary nature and states that “no national estimates of proportions, relationships, or risks should be inferred from them.”

Analytic Methods

The determination of accident causes is almost entirely an inferential process. In certain areas the circumstances under which accidents occur are so well recorded, through onboard or remote equipment, that causes are completely and unequivocally revealed. Research is currently under way into the recording of various forms of vehicle motion, along with video images of drivers and driving scenes, to permit conditions immediately preceding an accident to be analyzed for insights into causes—much like flight data records on aircraft. However, the benefits of such instrumentation are yet to be realized. Instead, causes must be inferred from the information that is available from investigation of crash scenes and vehicles, as well as from interviews with drivers and witnesses some time after the crash has occurred. The inferential processes can be divided into two basic methods, which, for want of better terms, will be labeled “investigative” and “statistical.” The effort to identify causes of large truck accidents being undertaken by FMCSA uses

an investigative approach, and the focus of this paper will be on that approach. A parallel effort using a statistical approach will be briefly summarized.

Investigative Analysis

Under an investigative method, causal inferences are drawn through the collection and analysis of facts about the circumstances under which a crash occurred. The validity of causal inferences is greatly dependent on the nature, accuracy, and amount of data available. Some accidents reveal no clues as to cause. However, reasonable inferences can be made concerning the contributing causes of most accidents. Unfortunately, the most common causes—human shortcomings—are the least certain; unlike broken parts or skid marks, acts that lead to accidents vanish with the accident. Confidence in inferences as to human causes will vary with the amount and validity of relevant information.

Inferences as to the causes of an accident are drawn largely from information gathered at the scene from observations, measurements, parties to the accident, and witnesses. In motor vehicle crashes involving injury or extensive damage, investigations are initially conducted by police called to the scene. The information collected is typically recorded in a police report form calling for details as to vehicles, location, weather, injuries, damage, and various facts about the accident. Causal information provided is generally recorded in terms of codes referring to broad categories of driver mistakes, often with an emphasis on traffic violations. Greater insight into the specific shortcomings contributing to accidents is generally secured through review of narrative descriptions entered by officers.

For a variety of reasons, certain accidents are often singled out by police for more intensive investigation. At the next higher level, officers given special training in advanced accident investigation are sent to the scene to make observations and take measurements leading to judgments as to stopping distances, speeds, belt use, and other factors. At the highest level, teams of officers trained in accident reconstruction, supported by technical specialists and professionals, look into precrash conditions, establish sight distances, and determine vehicle deformation to calculate crash forces.

Statistical Analyses

The greatest limitation of the investigative approach is that the further back one goes in the causal sequence, the less certainty can be attached to causal influences. While a crash-involved driver may have been tired, ill trained, or just psychologically unsuited to the job, inferences involving the contribution of these conditions to a crash from information available on the scene are highly conjectural. The role of more remote factors in accident causation is generally better determined by quantifying relationships between various factors and crash likelihood. A frequently used method involves statistical comparisons of the characteristics of people, things, or conditions involved in accident cases with control samples from the population at large. The control samples are selected so as to be similar to the cases in all respects except for the particular characteristic under study.

Perhaps the best known applications of the “case-control” method in motor vehicle crash research involve alcohol. Through comparison of the blood alcohol levels of fatally injured drivers with those of drivers not crash-involved, the relative crash risk is established for each level of blood alcohol. The results have been applied to establish legal limits for motor vehicle operators, with separate limits for those operating trucks. More directly related to trucking is the application of case-control methodology to hours of service (HOS), which reveals the manner in which crashes vary both with hours of the day and number of continuous hours at the wheel.

Ten of the most critical crash causation policy questions confronting truck safety have been identified by Hedlund (2003). Among the concerns are driver fatigue, vehicle maintenance and inspection, and the driver working environment. While several elements of the working and roadway environment are difficult to address through statistical analysis, only one is excluded: truck driver performance failures leading directly to crashes, which is in the domain of investigative analysis.

Use of a statistical approach in identifying the causes of large truck accidents is to be undertaken by the University of Michigan Transportation Research Institute. The method contemplated does not involve collection of control data from a separate sample drawn from the population at large. To seek out and gather information from samples of trucks and drivers matching the accident sample except for the characteristics under study would be extremely expensive. For example, to assess the effect that varying HOS has on truck crashes would require collecting information on service hours from a sample of drivers matching the LTCCS sample except for service hours. Technically, different samples would be required for each variable under study.

Instead of separate control samples, more readily available samples are used, such as drivers or vehicles from the same accident. For example, drivers causing accidents are compared with their passengers or with the not-at-fault drivers. One proposal to evaluate the effect of HOS is to compare single-vehicle crashes with multivehicle crashes. The former are considered more likely to result from long hours than the latter. “If 40 percent of the drivers in single vehicle crash at night were driving over HOS limits, while only 20 percent of the drivers in multi-vehicle crashes at night had HOS violations that would be consistent with the hypothesis that HOS violations played a role in the crashes” (Craft and Blower 2001). Since one can never be sure that case and control samples are perfect matches except for the variable under study, inferences as to cause face threats to validity different in nature from but equal in magnitude to those encountered in investigative analyses.

Requirements of Investigative Analysis

Investigative analyses of accidents in various areas of risk have succeeded in shedding light on the causes, which has helped in identifying and prioritizing preventive measures. The NASS Crash Event Assessment Form lists a large number of precrash events that are deemed to have played a critical role in bringing about a crash—they are largely the motions of vehicles and other objects that immediately preceded the crash. They are

accompanied by a host of factors that may have contributed to the crash. Neither the events nor the factors are referred to as causes until an inference is made that they contributed to crash causation. The factors listed vary considerably in their relation to causation. “Failed to look far enough ahead” certainly appears as a factor leading to a crash, as does “inadequate evasive action” or “steering failed.” “Fog” presumably would not have been mentioned if it were not thought to have played some role. Other factors, such as medication or familiarity with the vehicle, are listed and can be checked off if they were present, whether or not they appear to have contributed to the crash. Such factors could be revealed as crash-related through statistical analysis.

While the LTCCS research provides a database that can be applied to identification of crash causes, it does not in itself provide the breadth and depth of analysis that will fully exploit its potential in accident prevention. This is not a criticism of the database itself or the FMCSA effort, but rather an acknowledgment of the limits in the ability to recognize crash causes simply through the factors that are presented in the crash event analysis. The remainder of this paper will identify needs in securing causative information through investigative methods, including the processes of *causal inference in investigative analysis*, *identifying casual sequences*, and *aggregating causes*.

INFERRING CAUSES THROUGH INVESTIGATIVE ANALYSIS

The investigation of individual accidents through the years has led to a variety of preventive measures. Analysis of events surrounding the *Titanic* disaster brought about changes in transatlantic navigation procedures, which have prevented similar maritime accidents. Analyses of the Air Florida and ValuJet crashes led to changes in deicing procedures and handling of oxygen canisters that have prevented recurrences of those types of incidents. In these cases the causes were fairly apparent once the circumstances were revealed. Such is not always the case; sometimes the accident-involved vehicle must be recovered, assembled piece by piece, and examined thoroughly to discover clues to the cause. An example is the TWA flight that crashed near Long Island.

LTCCS Causal Factors

LTCCS field staff gather an enormous amount of information through the several data collection forms that have been mentioned earlier. Their task is simply to record what is revealed through inspection of crash scenes and the vehicles involved as well as through information collected from the parties to the crash and witnesses. They are not encouraged to make inferences as to cause. The more causal factors identified in the Crash Assessment Form are the result of conclusions reached by the Veridian staff. Some comments as to cause also appear in the narrative descriptions of crashes.

As noted earlier, causal factors underlying critical crash events are divided into driver, vehicle, and environmental factors, as shown in Table 1. The numbers in parentheses refer to the number of levels or subcategories of each factor. They total more than 500 individual factors.

The ability to identify causes varies greatly from one truck crash to another. In many there is insufficient information to draw any conclusions regarding causes—for example, a tanker truck that capsized and burned, killing the driver. In many others the cause appears rather clear. This is particularly true of purely physical causes, including medical conditions—drivers suffering heart attacks and insulin shock; fatigue—drivers falling asleep and leaving the roadway; equipment—failure of brakes or disintegration of tires; and road conditions—tractor-trailers braking on a slippery surface and jackknifing. These causes can be inferred from observations of conditions following the crash.

Less easily inferred are causes arising from human shortcomings, which, absent onboard recording equipment, are rarely evident after a crash. Insight into the human (primarily driver) contributors to accidents comes primarily from analysis of the accident scene and information supplied by witnesses, including the involved drivers. Human error is generally acknowledged to be the most frequent contributor to accidents. Indeed, almost all accidents involve human shortcomings to some degree: although fog or slippery highways may contribute to a crash, the driver's failure to adjust to them is a contributor; when parts fail, the cause ultimately lies somewhere in design, production, or maintenance. Ultimately, prevention must occur through changes in what people do.

Table 1 Causal Factors in the Crash Assessment Form

Driver-related factors	Illegal maneuver (9)
Physical factors	Inadequate evasion (6)
Alcohol (15)	Aggressive driving (20)
Drugs, illegal (17)	Other (9)
Drugs, over the counter (18)	
Drugs, prescription (42)	Emotional factors
Fatigue	Upset (9)
Fatigue condition (4)	Under work pressure (9)
Sleep condition (12)	In a hurry (9)
Sleep related to (9)	Other (6)
Sleep pattern (17)	
Work schedule (6)	Experience factors
Other fatigue (9)	Unfamiliar vehicle (7)
Illness (9)	Unfamiliar roadway (7)
Visual (11)	Other (6)
Other physical (9)	
	Carrier/employer relations
Recognition factors	Pressure to accept loads (7)
Inattention (9)	Pressure to operate while fatigued (6)
Distraction	Other factors (6)
Conversation (27)	
Interior factors (9)	Traffic flow factors (5)
Outside factors (27)	
Inadequate surveillance (49)	Vehicle condition factors (9)
Other (5)	
	Environmental factors
Decision factors	Roadway (13)
Too fast for conditions (15)	Weather (9)
Following too closely (18)	Other (9)
Gap misjudgment (47)	
False assumptions (7)	

The recognition that human inadequacy underlies an accident does not imply “fault,” a point made in FMCSA’s documentation of the approach being taken. In some instances the victims of a collision could have anticipated the action on the part of the other road user that led to the crash and taken defensive measures. While failure to do so cannot be considered an “error,” the investigative analysis could benefit from a broadening of the identification of contributing factors to include lack of defensive precautions where conditions indicate an accident potential. For example, a car may pull out from a side street at a blind intersection and be struck by a truck. An experienced truck driver might have anticipated the inability of a driver to see approaching traffic and therefore might have slowed down and been ready to brake and sound the horn at the first sign of a car. Determining whether such a defensive response would have reduced the chance of a

collision would require further study of the database. Investigative analysis of crash causes may actually go beyond and expand the database. Reviews of narrative crash descriptions may reveal contributing factors that add to or modify the factors falling within the categories making up the preceding table. This is anticipated in the space for “other” among the factors in most categories.

Bases of Causal Inference

In most of the LTCCS crashes, causes must be inferred from a combination of what is visible at the crash scene and information supplied by witnesses. A tractor-trailer rollover at a tight curve was readily traced to excessive speed, while a truck-car collision was clearly caused by a car driver’s attempting too tight a merge. However, in many crashes where human error is involved, the nature of the error is unclear. It appears that causal inferences within LTCCS are, by design, rather closely tied to the information furnished by the field staff. The field data collectors, who lack the technical expertise of accident reconstructionists, are not encouraged to offer causal inferences. Moreover, while the field staff can seek to question witnesses, they lack the authority to compel accurate testimony, or any response at all in some instances.

In one case, a novice car driver pulled out in front of a truck at an intersection. The related factor was listed as “looked but did not see” on the basis of the driver’s statements. However, given the available sight distances and the speed of the truck, it appears unlikely that the truck would not have been visible at the position it occupied when the driver pulled out. Further testimony disclosed that the driver looked left, saw nothing coming, looked right, waited for two cars to pass, and then pulled out. This is not an uncommon mistake. When the normal search pattern is interrupted by having to wait for approaching traffic, inexperienced drivers often fail to recognize that conditions may have changed and that they need to check upstream in the lane about to be entered. The fact that the driver was newly licensed adds validity to this interpretation.

A similar shortcoming arises in left turns, where a driver sees no oncoming traffic but is forced to wait for some reason. When the path to the left is clear, the driver pulls out without rechecking for oncoming traffic. One of the FMCSA cases involves a car making a left turn, pausing, and then pulling into the path of an oncoming truck. Photographs of the scene indicate that the truck would have been visible to the car driver. A final example involves a tractor-trailer struck by a train at an unsignalized crossing. The fact that the driver had used the crossing five times a week and the train was operating at high speed and not on its usual schedule would strike a chord familiar to those who are aware of the role of expectation among frequent users of unsignalized crossings.

Specialists in accident prevention, given the opportunity to review the LTCCS database and freed from the inferential constraints under which FMCSA operates, may be capable of furnishing insight that is more revealing of causes than what currently emerges from the crash event assessment. While legitimate concerns may be raised as to the apparently speculative nature of the inferences that have been mentioned, all inferences are subject to error, including those based on statements made by parties to crashes. The objective is

to arrive at the causal inferences that are most consistent with available data. Multidisciplinary teams of professionals and technicians with competence in truck design, motor carrier operations, human factors, and related disciplines, coupled with backgrounds in motor vehicle crash investigation and research, are likely to offer the most valid insight into the causes of truck accidents.

One way to minimize error is to compare the independent judgments of team members to identify areas of uncertainty and make them the focus of discussion. While consensus does not ensure accuracy, its absence undermines confidence—it is a necessary yet not sufficient condition. The authors of the Indiana *Tri-Level Study of the Causes of Traffic Accidents* (Treat et al. 1979) took a different approach. They had team members rate their confidence in their judgments and used the results to assign credibility levels to causal inferences. In the end, action with respect to trucks will rarely be taken on the basis of any one crash. As will be discussed later, individual crashes will be grouped into categories having similar causes and aggregated to allow preventive measures to target the biggest problems. Here it is not exact numbers but the general order of magnitude that guides preventive efforts.

It is worth noting that the investigative process may also be useful in identifying candidates for statistical analysis, that is, factors that appear to have played a role in a particular accident but that cannot be identified as causes through available information. The problems identified by Hedlund (2003) are well established as possible crash causes and warrant statistical analyses to quantify the extent of their influence. Other conditions that a multidisciplinary team perceives as occurring frequently in crashes may also be suitable for testing through case-control methodology.

SEQUENCES OF CAUSE

Rarely are accidents the result of a single cause. Most are characterized by a sequence of events, and interruption of any event would have prevented the accident from occurring. A hypothetical example is a truck driver who is advised that his brakes are defective but who nevertheless decides to continue with a delivery. On a long downgrade he is unable to stop and runs into a line of vehicles stopped for a traffic light at the bottom. The brake failure on a downgrade with a traffic control at the bottom was certainly a cause. But other causes were the driver's decision to proceed with known brake defects, his failure to anticipate the possible difficulty in stopping at the bottom of the hill and therefore to downshift, and, when he recognized his situation, his failure to take to the berm rather than crash into vehicles queued up at the bottom. A different choice at any one of these points in the sequence might have prevented the crash. The defining characteristic of a causal factor is whether some change is likely to have prevented the crash, often referred to as the "but for" criterion. Any one of the changes in the series just described could have prevented the crash at the bottom of the hill.

Multiple Causation

The sequential nature of accident causes has been likened by Reason (1990) to the holes in a block of Swiss cheese, the alignment of which generally prevents seeing through the block. It is only when the holes line up—all of the causal factors are presented—that an accident occurs. The truck crash just described is an example of such an accident. The various layers through which light must pass are *unsafe acts*, the specific mental and physical behaviors that directly cause the situation; and *latent factors*, the predisposing conditions that raise the probability of an unsafe act. The latter can be divided into two general subcategories: *personal*, characteristics of the people contributing to an incident, including both the physical and the psychological; and *systemic*, characteristics of the interface of people with elements of the system in which they function, including other people, hardware, and the natural, physical, and organizational infrastructure. Reason's analogy illustrates an approach to accident investigation that has been widely recognized and is currently being applied to several analytic efforts ongoing in air, marine, and rail transportation.

The FMCSA process uses a method developed by Perchonok, a late associate of the Veridian staff, that identifies for each crash a “critical event” and “critical reasons” for that event. The Reason model does not distinguish among the events contributing to an accident. Any event whose absence would have prevented the accident is considered as critical as any other. With access to the LTCCS database, researchers and crash investigators could extend the search for events and reasons well back from the crash itself.

Limits to Investigative Analysis

The further back one seeks causes in the chain of events leading up to an accident, the more tenuous becomes causal inference. A crash can be readily traced back to “looking for a street address” so long as it can be verified by testimony of the driver or witnesses. But “drives on this road once per month” cannot be inferred as a cause from a purely investigative analysis. Inferences of this nature are better derived statistically through case-control analyses relating crash involvement to frequency of road use.

The difficulty in identifying the more remote causes of accidents through an investigative process has not discouraged the attempt to do so. Presently, efforts to identify the strings of causes leading to accidents are taking place in the air, marine, and rail applications mentioned previously. The system-hardware-environment-liveware (SHEL) matrix addresses background accident contributors (Edwards 1985; Hawkins 1987) and has been applied to the study of accidents and dangerous incidents in several modes of transportation. It distinguishes five categories of variables:

- Individual: variables related to characteristics of people engaged in an activity;
- Person–person: variables related to interaction among people;
- Person–hardware: variables related to interaction of people with hardware;
- Person–system: variables related to interaction of people with system procedures; and

- Person–environment: variables related to interaction of people with the physical, natural, and social environments.

The cost of the intensive investigation required to reveal the more remote causes has largely confined application of the SHEL model to modes of transportation in which accidents are fewer in number and more serious in consequence than the thousand large truck accidents under study by FMCSA. While the LTCCS database would not support such analysis, some recourse to the rather exhaustive list of possible causes making up the SHEL model might offer suggestions as to candidate factors for statistical analysis that might otherwise be overlooked.

AGGREGATION OF CAUSES

While investigation of catastrophic accidents such as those that have been mentioned has led directly to preventive measures, accidents involving user-operated vehicles such as trucks, cars, and motorcycles are far too numerous and their causes far too diverse to base preventive measures on individual events. As noted earlier, it is the number of incidents involving a particular cause that makes it a target of prevention. The fact that a part failure results in one accident does not necessarily make it an object of concern or even attention. However, finding that the same failure contributes to significant numbers of accidents can lead to recognition and correction of a problem. For example, transmission failures that caused automobiles of one model year to shift into reverse did not become the basis of lawsuits and redesign until the number of crashes associated with such instances became known. For years, the prevention of car crashes tended to focus on speed, until the analyses showed poor visual search and inattention to be far more frequent contributors. Although each event is unique, some aggregation of causes by category aids in deriving useful information where large numbers are involved.

Classification

The aggregation of accident causes requires some means of classifying them into categories that are relatively heterogeneous across and homogenous within, something approximating a qualitative factor analysis. A term frequently applied to the classification of things is “taxonomy.” Strictly speaking, this term implies an inherent structure, whereas the classification of accident causes is functional in that, like a filing system, it puts things together in terms of their use. Like any filing system, its value lies less in its correctness than in its utility. Because similar causes are grouped together, they can be more effectively and efficiently addressed than by trying to consider each separately. It appears most useful to group the causes of truck crashes together in terms of the steps needed to prevent them. For example, the fact that 10 of 126 crashes involved truck drivers who were considered to have exercised inadequate surveillance and a total of 61 interior and exterior distractions were involved (some crashes involved more than one distraction) indicates that simply watching where one is going is an important factor in crash prevention among truck drivers (FMCSA 2002). On the other hand, the fact that only two of the crashes investigated involved brake failure suggests that this item may not be significant.

The starting point in a taxonomy of accident causes is typically an a priori classification, much like the list of more than 500 causal items in the LTCCS presented earlier. The list will ultimately have to be pared by dropping individual factors that arise too infrequently to warrant attention or by combining them with others that are similar enough in their preventive requirements to be addressed as a single category. A taxonomy of recreational boating errors started as a list of more than 500 possible boating accident contributors and was ultimately reduced to the 68 errors occurring in more than 1% of accidents to any boat type.

The numbers and percentages of crashes attributed to various causes must be viewed as only general estimates of what actually prevails in truck operations. They are subject to error in both the sampling of cases and inferences as to cause. The targeting of preventive measures requires an order of magnitude rather than exact numbers, as the examples in the next section will demonstrate.

Examples

The ability to classify and aggregate accidents in terms of the underlying human factors has played a significant role in their prevention. The role of search and attention in automobile crashes revealed by an Indiana study has been mentioned (Treat et al. 1979). Human factors causes were predominant, and one of the most common was “improper lookout.” The percentages of crashes specifically due to “entering travel lane from intersecting street or alley,” by level of certainty and depth of analysis, are as follows:

	<i>Certain (%)</i>	<i>Certain or Probable (%)</i>	<i>Certain, Probable, or Possible (%)</i>
On site	7.5	12.4	13.2
In depth	12.1	16.4	16.7

There were clear differences by level of certainty and depth of analysis. However, examination of the full report indicates that all the percentages given far exceeded other forms of improper lookout, which in turn exceeded all other human factors causes. It turned out to be something of a revelation in the understanding of human causes and stimulated greater emphasis on checking both ways at cross streets in instructional programs and materials.

A human factors analysis of motorcycle crashes (McKnight, McPherson, and Knipper 1980), which used data collected on 900 incidents (Hurt, Ouelett, and Thom 1981), indicated that braking errors occurred in three-quarters of all crashes. The specific errors broke down as follows:

<i>Error</i>	<i>Percent</i>
Insufficient force applied to front brake	27
Braking while turning sharply	2
Locking rear wheel	23

Letting up on rear brake after excessive skid	1
Maintaining rear brake during skid	4
Excessive front brake force	1

Most riders at the time were fearful of using the front brake, since locking it could cause a fall. Also, it was easier to apply the rear foot brake. The problem is that in an emergency, an attempt to stop quickly pitches the motorcycle forward, with the result that most of the stopping power comes from the front brake. In one-quarter of crashes, greater front brake force and not locking the rear brake were judged capable of preventing the crash. The only way to ensure that the front brake will be applied in an emergency is to develop the habit of using it all the time, and the results of the study were useful in making this a part of instructional programs. The findings also gave support to efforts to redesign motorcycle braking systems to allow the foot brake to apply appropriate force to both brakes.

A final example, outside of motor vehicle crashes, is an analysis of human factors in recreational boating accidents (McKnight et al. 2003). This analysis of more than 3,000 accidents indicated for the first time the nature and frequency of boater errors. The large differences in errors across boat types are particularly enlightening. While sail and power boats were already known to pose very different requirements and lead to different errors, the analysis indicated large differences by boat type within each of these broad categories. Table 2 gives the five most frequent errors for three types of power boats: *open motor boats* (by far the most common), *personal watercraft* (by far the most accidents per vessel), and *canoes and kayaks*. In this example, results of the analysis are expressed in terms of measures that would have prevented the accidents. The obvious differences across boat types point to the need for inclusion of boat-specific instruction in boating safety programs.

Table 2 Five Most Frequent Errors for Three Types of Power Boats

Type of Boat and Error	Percent
<i>t</i> ^a	
Open motor boats	
Controlling consumption of alcoholic beverages	14.6
Looking ahead to see obstructions to the intended path	13.8
Waterskiing safely and operating the boat in a safe manner when towing skiers	8.4
Assuring a firm grip or secure footing on the boat when conditions warrant	7.8
Wearing PFD when conditions create significant risk of immersion	7.5
Personal watercraft	
Keeping sufficient distance from other boats	34.6
Looking ahead for boats and other obstructions to the intended path	23.4
Adjusting speed to limits imposed by the proximity of other boats	15.8
Looking to the side and behind before starting a turn	9.5

Avoiding deliberate wave jumping	8.0
Canoes and kayaks	
Wearing PFD when conditions create significant risk of immersion	17.2
Controlling consumption of alcoholic beverages	14.8
Operating safely while constrained by current	14.1
Remaining seated to avoid capsizing or swamping the vessel	9.3
Having the required number of PFDs (e.g., wearable, throwable)	7.6

NOTE: PFD = personal flotation device.

^a Percent of all accidents involving the boat type in which the error was a cause.

Degree of Detail

Devising a classification system requires choices as to level of detail in creating cause categories. The categories must be specific enough to allow targeting of preventive measures, yet broad enough to allow aggregation of causes requiring similar measures. Arriving at a useful taxonomy becomes a process of successive approximations. It cannot effectively commence until enough accidents have been analyzed to provide a representative sample of causes. In any single study, such as the LTCCS, it is inefficient to attempt development of a useful taxonomy until analysis has been completed for a large sample of crashes. As noted, most classification efforts begin with a highly differentiated system, with very specific causes. As sets of accidents are analyzed and coded, the categories with too few accidents may be combined, new categories may be added to accommodate unanticipated causes, and some categories may be dropped entirely.

The ability to support a highly differentiated taxonomy in the LTCCS will be limited by sample size. While 1,000 crashes looks like a large sample, the groupings rapidly diminish when the sample is stratified by factors that are likely to lead to different patterns of causes. For one, in the multivehicle crashes that make up the majority of cases, the causes are split between trucks and other road users, primarily automobiles. It appears that the crashes caused by other than the truck will serve primarily as an induced exposure sample for case-control statistical analyses, although this may not have been anticipated in the study design. Even within the population of crashes caused by trucks, patterns of cause may vary across truck type, such as straight truck versus tractor-trailer. To the extent that the different types need to be analyzed separately to furnish meaningful results, it may prove desirable to continue data collection, either across the board or for certain categories of trucks or crashes. The results of the present study would be useful in focusing further data collection on factors that appear to contribute significantly to truck crashes.

The need for a useful taxonomy of truck crash causes has yet to be addressed. At some point the responsibility for meeting the need must be assigned. Since the function of the taxonomy will be to help guide preventive efforts, it appears appropriate to involve specialists from various aspects of truck crash prevention in the formulation of a useful taxonomic structure.

SUMMARY OF INVESTIGATIVE ANALYSIS NEEDS

The LTCCS will generate a database rich in information relating to the causes of large truck crashes. Indeed, it will provide the largest repository of causative data available. Deriving the greatest possible benefit in the prevention of truck crashes will require analyses that extend beyond the boundaries of the LTCCS as it is presently constituted. Additional needs are summarized below.

Depth of Analyses

The ability to identify crash causes in a manner that will facilitate preventive efforts requires a depth of analysis beyond what is called for in the LTCCS. Specifically, it will require

2. • Analysis of the database by professional and technical specialists in various aspects of truck crash prevention;
3. • Full availability of the database to qualified specialists, with appropriate steps to safeguard confidentiality and, where appropriate, anonymity; and
4. • The allowance of inferences as to cause based on the best available evidence without placing administrative constraints on interpretation of data.

Multiple Causes

The method used in the LTCCS is oriented toward a single critical event and the factors leading to it, in contrast with a more widely used approach that looks for a series of causes leading up to the crash.

- 5.
6. • The existing database should be reviewed for all factors preceding a crash that can be identified as playing a direct causal role.
7. • Any factor may be inferred as a crash cause if some change might have prevented the crash from occurring.
8. • Factors too remote in the chain of causality to be directly tied to a crash through contents of the FMCSA database are more appropriate candidates for case-control statistical analysis.

Aggregation of Causes

Effective accident prevention requires that efforts be directed to the most frequent causes. This, in turn, requires some means of classifying individual causes into categories requiring similar preventive efforts. A lengthy preliminary list of causes must be devised to permit causes to be classified as investigation proceeds. The current list of more than 500 potential causes meets this requirement.

- 9.

10. • A classification system or “taxonomy” of causes intended to support crash prevention efforts would group the causes into categories having similar preventive requirements.
11. • Development of a useful classification system must await completion of the investigative analysis and be performed by specialists in truck crash prevention.
12. • The sample of crashes in which the truck played a causative role is likely to prove too small to reveal all but the most frequent causes; continued sampling can benefit from the results of the present study.

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December 19, 2002

Ms. Annette M. Sandberg
Deputy Administrator
Federal Motor Carrier Safety Administration
Room 8202
400 7th Street, SW
Washington, DC 20590

Dear Ms. Sandberg:

The Committee for Review of the Federal Motor Carrier Safety Administration's Truck Crash Causation Study held its fourth meeting on August 20–21, 2002, in Washington, D.C. The enclosed meeting roster lists the members, government staff, guests, and Transportation Research Board staff in attendance.

TRB formed the committee in 2000 at the request of FMCSA to provide advice on study methods. This is the committee's fourth letter report. The others were submitted on November 15, 2000, March 9, 2001, and December 4, 2001.

On behalf of the committee, I thank the staff members of FMCSA and the National Highway Traffic Safety Administration for their presentations and responses to committee questions. The committee believes that this continuing exchange of views and ideas will help the project achieve its objectives.

The committee recognizes that the Truck Crash Causation Study is potentially of great importance to highway safety. It is the first study to conduct on-scene investigations of a large and nationally representative sample of truck crashes and the first to employ crash investigators as well as truck safety inspectors for data collection. The goal of FMCSA and NHTSA is to ensure that this study is a landmark in understanding the causes of truck crashes and that it leads to actions that reduce the number and costs of truck crashes. The committee's advice is intended to contribute to the achievement of this goal.

At the latest meeting, the committee reviewed questions arising from a recent review of crash files that had been conducted by a task force of five committee members (John Billing, Michael Belzer, Anne McCartt, James McKnight, and Frank Wilson). The task force visited FMCSA in

Washington in July to review crash case files and reported on their observations at the meeting. In addition, the meeting included presentations and discussions on FMCSA's plans for data analysis in preparation for its report to Congress.

The committee's discussions are summarized in this letter, and several recommendations to FMCSA are presented. Our comments and recommendations are in three areas: requirements for presenting the data in public access files, data quality, and analysis planning. A section summarizing all of our recommendations follows the sections on these three topics.

DOT may have already undertaken some of the recommended activities. Nonetheless, to ensure that they are not overlooked, we identify below all the actions that we believe are urgently needed.

DATA PRESENTATION

The task force report and past committee discussions have identified several areas for attention that relate to the organization, content, and documentation of the public database that will be released at the conclusion of the study. The task force reviewed the database in its most complete form, as it will be maintained by FMCSA as the primary record of the investigations. Public versions will have different content. The committee's recommendations in this area are presented below. Some of these amplify recommendations in our earlier letters, in particular, our recommendations regarding presentation of information from interview responses on pages 5 and 7 of our December 4, 2001 letter and our recommendation regarding the importance of complete and accessible documentation on page 5 of our March 9, 2001 letter.

Documentation and Other User Aids

The task force's experience highlighted the inevitable difficulty of using such a complex database and the dangers of misunderstanding and misinterpretation. Public data files derived from the study must be accompanied by complete, carefully prepared, and user-friendly documentation. Developing these materials will be a demanding task. In addition, readily available assistance to users from competent DOT staff will be necessary. At the meeting, NHTSA staff indicated that they are aware of the importance of this task and pointed out that they have long experience in providing support for public research databases (for example, the FARS database of fatal highway crashes). Nonetheless, it is not too early for FMCSA to begin planning the documentation and support arrangements and considering the costs of these activities.

Recording of Sources

Documentation must make unambiguously clear to users the source of each item in the database. The source of an item that is the same in all cases can be explained in manuals, but sources that can vary from case to case must be identified in the record of each case. Elements of the assessments contained in each crash record (e.g., critical event, critical reason, and related

events) in general should be documented by identifying their sources and by narrative explanation of the analyst's reasoning.

Lack of clear identification of sources of information would lead to problems for future users of the database. As one example, if speed is identified as a factor in a crash, it should be clear to the user whether this conclusion was supported by direct evidence of speed (e.g., from measurement of skid marks or statements of witnesses) or whether speed was implicated solely as a deduction from the circumstances of the crash (e.g., coding speed as a factor because a crash involved a rollover on an exit ramp).

Case Summary and Point of Entry

The task force used the crash summary narratives written by the crash investigator as the "point of entry" to the database, that is, the first data element scrutinized to determine whether a case was of interest. NHTSA staff explained at the meeting that these narratives, prepared by the primary investigator in the field, were not intended to serve as the point of entry and that other data elements will be more appropriate for this purpose in the completed database.

The crash summaries that the task force reviewed varied greatly in content, were sometimes not carefully written, and sometimes contained apparent errors. Since we believe that users of the data will naturally refer to these summaries if they are in the public file, we recommend that, if they are to be made public, FMCSA and NHTSA training and oversight of field staff ensure that the summaries follow a standard format and are reasonably accurate, complete, and comprehensible. Examples provided in NHTSA's field coding manual are excellent and could be used by field investigators as models.

The Crash Assessment Form is the key record of analysts' conclusions regarding critical reasons and related factors for each case. These assessments probably will be central to addressing the congressional mandate to examine causation. The committee suggests that the Crash Assessment Form be expanded somewhat beyond the format and content in the cases that the task force reviewed. The form should provide a detailed narrative identifying all facts used in the assessment and include the basis for the decisions made concerning the critical event and reason. In particular, it should explain judgments made by the assessor when sources of information conflict. Again, the examples provided in the coding manual are good models.

Project staff presented to the committee a description of a new "Overview Form," a one-page summary form under development, which is to be part of the computerized database and which would allow the user to easily ascertain the essential aspects of each crash. We believe that this is a very promising step toward facilitating use of the database. We do not believe that we need contribute to the detailed development of definitions of information to be presented in this form, since it should evolve in accordance with the needs of users of the database, but we would be happy to comment on the form as work on it nears completion if requested to do so.

Presentation of Information from Interview Responses

In the master database, certain data fields contain unedited interview responses. We understand that if the investigator concludes on the basis of other information that an interview response is

untruthful, this judgment is noted (with a “flag”) in the data file. We also understand that certain information from interviews obtained with the assurance of confidentiality will not be placed in the public file.

If the public file does include any unedited interview responses (that is, if confidentiality restrictions do not exclude all such data), then the source of such data elements must be clear to users, documentation should note possibilities for substantiating interview responses by comparison with other data fields, and DOT should consider retaining in the public database the flags marking implausible responses that appear in the master file.

The committee believes that FMCSA and NHTSA should take advantage of all opportunities for obtaining information from public sources (e.g., public police or court records or other independent sources) to substantiate interview information, in order to minimize the impact of exclusion of confidential interview responses on the utility of the database.

To aid committee discussion of this issue, we request that FMCSA provide information before the next meeting concerning the specific data items that will be included in the public version of the file.

DATA QUALITY

In its second review of the data in July 2002, the five-person task force examined the five crash cases that it initially reviewed in July 2001 and approximately 25 other completed cases. The 30 cases are all early ones, mostly among the first half-dozen conducted by each of the investigative teams. They were provided to the task force because later case files were not yet complete. It is reasonable to expect that the proficiency of the investigators will increase markedly with experience and that later cases will be much more complete and accurate than the first ones.

Also, discussions at the meeting suggested that some of the impressions the task force formed of the case data may have derived from misunderstandings of the definitions of data elements or of the structure of the database. However, in the cases the task force reviewed, the apparent frequency of missing and miscoded data is a source of concern, especially since these cases have been completed and have undergone quality-control checks.

Missing data and other data quality problems could seriously diminish the value of the study if they are not diagnosed and addressed as soon as possible. Therefore, the committee believes it is essential that FMCSA and NHTSA begin a systematic and quantitative analysis of rates of missing data, data quality, and the causes of missing data and coding errors and take action to reduce these problems wherever they are found to be significant. The committee recommends the following actions:

1. Automated edit checks should be employed that compare data elements for consistency. For example, information related to truck configuration is coded in several fields in the database. These fields should be compared with each other, and cases containing apparent inconsistencies should be flagged for further examination. NHTSA staff reported that the

data entry process incorporates hundreds of such checks; however, the task force came across some apparent instances of lack of cross-checks.

2. Manual edit checks should be systematized. The full case files contain much uncoded information, including photographs of the vehicles, interview transcripts, and police accident reports. NHTSA and FMCSA staff reported at the meeting that these materials are now used in editing. Such manual checks should be conducted wherever there is reason to believe that they could contribute to data quality. They should be performed systematically, according to written protocols, and records kept of the checks performed and resulting changes to coding. For example, a checklist of comparisons of the photographs with the coded data could be developed, so that the same checks are done on each case. During comparison of uncoded with coded information, analysts should take the opportunity to fill in missing coded data items wherever possible. (For example, it may be possible to estimate truck dimensions.)
3. NHTSA should continuously tabulate missing data rates for each data field. These tabulations may highlight specific data collection problems that can be remedied while collection is still under way. They will also allow FMCSA to plan its analysis, since missing data may render some questions impossible to analyze.
4. Cross-tabulations of missing data, for example, rates by date of collection and by field office, should be prepared to search for sources of problems. FMCSA reported at the meeting that it plans to conduct such analyses. Missing data rates should also be tabulated by such key characteristics as vehicle type, truck type, and time of day. If a data item has a missing data rate for trucks different from that for nontrucks or the rate is different for two truck types, any comparative analyses of the two vehicle types probably will be biased, since missing data are seldom random. This effort can generate feedback to the field and to assessors and identify cases where further investigation may be necessary to fill data gaps.
5. Coding should distinguish among circumstances of missing data, including “not collected,” “refused to respond,” and “not applicable.”
6. FMCSA also should tabulate rates of form completion (for example, of the fraction of multivehicle crashes with interviews with the other driver, or of the fraction of crashes with the Level 1 vehicle inspection completed).
7. For certain high-priority data items where problems with missing data or low reliability are discovered, FMCSA should consider devoting greater effort to obtaining more credible data in the remaining cases. Deciding which data elements deserve more resources depends on FMCSA’s judgment about important database applications. For example, fatigue-related information is an area where the task force found questionable data entries and missing data, indicating the difficulty of documenting fatigue. Under present data collection procedures, there is a risk that fatigue data may be too unreliable or incomplete to be useful. After analyzing the quality of fatigue data obtained so far, FMCSA should consider the need for changing standard procedures to devote a greater share of investigative resources to collecting the fatigue-related information items. A second example highlighted in the task force’s report to the committee is information related to driver pay and work organization.

The task force review suggests that it will be difficult under present procedures to produce useful data on this topic.

The committee would like to clarify that this recommendation is aimed at ensuring accurate data; the committee is not proposing in-depth accident reconstruction investigations, which it understands is not the methodology that FMCSA has chosen for the study. Decisions to devote greater effort to pursuing certain data items should not be made on a case-by-case basis according to ad hoc considerations, since such a procedure could bias the database.

8. FMCSA and NHTSA should consider developing a systematic way of checking the validity of data elements that depend on the exercise of judgment by analysts. For example, a coder might be given a case that the coder analyzed a year previously as a test of consistency, or the same case might be given to each of the coders to test whether all analyze it the same way. Outcomes of these comparisons, and any resulting changes in coding, should be recorded and reported.
9. FMCSA and NHTSA should compare rates of case completion (with respect to the population of eligible crashes) by data collection center, time of day, and other characteristics to search for potential sources of data bias or procedural problems.
10. Once the extent of missing data and nonresponse problems is documented, NHTSA and FMCSA should develop and document a plan for resolving or correcting for the problems as far as possible. Techniques are available to adjust for bias introduced by missing data in some circumstances. An example is the method used in the NHTSA study “Multiple Imputation of Missing Blood Alcohol Concentration (BAC) Values in FARS” (D. B. Rubin et al., 1998). Where missing data are the result of nonresponse to interview questions, adjusting for bias may require personal (e.g., gender and estimated age) data on respondents and nonrespondents. Interviewers should collect such information. However, it is important to stress that the bias introduced by nonrandom missing data cannot be removed by simply reweighting the responses for under- or overrepresentation.

Since the results of the missing data analysis will be relevant to future committee efforts concerning analysis planning, as described below, we request that FMCSA communicate them to the committee.

ANALYSIS PLANNING

In past meetings, the committee discussed at length the definitions and relative importance of two applications of the database: (a) statistical testing of hypotheses concerning factors associated with increased accident risk and (b) assessment by expert evaluators of the events or conditions precipitating each crash. These discussions were summarized in previous letter reports. FMCSA has told the committee that it plans to present results of both applications in its report to Congress. We expect that the completed database will prove to be useful to government, researchers, and the public for both of these kinds of applications.

In its preceding letter reports, the committee recommended that FMCSA should conduct analysis planning, that is, that it should begin outlining in detail how it would initially employ the database in carrying out each of these two kinds of application, and especially that FMCSA should begin to plan the analyses for its report to Congress. The presentations at the meeting by Dan Blower of UMTRI and Ralph Craft of FMCSA described FMCSA's progress on analysis planning.

Our specific comments on the FMCSA work presented at the meeting are in the following two subsections. In summary, it is the committee's view that, although FMCSA now has taken some sound initial steps in the development of its analysis plan, it would be desirable to develop this plan to an advanced state while substantial data collection still remains to be carried out. In our first letter report 2 years ago, we concluded that "there is a clear need for a thorough analysis plan that documents agency plans for interim and final analyses for the study. . . . Regardless of methodology, data collection must be based on the research questions being addressed and the analysis to be undertaken." Although the study is no longer in the preliminary stage, there would still be benefits from developing a thorough plan now, before data collection is complete. It is not evident that a sufficient level of effort has yet been devoted to this task. Therefore, we recommend that FMCSA consider whether a reallocation of resources is necessary among the tasks of data collection, database design, and analysis planning.

We also note that the congressional charge to DOT provides for review and updating of the study every 5 years. Therefore it is worthwhile to identify possible improvements to the data collection and analysis methodology even if they could not be practically implemented in the present effort.

Statistical Assessment of Factors Affecting Crash Risk

The presentation at the meeting on plans for statistical testing of hypotheses with regard to factors influencing accident risk shows that FMCSA has made progress on this part of the analysis plan. In the presentation, four specific candidate hypotheses about factors affecting crash risk were defined and the statistical method for testing each was outlined. The committee agrees that the preliminary step identified in this plan—examination of the completeness and consistency of the data elements needed for each of the planned statistical analyses—is the correct one, and recommends that FMCSA begin this process.

Also, as stated by Dr. Blower in the presentation, more work is needed on defining the details of each of the four proposed statistical analyses, in particular, determining the appropriate "comparison crash types," which are critical to this form of analysis. Assuming that the four hypotheses presented to the committee are indeed high-priority issues for FMCSA, we recommend that FMCSA develop these detailed analysis plans.

In addition to determining appropriate comparison crash types, obtaining adequate sample size may be a problem for the four proposed statistical analyses or for other similar analyses that FMCSA decides it would like to be able to carry out. Considering that the total sample is not large, that only a subset of cases will be pertinent for any particular hypothesis being tested, and that the magnitude of the problem of missing or unreliable data elements is at present unknown,

sample size could be a serious constraint. We recommend that FMCSA estimate sample size requirements for each of the four proposed statistical analyses, and for any additional ones it devises, and compare the requirements with the content of the database, taking into account rates of missing data, the likely frequency of errors in the data, and the likely size of the effects sought, as indicated by past research. Also, FMCSA should estimate the significance level and power of the statistical tests it plans to conduct, given the available sample size. These comparisons might reveal that reducing rates of missing data would be necessary before a particular statistical analysis could be conducted.

The committee recommends that FMCSA expand this portion of its analysis plan by adopting a comprehensive and strategic perspective, rather than by searching through the data being collected to seek analyses that are feasible. That is, FMCSA should identify a list of high-priority potential risk factors, including factors that it believes are related to important tactics for reducing crash frequency as well as factors concerning which there is greatest interest on the part of Congress, industry, and the public. FMCSA should then determine which of these can be assessed using the database and the planned statistical analysis method, and which would require other approaches.

Use of Crash Assessment Results and Report to Congress on Causation

Along with planning of the statistical analyses, there is a parallel need for planning how the critical event, critical reason, and related factors data will be analyzed, that is, how causation will be examined. The critical reason assessment for each crash case is the element of the study that appears to approach Congress's question about causes of crashes most directly. Examination of the role of the related factors in each crash also is important in deriving a full conception of crash causation. Presentation of this information in the report to Congress will require sensitive and sophisticated discussion and analysis. Our understanding is that FMCSA does not yet have a detailed analysis plan for this effort. Until a plan is prepared, FMCSA cannot be certain that it is collecting and coding the data needed to support this aspect of the study. The committee recommends that FMCSA begin systematic planning of this critical part of the study.

SUMMARY OF RECOMMENDATIONS

The committee's recommendations, extracted from the sections above, are repeated below.

Data Presentation

- It is not too early for FMCSA to begin planning documentation and support arrangements for public use of the database and considering the costs of these activities.
- Documentation must make unambiguously clear to users the source of each item in the database.
- If the crash summaries now in the file are to be made public, FMCSA and NHTSA training and oversight of field staff should ensure that they follow a standard format and are reasonably accurate, complete, and comprehensible.

- The Crash Assessment Form should provide a detailed narrative identifying all facts used in the assessment and include the basis for the decisions made concerning the critical event and reason.
- If the public file includes any unedited interview responses, then the source of such data elements must be clear to users, documentation should note possibilities for substantiating interview responses by comparison with other data fields, and DOT should consider retaining in the public database the flags marking implausible responses that appear in the master file.
- FMCSA and NHTSA should take advantage of all opportunities for obtaining information from public sources (e.g., public police or court records or other independent sources) to substantiate interview information,

Data Quality

- FMCSA and NHTSA should begin a systematic and quantitative analysis of rates of missing data, data quality, and the causes of missing data and coding errors and take action to reduce these problems wherever they are found to be significant.

Analysis Planning

- FMCSA should consider whether a reallocation of resources is necessary among the tasks of data collection, database design, and analysis planning.
- FMCSA should begin the examination of the completeness and consistency of required data elements which was identified as the first step in the planned relative risk analysis described at the August 2002 committee meeting.
- FMCSA should develop the detailed plans for its proposed relative risk analyses.
- FMCSA should estimate sample size requirements for each of the proposed relative risk analyses, and for any additional ones it devises, and compare the requirements with the content of the database, taking into account rates of missing data, the likely frequency of errors in the data, and the likely size of the effects sought, as indicated by past research. Also, FMCSA should estimate the significance level and power of the statistical tests it plans to conduct, given the available sample size.
- FMCSA should expand its analysis plan for statistical assessment of factors affecting crash risk by adopting a comprehensive and strategic perspective.
- FMCSA should begin systematic planning of how it will use the critical event, critical reason, and related factors data to examine crash causation.

PLANNED COMMITTEE ACTIVITIES

The committee believes that it may be able to assist FMCSA in the two components of analysis planning by preparing two background papers. The content of these papers was discussed in open session at the August, 2002 meeting. The committee will use the papers as a resource to help it formulate its advice on the study more clearly and completely. Before formulating its final recommendations, the committee would like to be able to consider in some detail the analysis planning needs of the study. The papers are to aid the committee in this respect. The

committee's intent is not to present a plan to FMCSA as a substitute for FMCSA's own efforts; rather, the committee's next report will illustrate the form or direction that planning could take.

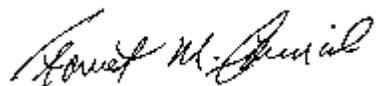
In the first background paper, the committee will list and rank critical policy questions related to truck safety. The committee plans to have a consultant review the literature and draft a list for committee review, and will develop a priority ranking of these issues on the basis of such factors as the probability of successful treatment and potential for reduction in accident losses. Then, with consultant assistance, we will consider which of these questions can be expressed as hypotheses that can be tested by the relative risk method (described in the presentation of Dr. Blower at the meeting) that FMCSA plans to employ, and which of them can be studied using the large-truck crash causation database.

In the second background paper, the committee, with consultant assistance, will attempt to provide guidance on a possible methodology for the crash causation analysis effort. The paper will consider how the critical reasons, related factors, and other data items in the current database could be used to explore causes in a way useful to DOT in developing programs to reduce accident frequency. The paper will also consider whether modifications are needed in the coding or presentation of data to support the examination of crash causation. Part of this effort will involve review of similar efforts in other fields.

Finally, because not all high-priority truck-safety questions will be answerable in the current study and because Congress has directed FMCSA to update the study in the future, the committee will begin to examine data collection and analysis methods that might be appropriate in a follow-up effort. Several alternatives have been raised in committee discussion in each of our meetings, including methods of automated data collection that conceivably could yield much more complete and accurate information than would traditional methods. We plan to further consider this option and discuss it among ourselves and with FMCSA at our next meeting.

FMCSA staff informed the committee that they are considering publishing a progress report on the study in December 2002. The committee will meet again after it has reviewed the progress report and has completed drafts of the background papers. This meeting is scheduled for March 2003.

Sincerely,



Forrest Council
Chairman
Committee for Review of the Federal Motor Carrier
Safety Administration's Truck Crash Causation Study

Enclosure

MEETING ATTENDANCE
August 20 and 21, 2002

Committee Members

Forrest M. Council, Chair
Michael H. Belzer
John R. Billing
Kenneth L. Campbell
James W. Dally (NAE)
Lindsay I. Griffin III
Anne T. McCartt
A. James McKnight
Raymond C. Peck
Lawrence A. Shepp (NAS, IOM)
Steven J. Vaughn
Frank R. Wilson

TRB Staff

Joseph Morris

Government Staff and Guests

Terry Shelton, FMCSA
Ralph Craft, FMCSA
Dale Sienicki, FMCSA
Joe Carra, NHTSA
Seymour Stern, NHTSA
Gregg Radja, NHTSA
Kirsten Theriaux, NHTSA
Gary Toth, NHTSA
Nancy Bondy, NHTSA
Jim Page, Veridian Corporation
Don Hendricks, Veridian Corporation
Steve Mavros, KLD Associates
Richard Ketterer, KLD Associates
Richard Reed, Accident Research and Analysis
Dan Blower, UMTRI
Nicholas Alexandrou, Volpe Center
Representative of Transport Topics
Peter Kissinger, AAA Foundation for Traffic Safety
Bella Dinh-Zarr, AAA

December 4, 2001

Mr. Joseph A. Clapp
Administrator
Federal Motor Carrier Safety Administration
Room 8202
400 7th Street, SW
Washington, D.C. 20590

Dear Mr. Clapp:

The Committee for Review of the Federal Motor Carrier Safety Administration's Truck Crash Causation Study (TCCS) held its third meeting on August 20–21, 2001, at the National Research Council facilities in Washington, D.C. The enclosed meeting roster indicates the members, liaisons, guests, and TRB staff in attendance. On behalf of the committee, I want to thank the staff members of the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA) for their presentations and responses to committee questions. The committee believes the continuing exchange of views and ideas on this project is highly beneficial.

The meeting provided the committee with an opportunity to review a set of questions stemming from a task force review of several crash files and to discuss again the agency's study methodology.¹ In addition, the committee heard a presentation about the database being prepared for the study and discussed the extent to which this database will be made available to the public. There was further discussion about the need to collect as much measurable data as possible about the crash characteristics of the roadway and vehicles involved. Finally, several committee members again underscored the need for the agency to document its method for assessing the crash data files and to consider using other analysis methods as well.

The committee then met in closed session to deliberate on its findings and begin the preparation of this report, which was completed through correspondence among the members. This report summarizes key points made during the committee's discussions and provides several recommendations to FMCSA. See Appendix A for a review of previous committee decisions that affect the committee's discussion and recommendations.

¹ A task force comprising five committee members—John Billing, Michael Belzer, Anne McCartt, James McKnight, and Frank Wilson—visited Veridian Corporation, an FMSCA crash investigation contractor, in Buffalo, New York on July 9–10, 2001 to review crash case files.

Study Purpose and Agency Expectations

The TCCS is a congressionally mandated study of the causes of truck-involved crashes leading to fatality or serious injury. The results of the study will be used to design and select cost-effective measures for reducing the number and severity of serious crashes involving large trucks. The study will consist of in-depth investigations of a nationally representative sample of 1000 large truck crashes, to be performed by teams of trained investigators from NHTSA's National Automotive Safety Sampling System (NASS) project and FMCSA-funded truck safety inspectors. The full study involves data collection at 24 data collection sites.

FMCSA staff reviewed the study's aims for the committee, emphasizing that the study is designed to enable the agency to draw inferences about circumstances and contributing factors associated with truck crashes, thus helping the agency meet its goals for reducing truck crash fatalities. The committee agrees with the agency that the primary objective of the study is to collect the most complete and accurate possible set of factual evidence for use by agency analysts as well as future researchers. However, the study's goals are complicated by the fact that in more than 40 percent of fatal truck crashes, the driver of the other vehicle is believed to be solely responsible for the crash.² Thus the committee remains concerned about whether the data being collected on the 1000 crash cases will yield sufficient causal information to identify the most effective truck-related countermeasures.

The TCCS is important for other reasons as well. It involves the largest nationally representative sample of truck crashes to date and is the first large-scale, on-scene investigation of such crashes. This study is also the first to use a combination of trained crash investigators and truck safety inspectors for data collection. Finally, the truck crash database being developed will be made available to the public and outside researchers as well as FMCSA and NHTSA researchers.

In funding the TCCS, Congress requested “a comprehensive study to determine the *causes* of, and contributing factors to, crashes that involve commercial motor vehicles...[emphasis added]” (Motor Carriers Safety Improvement Act of 1999, Section 224). Extracting causal information in complex events like crashes is quite difficult and depends on collecting reliable and valid data on each possible causal or contributing factor. FMCSA staff informed the committee that the agency is focusing on the contributing factor(s) that increase the risk of crashes; the agency is not attempting to isolate individual or primary causes of crashes. According to the agency, the TCCS—based on the Perchonok method—will yield findings about critical precrash events, the critical reasons for these events, and relative risks in truck crashes. While these findings may help the agency improve the effectiveness of truck crash countermeasures, they may not meet the goals set by Congress. The agency recognizes these expectations and is addressing them as it prepares a crash data analysis plan based on the analysis methodology described by Blower in Appendix B, pp. 13-19. The committee supports this effort and urges the committee to consider other analysis approaches as well. Several committee members also noted that some of the distinctions the agency is making—for example,

² Daniel Blower. Relative Contributions of Truck Drivers and Passenger Vehicle Drivers to Truck-Passenger Vehicle Traffic Crashes. UMTRI Report 98-25.

between causation and contributing factors that increase the risk of a crash—may be lost to decision makers and the public. Thus, clarity in both analyses and report writing is critical.

Crash Event Assessment (Study Methodology)

In its first letter report, dated November 15, 2000, the committee noted that FMCSA has chosen a clinical or case analytic methodology for the study. The discussions at this meeting, however, indicated that both a clinical approach (on the part of NHTSA) and a statistical approach (on the part of FMCSA) are envisioned for the analysis. (Material provided to the committee on these approaches is included in Appendix B, pp. 2-8.) While the committee believes that both are rational approaches, it continues to be concerned about whether the methodology to be used in coding and analyzing the data will yield valid results.

There was considerable discussion about how a critical event for each crash is identified in the Perchonok approach. (Appendix C contains background information on this approach provided previously by FMCSA.) The above-mentioned task force, which reviewed preliminary results from five crash investigations, disagreed with several critical events identified by agency analysts and also disagreed among themselves about appropriate critical events. The committee's concern is not whether universal agreement can be achieved on every critical event, but whether the Perchonok method leads analysts to identify a critical event that can be challenged in light of the data in the crash case files.

For example, the traditional Perchonok method does not recognize that failure to take an appropriate or expected action can be a critical event. This point is illustrated by a crash case involving a passenger car that did not stop at a red light and was struck by a left-turning truck (Appendix B, p. 11). In this example, the passage of the nonstopping car into the intersection after the light had turned red was not coded initially as the critical event. Agency staff now recognizes this limitation and has adapted the method to accept a driver's failure to make an appropriate maneuver as a critical event. The risk, however, is that similar challenges, even on just a few cases, could lead to the judgment that the methodology is subjective or arbitrary, which would undermine the study's conclusions. The committee previously urged FMCSA to follow the procedures of the version of the Perchonok method that is recognized as being the most objective for identifying key crash factors—the version shown to have the least bias toward any pre-determined outcome. The agency must thoroughly document the method being used so that other researchers can review the crash cases and independently analyze the results using the agency's method.

Previously the committee urged FMCSA to conduct two independent assessments of each crash case and was informed that such assessments are planned for each of the TCCS's 1000 cases. At the meeting FMCSA reported that it has also established a review panel to make final determinations about critical events in cases where the results of the independent assessments differ and these differences cannot be resolved. This is commendable. Nevertheless, FMCSA should identify the members of the review panel and document the procedures used by the panel to make final determinations.

The agency discussed its plans to examine likely crash causes on the basis of statistical association and relative risk in the aggregate data, as well as case-by-case assessments. (A relative risk calculation regarding brake violations and crashes based on truck crash data collected in Michigan is described in Appendix B, pp. 17–18.) The committee suggests that FMCSA prepare a detailed, theoretically-based analysis plan for testing hypotheses. This plan should include a list of likely causes to be examined using statistical methods; a detailed analysis scenario for each cause; and a description of analyses that will examine alternative explanations for the observed effect (e.g., the examination of other equipment problems in the brake analysis to disprove the poor driver/poor equipment alternative theory). Such a plan will help the agency determine whether additional data are needed to support these analyses. Agency staff indicated that a preliminary analysis plan would be available to the committee early in the first quarter of 2002.

Crash Event Assessment (Alternative Analysis and Data Collection Issues)

The TCCS represents an important opportunity for causal analysis using methods other than those chosen by FMCSA. Moreover, the committee previously suggested that the agency consider conducting such analyses (for example, the “but for” analysis discussed in its March 9, 2001, letter report). The potential for such alternative analyses is directly related to the depth of the investigation conducted—how far back in time the investigator pursues each possible causal chain of events for each vehicle involved in a crash. It was clear for some of the cases reviewed by the task force, as well as those presented at previous committee meetings, that such causal chains had been thoroughly pursued. (In one case, for example, the event chain went back in time from a rear-end crash to the failure of the driver to reduce speed at the top of a hill to an incomplete or unsuccessful brake repair which the driver was aware of.) The committee urges FMCSA and NHTSA to reinforce in their instructions to investigators the need to examine these event chains thoroughly for each vehicle and driver and to include this information in the database and in the narratives.

In some cases reviewed by the task force, there appeared to be data—potentially useful for current FMCSA analysis and for future agency and independent efforts to reconstruct the crashes more completely—that could have been collected but were not. These data were related to vehicle components and vehicle dynamics of the crash and they included brake condition, measurements of skid marks, and objective estimates of precrash speeds based on physical evidence at the crash scene. Agency staff indicated that they would instruct their investigators on the need and methods for collecting such data and for analyzing the data when necessary to identify the most likely of several possible critical events.

In addition to the data currently being collected and suggested for collection, the committee believes future alternative causal analyses would be further enhanced by recording the crash investigator’s assessment of whether a defensive avoidance maneuver or preventive action could reasonably have been taken by either the truck or nontruck driver to avoid the crash and what that maneuver or action might have been. This assessment could be based solely on the investigator’s judgment in light of the crash data file and could be described in the narrative that is part of every crash case file. A reasonable maneuver is one that could be taken by an average

driver given the roadway and roadside environment, traffic volume, and ambient weather conditions. Judgments about potential avoidance maneuvers, while subjective, provided important information in the Indiana Tri-Level study (see Appendix B); such maneuvers were judged to be possible in one-third of the cases examined. If a similar finding applied to truck crashes, it would be very important for identification and development of countermeasures, as well as for FMCSA's enforcement and licensing/relicensing programs, especially because truck drivers can be required to undergo remedial training. In addition, the existing set of uncompleted cases should be reviewed by the investigators to determine whether avoidance maneuvers can be identified for them.

Crash Data Files

As noted above, a committee task force recently reviewed five crash case files. While these files were not yet complete—some follow-up data and interview information can take several months to obtain—the review provided the task force with a unique opportunity to become more familiar with the data being collected and the analysts' interpretations of the contributing factors involved. The review led to a set of questions that was addressed by agency staff at the meeting. The discussion of these questions is reflected throughout this report. Some specific issues are addressed in the following paragraphs.

Several committee members would like to review the five crash case files once they have been completed and entered in the database; they would also like to review additional completed files, time permitting. Agency staff pointed out that data continue to be added to the files, and data edits will take approximately 4–5 months to complete. According to agency staff, approximately 15–20 complete crash files should be available by March 15, 2002. The committee would like access to these crash files, as well as the interview forms, investigator notes, and other documents pertaining to the cases so they can be reviewed in detail. A review of completed cases will inform the committee as to what final case files look like, give members another opportunity to review the data coding and critical event decisions, and allow them to check the usability of the public crash file structure. Agency staff assured the committee that this review could be arranged.

Information attesting to the truthfulness and accuracy of data is often as important as the data itself and must be included in the database. Task force members noted their concerns about data known or suspected by the crash investigators to be erroneous. When the crash investigators know or suspect a data item is false, they make written notations to that effect on the data forms. However, agency staff informed the committee that these qualifying notes—sometimes called flags—are lost when the data are extracted from the database for release to the public. The committee strongly recommends that such qualifying information be included in the electronic database because, in its absence, future independent analysts will be unaware of such potentially false data items.

The task force review of the crash files underscored the need for calculations based on physical measurements made at the crash site to verify data and information provided by drivers or others involved in or witnessing the crashes. Even basic calculations based on tire tracks or

skid marks can help verify or disprove such subjective data. NHTSA staff indicated their intention to adopt simple speed-estimating procedures so that analytical methods will be used to the extent possible in future cases.

Several committee members emphasized the need, in some cases, for accurate information on roadway geometry and related topics, including shoulder and lane widths, radius of curvature, superelevation, presence and dimensions of rumble strips, sight distance, sideslope grades, and final vehicle resting position. In certain cases it is also necessary to include information about the roadway upstream from the crash site, especially if there are questions about whether sight distance was adequate or stopping distance was a factor. Currently these items are noted only on a scaled sketch included in the crash case file. However, the committee recommends that information on critical roadway geometry be tabulated for each case and included in the database. Doing so will facilitate future analyses by FHWA and other researchers interested in the relationships between highway design and safety.

The committee inquired about the extent to which previous committee member suggestions for changes to the data forms have been adopted. Agency staff indicated that nearly every suggested change has been made. Several committee members, after a brief review of selected revised data forms, noted items that still could be improved. The committee's concern is that data items must be well defined on the forms to yield data useful for analyses. Agency staff agreed to send copies of all the data forms to each of the members. At the request of agency staff, individual committee members will continue to review the forms and provide comments. Finally, agency staff agreed to change some of the terminology in the crash event assessment form so that fault will not be inferred. For example, under driver-related factors, "decision errors" should be termed "decision factors", and "performance errors" should be termed "performance factors."

Public Access to Data

An important aspect of the TCCS is that most of the data collected will be available to the public for analysis once the project is completed. However, data obtained in interviews conducted under nondisclosure agreements with interviewees may not be released. Two important issues emerged from the discussion about public access. First, the committee understands the need to protect information that might lead to the identification of specific crashes and the individuals involved. While the agency standard and capability for protecting privacy appears to be high, it appears some information thus obtained, such as length of last sleep interval, will apparently be disclosed in an aggregated form. The rules regarding nondisclosure should be explicit and adhered to consistently or the agency risks losing the voluntary cooperation of crash-involved witnesses. Accordingly, the committee urges FMCSA and NHTSA to review their nondisclosure rules and the way interviewers explain these rules to the interviewees to ensure that data sources are well protected. The agencies should also ensure that their field investigators comply with these rules and procedures.

Second, while recognizing that privacy concerns are important, the committee believes that information critical to successful analysis by others once the data have been made public

should not be withheld unnecessarily. Of concern is interview information about driver hours of service, fatigue, work compensation, working conditions, and truck ownership. Agency staff stated that when such information can be obtained from secondary sources, it will become part of the public record. In addition, FMCSA plans to prepare analyses that aggregate much of this information, thereby disclosing it in a form that does not violate nondisclosure agreements. Nevertheless, the committee urges FMCSA to find secondary sources for as many of such data items as possible; doing so will increase the amount of data released to the public and their usefulness. For example, it may be possible for FMCSA inspectors to collect information on work compensation, truck ownership, and related items from truck companies and owners, thereby reducing reliance on the driver and/or company interviews by NHTSA investigators. In many cases it will be necessary for investigators to check hours of service and sleep claims independently. The committee suggests that such independent checks be standard practice for all crash case investigations.

Study Sampling Plan

FMCSA staff noted that data collection is now under way at all 24 study sites, and while some sites are yielding crash cases at a rate within an expected range for these sites, others are falling short in this regard. Because the agency's sampling plan is critical to achieving a nationally representative sample of crashes, the committee would like to know whether the data collection effort is yielding the desired representative sample of truck crashes. Specifically, the committee would like to know how many crashes are expected each year from each site, and how these figures compare with the basic NASS sample for these sites. The committee would also like to know, from the beginning of the study and for each study site, how many truck crashes have occurred, how many crash cases are under investigation, and how many crash investigations have been completed. In addition, the committee requests that the agency categorize the crashes under investigation by type (e.g., rollover, rear end). and location (e.g., freeway, rural two-lane road, intersection). This information will provide a preliminary indication of the nature of the sample thus far and allow the crash selection methodology to be reviewed and any expected bias identified and assessed. The committee would like to have this information by January 31, 2002.

Study Report Preparations

There was considerable discussion about the potential study findings and how FMCSA plans to analyze and report them to Congress. To further ensure an adequate data collection and analysis plan, agency staff should begin preparing a strawman version of the report's expected key findings based on a coherent theoretical statement of what the possible, causal or contributing factors are and including suggested formats for tables of key data the agency expects to be able to summarize. Preparing a draft of the opening paragraphs of the executive summary for the study's final report would also be a useful exercise in this regard, since these paragraphs ultimately will provide the most important version of the study rationale and scope. Addressing these tasks now might reveal the need for additional data or analysis. As noted above, agency staff indicated that a draft analysis plan would be available for review and comment by January 31, 2002.

Future Meeting Plans

If the committee receives the completed crash case files by March 15, 2002 it plans to meet on or around June 15, 2002. This schedule will give the committee time to review the files and prepare questions for the agency. Final meeting plans will depend on when the crash case files are available.

Sincerely,

A handwritten signature in cursive script, appearing to read "Forrest M. Council".

Forrest Council
Chairman
Committee for Review of the Federal Motor Carrier
Safety Administration's Truck Crash Causation Study

Enclosures

MEETING ATTENDANCE

Committee Members

Forrest Council, Chair

Michael H. Belzer

John R. Billing

Kenneth L. Campbell

James Dally (NAE)

Lindsay I. Griffin, III

Anne McCartt

Hugh W. McGee

A. James McKnight

Raymond C. Peck

Lawrence A. Shepp (NAS, IOM)

Frank R. Wilson

TRB Staff

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Liaisons and Visitors

Joseph Carra, NHTSA

Ralph Craft, FMCSA

William Gay, Volpe National Transportation Systems Center

Donald Hendricks, Veridian Engineering, Inc.

Rich Ketterer, KLD Associates, Inc.

Stephen Mavros, KLD Associates, Inc.

Michelle McMurtry, National Transportation Safety Board

James Page, Veridian Engineering, Inc.

Greg Radja, NHTSA

Richard Reed, Consultant

Terry T. Shelton, FMCSA

Seymour Stern, NHTSA

Gary Toth, NHTSA

Daniel Whitten, Transport Topics (American Trucking Association)

Robert Woodill, Veridian Engineering, Inc.

Appendix A

Review of Previous Committee Decisions

The Committee for Review of the Federal Motor Carrier Safety Administration's Truck Crash Causation Study (TCCS) was convened after FMCSA had completed the TCCS study design and just as a pilot study was beginning. [See letter report dated November 15, 2000.] Thus, before the committee became involved in the project, FMCSA had already made two key decisions about methodology that affect every committee action and recommendation. The first FMCSA decision was to team with NHTSA to utilize that agency's experience with post-crash data collection developed for the NASS (National Automotive Sampling System) program. However, NASS does not address truck crashes, the level of pre-crash data collection envisioned for the TCCS, or on-scene crash investigations that the TCCS does. Therefore, the agencies had to develop new truck-related data collection instruments, investigative processes, and record-keeping systems for the TCCS. At the committee's first meeting, agency staff encouraged committee review of the full set of TCCS data collection forms and asked for detailed suggestions from the committee regarding truck and truck operating issues. This request established an atmosphere of open discussion and interchange of ideas regarding the data collection instruments and activity that continues.

The second decision—jointly made by FMCSA and NHTSA—was to adapt the method of classifying crash data and coding crash events developed by Perchonok (see Appendix C for the agency description of the method). In the TCCS crash investigators will record the presence or absence of a wide range of data items to create individual crash data files. When a crash data file is complete, experienced crash analysts will use the Perchonok method to determine a critical event and a critical reason for the critical event, as well as the contributing factors, for each crash. While some committee members are unconvinced that the determination of the critical event is sufficiently objective, the committee has chosen to provide guidance on three specific methodological issues. First, the committee continues to review the Perchonok method in as much detail as possible and provide suggestions about data needed for its successful use in determining the critical events. Second, the committee has suggested that the agency use alternative analysis methods. Discussions about alternative methods led the agency to request the preparation of the paper by Dan Blower of the University of Michigan Transportation Research Institute included as Appendix B. The committee has also made recommendations for additional data to support alternative analysis methods. Third, the committee supports the development of a truck crash data base that will allow the use of alternative analysis methods in future analyses that will be conducted by the agency and by other researchers.

The committee has emphasized these points in open meeting discussions with agency staff and in previous letter reports. Agency staff encouraged this ongoing dialogue. Previous committee letter reports provides details on each of these points.

Appendix B

The Large Truck Crash Causation Study

Introduction

This paper will provide an explanation of the approach and methodology of the Large Truck Crash Causation Study (LTCCS). The LTCCS is a study of a nationally-representative sample of serious or fatal heavy truck crashes. The data collected will provide a detailed description of the physical events of the crash, along with an unprecedented amount of information about the vehicles, drivers, truck operators, and environment.

Roughly 5,000 medium and heavy trucks are involved in fatal traffic crashes each year; on average, 5,400 people are killed in those crashes. The purpose of the LTCCS is to advance understanding of how and why truck crashes happen in order to reduce this toll. In 1999, then-Secretary of Transportation Rodney Slater set a goal to reduce the number of fatalities in truck crashes by half within 10 years. In order to meet this ambitious goal, it will be necessary to advance on all fronts, to cast the broadest possible net for way to prevent crashes involving trucks.

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.[1]* The LTCCS has the potential to enhance understanding 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.

The amount of data collected is vastly greater than any previous truck crash investigation program in the United States. The data elements were all chosen for the light they might shed on

* Numbers in square brackets refer to references found at the end of the paper.

factors that affect the risk of crash involvement. The objective of the analysis is not to establish culpability in each crash investigated. Ultimately, the goal of the LTCCS is to support the search for countermeasures to reduce the number of trucks involved in traffic crashes. While establishing fault in traffic crashes may point to certain solutions in preventing future crashes, countermeasures may be found everywhere. In fact, the most effective countermeasures may not be related to causes. The design of the LTCCS will support the widest possible search for countermeasures in truck crashes by providing a comprehensive set of data covering all the elements of a truck crash.

Approaches to causation: the clinical method and statistical association

To provide some background for the methodology of the LTCCS, it is useful to discuss how crash causation has been studied in the past. In this section, two general approaches to studying crash causation will be discussed to provide some context for the discussion of the LTCCS methodology. In addition, a brief discussion of the meaning of “causation” in relation to traffic crashes is offered.

In broad terms, there are two primary approaches to studying causation in traffic crashes. The first can be roughly described as the “expert” or clinical method in which experts determine the causes of particular crashes; the second method—the “statistical” approach—relies on data analysis to search for associations between various factors and increased risk of crash involvement, either in relative or absolute terms. In the clinical method, typically, multidisciplinary teams of experts study individual crashes in great detail, drawing on team members’ expertise in crash reconstruction, vehicle dynamics, psychology, and other relevant disciplines. For each crash, the team members determine primary and contributing causes according to some hierarchy of causation. The resulting data can then be analyzed by statistical means to examine the association between particular causal factors and crash types and so on. But a determination of cause and relative contribution of various factors is made for each crash by the clinical judgment of the experts.

In contrast, in the “statistical” approach, “causation” is not determined at the data collection stage by researchers, however expert. The “causes” of specific crashes are not determined or assigned at any point. Instead, crash cause is defined in terms of changes in risk. Researchers

attempt to collect objective data describing the crash, the environment of the crash, and the vehicles, and drivers involved. Then analysts search for associations between factors of interest and changes in the risk of crash involvement. In the “statistical” approach, cause is defined, either explicitly or implicitly, as a factor that increases crash risk.

“Risk” in this case can be measured in either absolute or relative terms. Sometimes appropriate measures of exposure are available, so absolute crash risks can be calculated. For example, travel estimates for tractor-semitrailers and tractors pulling two trailers might be available, allowing absolute rates to be calculated and the crash risks per mile traveled of the two combinations to be compared. In other cases, exposure information is not available, and the crash data is analyzed to provide conditional or relative risks.

Indiana expert approach

The best-known example of the clinical method is the Indiana Tri-level study of the causes of traffic crashes. In that study, a cause was defined as “a factor necessary or sufficient for the occurrence of the crash; had the factor not been present in the crash sequence, the crash would not have occurred.” [2, page 16.] In identifying causes, the investigators applied a “but-for” test: “but for” the causal factor, the crash would not have occurred. The method of determining these “causes” was the clinical method. The Tri-level study employed an elaborate, multi-level methodology, combining police-reported data, on-scene investigation, and investigation by a multidisciplinary team of specialists. They employed a variety of analytical techniques. But the fundamental approach was to gather information about the crash and then make a clinical judgment, by a panel of experts, assigning the cause or causes of each crash.

In the Indiana approach, a framework of causes is defined. At the top level, the causes cover vehicles, drivers, and the environment. Within each of those areas, a variety of causes are defined. For example, human direct causal factors are subdivided into critical non-performance, recognition errors, decision errors, and performance errors. At the most in-depth level of investigation, an interdisciplinary team of experts collected very detailed information about the crash and identified the factor(s) that caused the crash and those that contributed to its severity. In the end, about 420 traffic crashes in one county of Indiana were investigated at the “third” or

most detailed level. While the Indiana tri-level approach has been considered successful, it is not often emulated because of the heavy commitment of experts in a number of disciplines required.

At least two observations may be made about the method of assigning causes by expert analysis of traffic crashes. Since traffic crashes do not occur in an experimental setting, it is impossible for the analyst to control all relevant factors. In an experiment, the researcher can control relevant factors and then vary the factor of interest and observe the effect. If dependent variable Y varies with independent variable X and all other factors are held constant, then X may be said to “cause” Y. But the experimental approach cannot be used in studying traffic crashes for moral, ethical, and legal reasons. Instead, crashes occur, investigators sift the events for clues, and then causes are determined. But this approach is inevitably subjective, biased by the fact that a crash did occur. While the causal determinations can be extremely plausible, they cannot be verified.

The second observation to be made is that the approach requires a heavy investment in expertise for each case. Psychologists, civil and mechanical engineers, and crash reconstructionists were all employed. Only about 420 cases over four years were completed at the most in-depth level. A similar effort to cover a nationally-representative sample of heavy truck crashes would be very difficult and prohibitively expensive to execute.

National Transportation Safety Board case approach

Another approach to studying heavy truck crashes is the National Transportation Safety Board (NTSB) case approach. In these studies, individual truck crashes are investigated extensively, sometimes by a team of experts. The team typically produces a lengthy crash report, detailing the findings. In some cases, a number of similar crashes will be studied together, as for example a study of truck crashes related to tire failure a number of years ago. Essentially the methodology is for the team of experts to study the crash intensively until the reason for the crash is discovered.

While this approach results in a thorough understanding of particular crashes, it is less useful in understanding truck crashes as a general traffic safety problem. First, the selection of particular crashes to study is not the product of systematic sampling, but is a matter of convenience or on some other ground. However selected, there is no context in which to put the NTSB-

investigated crashes. If low inflation pressures are identified as the cause of the blowout that led to the crash, without a systematic sampling scheme one has no idea if this is a widespread problem, or unique to the crash investigated.

The second problem with the NTSB method is that it does not appear that investigators approach each crash with a systematic framework that is applied to all crashes. There appears to be no common set of data elements that is collected for all crashes investigated, no set of rules that guides the effort. This may be appropriate since each investigation essentially stands alone, but the lack of a systematic selection of crashes or a consistent investigative approach makes generalizing from the findings impossible. No database accumulates the results—each is unique.

The LTCCS approach

The LTCCS relies on a statistical approach to “causation,” defining cause in terms of relative risk. A statistical view of causation has two elements, both of which are necessary. The first element is a statistical association between crash types and factors of interest. One analytical technique will be to show that certain factors are over-represented in certain crash types.

Association is not causation, however. Statistical association itself does not indicate the direction of the causal arrows, as it were. The second element necessary to establishing a “causal” relationship is some plausible mechanism to explain how the factor relates to the crash. By providing detailed information about the physical events of a crash, data in the LTCCS will establish the necessary link between the statistical association and the physical mechanism that explains the association.

The methodology of the LTCCS collects some of the same types of data as the Indiana tri-level study, but takes an alternative approach to determining “causation.” Rather than crash experts assigning causes to each crash, the LTCCS approach is based on statistical associations in the aggregate data. The crash assessment data provides information on what physically happened in the crash, including prior movements of each vehicle, the critical event in the crash, and the reason for the critical event. Basically all of the other data in the LTCCS provide the context, by providing a detailed description of the environment (road type, time of day, weather, road conditions, etc.), vehicle (weights, lengths, cargo, truck inspection, etc.), and driver (experience, driving record, fatigue, hours of service, etc.). “Causes” can be determined through the analysis

of this information, by identifying associations between vehicle, driver, and environmental characteristics, and particular crash types or modes of involvement.

This approach will produce a great deal of information about what happens in truck crashes. There are many hypotheses about how various factors increase the crash risk. Many “risk increasing factors” work through physical mechanisms. Since the way the crash physically occurred is known, statistical tests can show if a particular “risk increasing factor” was overinvolved in the kind of crash where the physical mechanism could be expressed. For example, the LTCCS data will provide information about the condition of the trucks’ braking system. Crash type coding can be used to distinguish rear-end crashes in which the truck was the striking vehicle from those in which the truck was struck. Hypothesis: trucks with poor braking are overinvolved in rear-end crashes in which the truck was the striking vehicle. Using the LTCCS data, this hypothesis can be tested and the conditional probability estimated of rear-end crash involvement of poorly-braked trucks.

So did poor brakes cause these crashes? This raises directly the meaning of the word “cause” in a non-experimental context. What is a “cause?” In the Oxford English Dictionary, the first definition of “cause” is “That which produces an effect; that which gives rise to any action, phenomenon, or condition.” This definition implies something like, “if a change in X produces a change in Y, X is said to be a cause of Y.”

One can observe that there is also a W that caused X, a V that caused W, a U that caused V, and so on. Every cause is itself the result of some prior cause or causes. There is no such thing as an absolute cause for an event, the identification of which satisfies and completes all inquiry. The alphabetic example just given implies a “causal chain,” but a more appropriate metaphor might be a network, since the system of cause-effect can have multiple dimensions.

Take, for example, a case that seems relatively clear-cut and simple: A tire blows out and a vehicle swerves into oncoming traffic where it collides with another vehicle. Is the blowout the cause of the resulting crash? Investigation reveals that the tire was defective. Is the defect the cause of this crash? The tire was under-inflated, allowing heat to build up and making failure more likely. Is maintenance the cause? The defect occurred because a worker made a mistake in manufacturing the tire. Is the worker the cause? Quality-control procedures failed to catch the

defect. Is a poor system of quality-control the cause? And so on. But let us return to the critical event. The tire blew and then the driver lost control of his vehicle. Some experts believe that proper driving techniques may allow drivers to safely stop a vehicle with a blown tire. So is inadequate driving skill the real cause here? Or the failure in licensing procedures for not requiring this skill? In driver instruction for not teaching it? But let's back up again. The vehicle is of a particular design, for example, a particular model sport utility vehicle. The design of the vehicle is such that tire failures are more frequent or the vehicle is less controllable than others if a tire fails. So is the cause of this crash vehicle design?

Let us now move in the other temporal direction, the events that follow the blowout. We've described a network of influences that produces a vehicle, out of control, with a deflated tire. Does a crash follow? Sometimes out-of-control vehicles come safely to rest. Other times there happens to be an old trash can or a small tree in the way of the skidding vehicle. And then again, there are times when the tire happens to blow just as a fully loaded tractor-semitrailer is passing in the other direction. In each case, the outcome of the event can be dramatically different, depending on factors entirely extraneous to the deflated tire, and may even result in no crash at all.

This seemingly simple example makes two points. First is the loaded problem of identifying causes. After the First Cause, every cause is the effect of some prior cause. How far to go back through the chain, or more accurately, out through the net of cause-effect is essentially an arbitrary decision.

The second point is the inherently probabilistic nature of traffic crashes. Some of the most obvious "causes" of crashes do not invariably produce crashes, thus presenting the logical problem of a "cause" without an "effect." Alcohol obviously increases the risk of crash involvement, yet many intoxicated drivers safely navigate home every Saturday night. Running through traffic lights or stop signs are high risk behaviors, yet most do not result in a crash. These are examples of "causes" without "effects."

With such clear-cut, well-accepted causes of crashes, why no crash? The reason is the myriad of other contingencies required to produce a crash. For crashes involving more than one vehicle, something has to get another vehicle to that same bit of the space-time continuum for a collision

to occur. In the case of a stop-sign runner who escaped unscathed, fortunately there was no one on the crossing road exercising his right of way at just that instant. There easily could have been. But it just so happened that no one ten minutes before (not 10 minutes and one second or nine minutes and 59 seconds, but exactly ten minutes) had to run out for a gallon of milk, or had a class to get to, or decided on a whim to go out for a ride and was feeling somewhat distracted.

So the various bad behaviors, driving errors, poorly maintained vehicles, and dangerous road conditions do not *cause* crashes, but they do *increase the risk* of crashes. A driver who ran a stop sign may not have collided with crossing traffic, but a collision is certainly much more likely running a sign rather than stopping for it. Similarly, drunk driving is much riskier than sober, even if most trips are completed safely.

The approach of the LTCCS is consistent with the probabilistic nature of traffic crashes. Analysis of the data will proceed by searching for associations between the various descriptive variables and involvements in particular types of crashes. The broad range of factors included will permit a wide range of hypotheses to be tested.

The methodology of the LTCCS also avoids the problem of determining causes for each crash. This is inherently subjective, as the authors of the Indiana study acknowledge. They also point out that there is a bias in evaluating whether a factor was “necessary” to the crash, since the crash did in fact occur. [2, page 20] This should not be taken as undue criticism of the Indiana study. The area is a very difficult one. The Indiana study has been very useful in the development of the LTCCS. Their system of driver factors has been adapted for the LTCCS. However, the Indiana study has been criticized both for logical problems with the definition of “cause” employed and for the somewhat tautological nature of some of the causes assigned. [3, pages 44-45.] The representativeness of the study area is also problematic. The LTCCS is an alternative method, also with strengths and limitations. There is no single methodology that is appropriate for all questions.

Methodology

The LTCCS is essentially a *collision-avoidance* or *crash-prevention* study. The study is focused on pre-collision events rather than injury consequences. The purpose is to increase knowledge of

the factors associated with heavy truck crashes. With greater understanding of the events and conditions that lead to crashes, it should be possible to devise strategies to decrease the frequency of heavy truck crashes.

The choice of data to collect was guided by the assumption that a wide variety of factors are associated with truck crashes. Accordingly, the net was cast broadly. Data collected include a detailed description of the vehicle and its condition, driver condition and experience, information about the motor carrier and type of trucking operations, and the environment at the scene of the crash. Similar and appropriate data is collected also about the non-truck vehicles and nonmotorists involved in the crash. A deliberate attempt was made to include sufficient information about vehicle, driver, and the environment so that the contribution of each could be legitimately assessed.

The focus of the data collection is on pre-crash events, rather than post-crash. Data is collected about injuries and damage, but the purpose of these data is primarily to characterize the nature of heavy truck crashes and put them in context, rather than to support, for example, a search for injury-mitigation methods.

Cases for investigation will be selected by a multistage, random selection procedure that will produce a nationally-representative sample of trucks involved in traffic crashes with serious or fatal injuries.

The approach to both data collection and analysis is structured around the view of traffic crashes as probabilistic events. The heart of the approach is to provide a good description of the physical events that lead to crashes. In this, the LTCCS adapts the method of coding accident events outlined by Kenneth Perchonok [4]. The critical event, defined as the event that immediately precipitated the crash, is determined. The immediate failure that led to that critical event, the critical reason, is also determined. A wide variety of descriptive factors is also collected on the vehicles, drivers, and environment. At this stage, no determination is made as to whether the factors are related to the events. The data collected is purely descriptive. The factors are either present (present in a certain quantity), or not. In fact, at no point in the coding of an individual cases will the relationship between a certain factor and a particular crash be determined. Instead,

later statistical analysis of aggregate data will show the relationship, if any, between particular factors and particular types of crashes.

Critical Event

The “critical event” is the starting point for the data collection, as it is for the analysis. All the other data essentially builds out from the critical event. One and only one critical event is determined for each crash. The critical event is defined as the event that immediately led to the crash. It is the action or event that put the vehicles on a course such that the collision was unavoidable given reasonable driving skills and vehicle handling. [4, pp. 7, 11-13]

Examples:

- A car veers into the opposing lane and collides head-on with a truck. The critical event is the car’s movement into the truck’s lane. Veering into the truck’s lane of travel put the vehicles on a collision course.
- A truck turns across the path of an oncoming car at an intersection. The critical event is the truck’s turn across the path of the other vehicle.
- A truck fails to slow down for slower or stopped traffic. The critical event is the failure of the truck to slow down for the traffic. (If, on the contrary, a vehicle in front of the truck suddenly slammed on its brakes and the attentive truck driver could not react in time, the critical event is the sudden braking by the lead vehicle.)

The critical event is coded without regard to legal fault or culpability. Right of way is captured separately. The critical event is determined to the extent possible from the physical movement of the vehicles. Critical event can be difficult to assess in some crash configurations. For example, in the case of same direction collisions, such as rear-ends, if the striking vehicle is always coded with the critical event, then the critical event adds no more information beyond that the crash was a rear-end collision. The definition of critical event has two primary components: 1) it is the action that put the vehicles on a collision course; and 2) the collision could not be avoided by normal driving skills or vehicle handling properties. But there can be difficulty in determining

whether the following vehicle had time to stop or evade, or whether the following vehicle was following too closely to respond safely to the actions of other road users.

Note that the critical event is not the “cause” of the crash.

Critical Reason

The critical reason is the immediate reason for the critical event. It is the failure that led to the critical event. [4, pp. 8, 13-17] The list of critical reasons covers driver decisions and conditions; vehicle failures; and environment conditions, including weather, roadway condition, and even highway design features. The list of critical reasons was constructed deliberately to permit the choice of any of the three primary categories of contributors—vehicle, driver, or environment.

Examples:

- A car drifts into the opposing lane and collides head-on with a truck. The critical event is the car’s movement into the truck’s lane. The car driver was fatigued and had fallen asleep. The critical reason is “sleep, that is, actually asleep.”
- A truck turns across the path of an oncoming car at an intersection. The critical event is the truck’s turn across the path of the other vehicle. The truck had the turn arrow and observed the on-coming vehicle, which he assumed would stop. The critical reason is “false assumption of other road user’s actions.”
- A truck fails to slow down for slower or stopped traffic. The critical event is the failure of the truck to slow down for the traffic. Most of the truck’s brakes were out of adjustment and when the driver attempted to stop, his brakes failed. The critical reason is “brakes failed.” If instead, the truck was following so closely it could not stop safely even with properly functioning brakes, the critical reason would be “following too closely to respond to the actions of other road users.”

The critical reason is not intended to establish the “cause” of the crash, though many of the code levels look like causes. But that is not the intent of the variable, and using the variable in that way both misconstrues the variable and can mask the range of contributing factors. In the second

example above, it would be clearly inadequate to say that the cause of the crash was the truck driver's exercising his right-of-way. More plausible interventions can be suggested by factors relating to the other driver. Right-of-way is captured in the data, so this avenue can be explored. And while in the last case, "brake failure" seems like a satisfying "cause" of the crash, the design of the LTCCS methodology permits more remote factors relating to the brake problem to be evaluated. For example, brake problems might be associated with responsibility for maintenance or carrier type or vehicle type. Those factors may in turn suggest targeted interventions to reduce the incidence of brake failures and associated crashes.

In other words, analysis of the data is not completed by an enumeration of the critical reasons assigned. Instead, the critical reason should be used as another bit of evidence of what happened in the crash. For example, in the case of the truck driver who exercised his right of way and turned in front of approaching traffic, the critical reason "false assumption" indicates that the driver saw the on-coming traffic and did not verify that the vehicle was going to stop.

Some researchers specifically object to "causes" such as "false assumption," in part because most of the time the assumption is warranted. [3, p. 45] But this difficulty can be resolved in how the variable is used. The critical reason is not the "cause" of the crash. It is the immediate failure that led to the critical event. The critical event is determined independently, to the extent possible, of the legal system. In the example given, the critical event is the turn, since that act put the vehicles on an unavoidable collision course. The critical reason is the explanation for the turn. If the driver saw on-coming traffic and thought it was going to stop, then "false assumption" is the logical explanation for the turn. The error is not in selecting the code, but in interpreting the selection as answering the "causal" question.

Associated Factors

A wide range of data is collected on a variety of factors. No judgment is made as to whether the factor is related to the crash. Investigators objectively record the presence or absence of the various items.

The list of factors was intended to serve two functions. The first is to provide enough information about the crash to describe it completely, permitting the range of crashes in the

LTCCS to be put in the context of other crash files and allowing the selection of meaningful subsets of cases for analysis. This can be as simple as selecting crashes by maximum injury severity in the crash or testing the representativeness of the distribution of involvements in the LTCCS against other national files.

The second function of the list of associated factors is to provide information on a wide range of factors that have been thought to be related to crash risk. For example, it has been suggested that different types of motor carrier operations may have different risks of involvement in fatigue-related crashes. Much more detail on motor carrier operations is collected in the LTCCS than is available in any other crash file. Data in the LTCCS can be used to test if, for example, truck-load carriers are overrepresented in fatigue-related crash involvements.

Analysis of the data

The LTCCS will provide much more information about truck crashes than is now available elsewhere. The events of the crash will be described in much richer detail than in any other crash data file. The LTCCS will supply unprecedented detail about the types of motor carriers, methods of payment to drivers, incidence of fatigue, recent sleep schedule, mechanical condition of vehicles, and so on for a nationally representative sample of trucks in traffic crashes. What can these data be used for? What kind of analyses can they support? These data can be used for several different types of analyses, including descriptive statistics and conditional probability calculations.

Some of these uses will be illustrated here using similar data collected by the Michigan State Police. The Motor Carrier Division (MCD) has a continuing program to collect data on fatal commercial motor vehicle (CMV) crashes in Michigan, called the Fatal Crash Complaint Team (FACT) program. The approach is similar to that of the LTCCS, though there are important differences. Since the MCD has primary responsibility for enforcement of CMV regulations, the FACT program focuses on trucks rather than passenger vehicles. Accordingly, relatively little data is collected on non-truck vehicles in the crashes. Crash type and critical event variables are similar to those in the LTCCS, but critical reason is not coded. The LTCCS collects data on the associated factors in greater depth. The FACT program also is restricted to traffic crashes in

which at least one fatality occurred. However, some of the results from the FACT file can shed light on the range of analyses that the approach can support.

Distributions of events and factors

Table 1 shows recent results from the FACT data on trucks involved in fatal crashes. Just as in the LTCCS, each truck is subject to a North American Standard level 1 inspection by a CVSA-trained inspector. These inspection data are much more thorough and reliable than the vehicle defect data in virtually any other crash file. Inspectors record the condition of the vehicle prior to the crash, to the extent that can be determined. Crash damage is excluded. As an item, note that over one-third of the trucks involved in a fatal crash in Michigan would have been placed out of service if they had been inspected prior to the crash. Some type of brake problem was found in over 31% of the trucks, and violations of the light/marker/signal regulations were found in almost 25% of the trucks. Brake-related inspection items are aggregated here; more detail is available about the nature of the violation and the unit of the combination where the violation occurred.

Table 1 Inspection results: All trucks that were inspected MSP FACT data	
Inspection item	%
All log violations	13.0
All hours-of-service	3.0
All other driver violations	18.1
All brake problems	31.4
All lights/markers/etc	24.2
All air pressure/hose problems	9.4
All tire problems	14.2
All steering axle problems, including brakes	13.9
All suspension problems	10.0
All violations	65.9
All OOS items	33.8

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

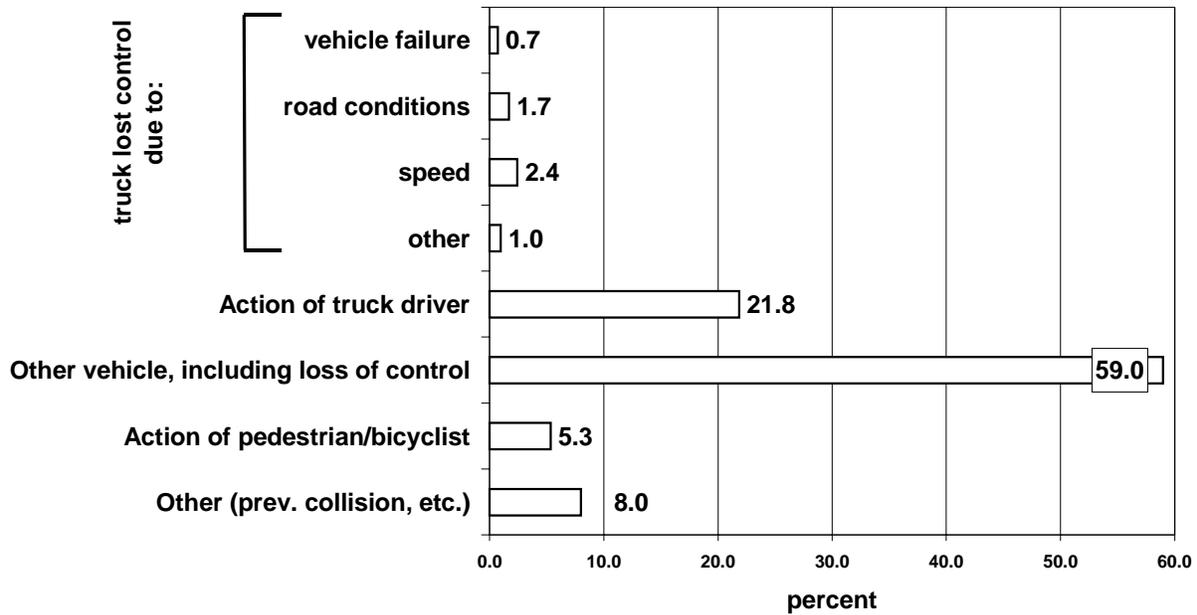
Condition	%
Alcohol	0.97%
Illegal drugs	1.93%
Fatigue	2.90%
Unfamiliar with area	1.21%
Driver inexperience	2.66%

It has been hypothesized that truckload carriers, at least small truckload carriers, have a higher incidence of fatigue-related crashes because of their irregular and unpredictable schedule of operation. Currently, the only crash database available that records carrier type is the Michigan FACT data. Table 3 shows the distribution of carrier type in the FACT data. Note that over 41% of motor carriers in a FACT crash were for-hire, truckload carriers, while only 7.1% were less-than-truckload.

Carrier type	%
LTL	7.1
truck load	41.5
private	38.7
other	5.3
unknown	7.4
total	100.0

In only about 3% of truck drivers in the FACT data was there evidence of fatigue, but fatigued drivers were distributed unequally across carrier types. No driver for a private carrier in the FACT data was fatigued, and fewer than 4% of the drivers for truckload carriers were judged to be fatigued at the time of the crash. But fatigue was recorded for almost 15% of drivers for LTL firms in the FACT data. The data are too sparse to draw conclusions with respect to carrier type and fatigue, but they are not consistent with the hypothesis. Some measure of exposure would be ideal, but merely the distribution is interesting and even suggestive. The LTCCS will provide a much more detailed description of the truck crash population than is available anywhere else.

Finally, the FACT data records a critical event that is very similar to the approach taken in the LTCCS. Figure 1 shows a distribution of broad categories of critical events recorded for fatal truck involvements investigated by the FACT team. Again, these descriptive statistics are valuable, purely for the insight they provide into the problem of heavy truck safety. At least as a first cut, the figure gives a general guide to where to look for countermeasures to reduce the incidence of truck crashes.



**Figure 1 Critical Event
FACT data**

Relative risk: involvement ratios

The most interesting way these data can be used is in testing hypotheses through conditional probability calculations. A primary component of the LTCCS methodology is to establish a relatively detailed picture of what physically happened in the crash. By incorporating this detail into the analysis, 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 others. Using the LTCCS data, one can essentially calculate conditional probabilities to measure the relative risk of involvement of driver or vehicles with certain properties in crashes where those properties should pose additional risks as compared to other vehicles/drivers without those properties.

Take, for example, hours of service (HOS) violations. HOS violations themselves do not cause crashes, just as night does not cause crashes or even excessive alcohol use. Each factor operates through a mechanism. The LTCCS will provide detail about what happened in the crash. Appropriately designed analyses can then test for over-involvement of HOS violations in that part of the crash population where they are expected. And we would not expect to find HOS

violations (or not as many) in the part of the crash population where they should not be part of the causal mechanism.

If crash-involved truck drivers with HOS violations were all in vehicles stopped at a red light, rear-ended by another vehicle, there could be an overinvolvement of drivers with HOS violations, but our knowledge of the details of the crashes would make the overinvolvement appear to be spurious. On the other hand, if 30% of drivers in single vehicle crashes at night had HOS violations, compared with 20% for multiple-vehicle crashes at night, that would be consistent with the notion that HOS violations played a role in the crashes.

The FACT data provides a useful example of a relative risk calculation. To test for the association between brake violations and crashes, crashes were identified in which braking is likely critical. These crashes include rear-end crashes and crashes where the vehicles were on intersecting paths or changing trafficways (basically intersection crashes where the vehicles were on different roadways or one was turning onto a different roadway). The role of braking in rear-end crashes is clear. Intersection crashes are included because of the observation made while reviewing cases that in some crashes the truck driver decided to go through a light on yellow (or red) because he knew he didn't have enough braking to stop for the light. This led to the idea that the effect of poor brakes can include the decision not to use them at all, as well as increased stopping distances. Braking is the primary collision-avoidance method at intersections just as it is in rear-ends.

Currently, the "brake-related" crash type includes 135 involvements in the FACT data. In table 4 below, cases are divided into those where the truck violated the right-of-way (striking vehicle in a rear-end or went through the light/stop sign in the intersecting paths crashes), and those where the truck did not. In the cases where the truck had the right of way, brake condition is not immediately connected to the crash. Where the truck did not have the right-of-way, brake condition is relevant to the crash. The top half of the table shows frequencies, the bottom column percentages.

Table 4 Brake violations and braking-critical crashes			
MSP FACT data			
brake violations	other braking critical	truck braking critical	total
none	68	24	92
one or more	23	20	43
total	91	44	135
none	74.3%	54.5%	68.2%
one or more	25.7%	45.5%	31.2%
total	100.0%	100.0%	100.0%

Chi-square=5.56, 1df, prob=0.018.

Cases where the braking capacity of the truck was critical in the crash were 1.8 times more likely to have a brake violation. Roughly half had brake violations, compared with 26% of trucks involved in the same crash type but where their braking was not relevant.

One explanation for this result could be that “at-fault” trucks are poorly operated and maintained and therefore the association of brakes and “at-fault” in the crashes reflects poor operations rather than the mechanical association that is hypothesized. The relationship of each of inspection categories listed in table 1 above was tested against violating the right-of-way in “brake-related” crashes. None of the items showed any statistically significant association. Log violations showed a similar magnitude of effect, but there are insufficient cases for the association to be significant. There could be an effect for lights, but the effect is the opposite as for brakes (trucks with light/marker violations are more likely to be the vehicle with the right-of-way), the effect is not significant, and the likely causal mechanism there is conspicuity.

Thus, the analysis shows that brake violations are statistically associated with being the “at-fault” vehicle in crashes where braking is important. The association is statistically significant, of significant magnitude, and supported by a physical mechanism. This demonstrates a link between vehicle condition and crashes in trucks. The FACT data is the first data where this is possible. NTSB has done special investigations showing the link in specific crashes, but those findings are not generalizable to the crash population, while these are. The LTCCS will support precisely this type of analysis.

Limitations to the LTCCS approach

Though the purpose of this note is to argue for the usefulness of the LTCCS approach, it is important to recognize its limitations and to contrast the LTCCS approach with other methods. Each has particular strengths and weaknesses. Each can answer certain types of questions and is not suited to others.

Absolute risk using VMT or some measure of exposure

An analytically attractive approach is to calculate risks in terms of crash rates for factors of interest using appropriate measures of exposure. Exposure provides an explicit control, and allows absolute rates to be calculated, not risks relative to something else or conditional on crash involvement. The most common measure of exposure is vehicle miles traveled or VMT, though other metrics are in some cases more appropriate. With the appropriate measure of exposure, one could calculate the number of crash involvements per the unit of exposure, and compare the resulting rates for the factors of interest. In theory, virtually any factor could be evaluated by this means, as long as an appropriate unit of exposure could be determined and measured.

One of the weaknesses of the LTCCS approach is that it cannot evaluate factors that operate to raise crash probabilities across all subsets. For example, it is known from other work that Interstate highways have the lowest fatal involvement rates in the highway system, while rates on major arterial roads are considerably higher. While differences in collision types will be readily identifiable, the higher overall crash risk on some road types cannot be detected using crash data alone.

Exposure data, however, can be very difficult and expensive to collect, often much more so than the crash data they are used with. In a study as broad-ranging as the LTCCS, it is hard to imagine a single exposure survey that could provide appropriate data for all the different components. The LTCCS includes data on vehicle configuration, vehicle, weather, driver and road conditions, company type and size, and so on. An exposure study that can simultaneously handle all those factors, and more, would be a mammoth undertaking. And what is the proper unit of exposure for a driver operating under pressure? However, the LTCCS will provide an accurate and detailed numerator for any exposure data that becomes available.

Alternative approaches with LTCCS data

Finally, it should be noted that the data produced by the LTCCS can support other methods of assessing “causation.” The approach of the LTCCS is to collect and preserve extensive objective information about pre-crash events and detailed information about all parties in the crash. This information will be available for review by experts. For example, the Indiana tri-level “but-for” test could be applied after the fact, and “causes” assigned based on that approach to causation. Other methods of assessment of causality or countermeasures could also be supported. A strength of the LTCCS approach is to preserve accurate detailed information that does not foreclose subsequent reinterpretation.

Justification: Why take this approach rather than some other?

There are two fundamental justifications for taking the proposed approach. The first is that it is the appropriate approach for a very broad study given the current state of knowledge about truck crashes. Compared with passenger vehicles, heavy truck crash research has been neglected. For example, there is no good estimate of the number of truck drivers in the country. The best estimates for the number of trucks and trailers comes from the Vehicle Inventory and Use Survey, (formerly the Truck Inventory and Use Survey) which is conducted only every five years by the Bureau of the Census. Estimates of vehicle miles traveled are limited to those published in Federal Highway Administration’s *Highway Statistics*, which breaks down truck travel by only two truck configurations and roadway function class. In terms of crash statistics, trucks were dropped from the National Automotive Sampling System Crashworthiness Data System (NASS CDS) sample in 1986. The NASS General Estimates System (NASS GES) has since increased its sample of trucks, but includes only data generally available from police reports. The accuracy of its identification of trucks is unknown. The Trucks Involved in Fatal Accidents file from the University of Michigan Transportation Research Institute (UMTRI) provides a good identification and description of trucks, but the file covers only fatal crash involvements.

When completed, the LTCCS will provide a good description of the landscape of serious heavy truck crash involvements. It will provide vastly more detail in virtually every area than is now available about truck crashes. We will know much more about the types of motor carrier operations represented in traffic crashes, the mechanical condition of the trucks, the status of the

drivers, and the types of crashes they are involved in. This will provide a good roadmap to further research, in some cases using the case materials collected for the LTCCS. For example, in the crash types in which brake condition was found to contribute, all those cases could be examined to determine the nature of the braking problem, whether slack adjustment, maintenance, air pressure, or some other factor.

As another example, the LTCCS will provide context and perspective on fatigue studies, measuring the size of the fatigue contribution for both truck drivers and non-truck drivers. There may be associations with types of trucking operations, maybe even associations between recent sleep schedules and types of crashes/crash precursors. This information would then provide the background for a more in-depth study of the role of fatigue.

The second justification for the approach taken in the LTCCS is feasibility. The experience of the Michigan State Police FACT team shows that this type of data can be collected with reasonable quality and at a reasonable cost. The FACT program is not perfect, the LTCCS will be more comprehensive, but the FACT data has already provided valuable insights into the problem of heavy truck crashes.

The primary next step beyond the LTCCS is to add an exposure component. But providing some measure of exposure for all the factors covered in the LTCCS is almost impossible to conceive, much less finance and execute. However, the data produced by the LTCCS may provide its own impetus for the collection of selective exposure data. This will happen in two ways. The first is that the “roadmap” to heavy truck crashes generated by the LTCCS will provide guidance as to the type of exposure information that is necessary. If vehicle condition is shown to be a considerable factor, then an appropriately randomized truck inspection study might be useful. On the other hand, if less-than-truckload drivers are much more likely to be involved in fatigue-related crashes, then exposure data of a different sort is called for.

Secondly, some results of the LTCCS will just cry out for exposure data, and thus provide a needed stimulus for its collection. With the great increase in detail about the type of trucking operations involved in traffic crashes, there could be a movement to increase the data available about population of truck operators. Some of this additional information could be readily added to at least a sample of the MCMIS carrier file and thus provide exposure data for the LTCCS.

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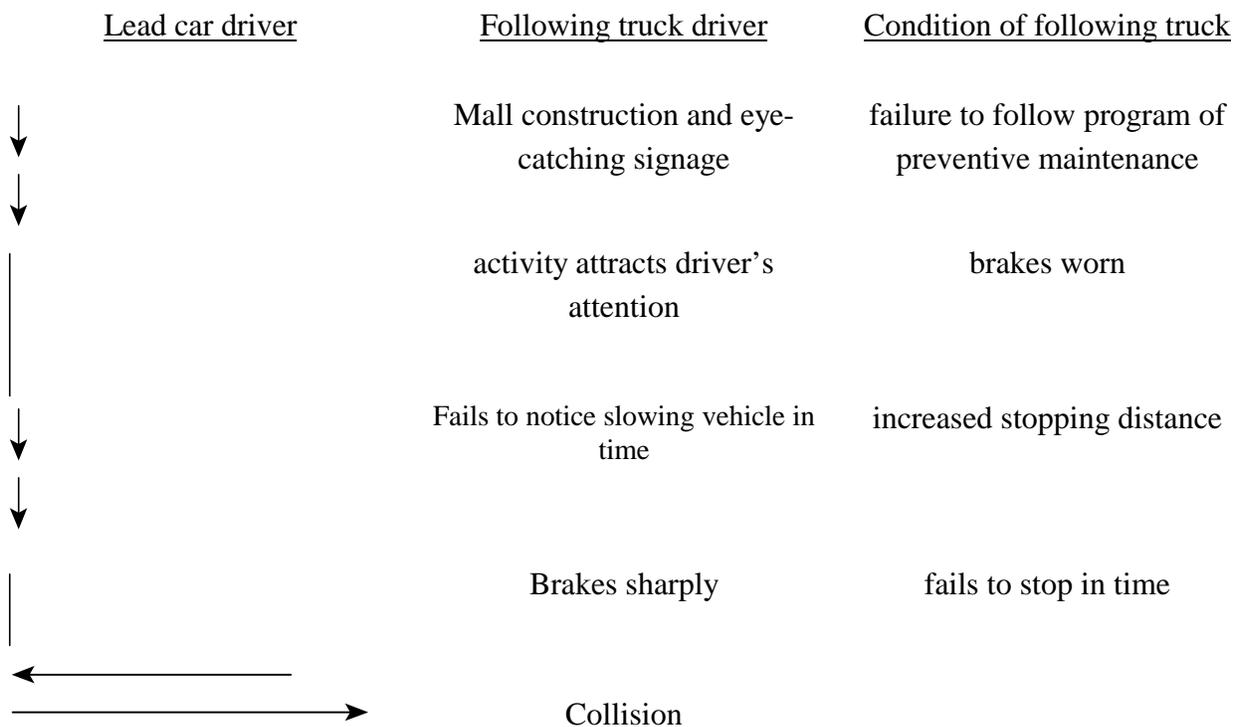
Appendix C

FMCSA Statement of Approach for Coding In-depth Accident Investigation Reports

The conceptual model for the in-depth accident database is taken from Kenneth Perchonok in *Accident Cause Analysis*. Perchonok describes traffic accidents as the product of causal chains, where events are linked to one another in a cause-effect relationship. Each effect serves as a cause for the next link in the chain.

Crash Event Chains

Consider a simple rear-end collision (this example is modeled on an actual fatal crash involving a heavy truck). The lead vehicle slowed to turn left into a driveway of a store's parking lot. There was no turning flare or center-left lane, so the car was slowing in the through-traffic lane. The truck driver of the following vehicle noticed some construction to his right in a mall and a sign advertising a two-for-one special at a fast food restaurant. He did not recognize that the lead vehicle was slowing until he was too close to stop safely. He braked, but couldn't stop in time and struck the lead vehicle in the rear. Cause-effect chains can be illustrated for the driver of the lead car, the driver of the following truck, and the following car itself in the table below. The arrows show the causal direction:



Each cause is itself the effect of some other cause. And the cause-effect chain could be extended indefinitely for each of the three factors. But all of the factors listed above had to come together to produce this particular crash. If the truck's brakes had been in better shape, it may have stopped in time or at least not hit as hard. If the trucker had been paying more attention to the roadway ahead, he would have noticed the car in front slowing. If there had been no lead car, there would have been nothing for the distracted driver to crash into. If there had been a turn lane, the car would have been out of the line of traffic. If the lead driver hadn't decided to shop at that particular store, he wouldn't have gotten into the other driver's way. And so on. Some of the examples are trivial, but the point is that traffic accidents are complex events and many things have to be present at the same time for a crash to occur.

Thinking about traffic crashes in terms of multiple cause-effect chains has two principal advantages:

First, it corresponds with our intuitive understanding of traffic accidents as complex events, in which many factors can play a role. We are not trying to find a single "cause" of a traffic accident. To use the rear-end collision above again: What is the cause of this accident? Inattentiveness by the driver of the following vehicle? Following too closely? Insufficient braking capacity? Poor maintenance? Insufficient friction from the roadway? Roadway design not up to the increased flow of traffic because of the development of the mall? Poor driving technique since he didn't attempt to steer around the stopped vehicle? Slow reaction time? The distracting signs? Many factors *contributed* to the occurrence of the accident. Which one is the *cause*? Identifying the range of factors that contributed to the crash better captures what happened than simply listing "driver inattention" or "brakes out of adjustment" as the cause.

Second, approaching traffic crashes as the product of multiple chains of events gives us a broader perspective on crash prevention. Once you start thinking about crashes as the product of many factors, you can more easily identify a variety of different ways to prevent the crash or to lessen its severity. In the example above, a better brake maintenance program might have helped lessen the severity of the crash. A forward obstacle detection system might have alerted the driver in time. Defensive driving training might have improved the driver's response. Better roadway design might have moved turning traffic into a dedicated lane, improving traffic flow.

The Critical Event

Perchonok used the concept of the *critical event* to organize the coding of accidents. He defined the critical event as the event after which the collision was unavoidable. The critical event is the action or failure to act that puts the vehicles on a course so that the collision cannot be avoided given the proximity and relative velocities of the vehicles. Turning in front of oncoming traffic can be a critical event, if there wasn't time to stop or steer around the turning vehicle. Pulling out

in front of a vehicle can be a critical event, if there was no time to stop. The critical event “causes” the accident in a physical sense because, given the mechanical properties of the vehicle and roadway, there was no chance to avoid the crash after the critical event occurred.

The critical event essentially gives the researcher a place to start in analyzing a traffic accident. The idea is to start with the event after which the accident was inevitable and then build the description and related factors from that point.

The *critical reason* is the reason for the critical event. It is the “cause” of which the critical event is the result. The critical reason is the failure in the vehicle, driver, or environment that explains the critical event. For example, a driver falls asleep and runs off the road. The critical event is running off the road. The critical reason is falling asleep.

While the critical reason may be conceived of as the immediate cause of the accident, a number of other factors may be important. It is easy to imagine that for any particular critical reason, a variety of factors are related, and for each of those factors, there is another set of factors. Accordingly, a wide variety of factors are considered for in-depth accident reports.

On the other hand, it is true that the chains of events could be extended indefinitely. There is no point in the chain at which, purely from logic, all factors that conceivable could be related have been covered. So, while the list of related factors is intended to be comprehensive, it covers the current understanding of risk factors for truck crashes and the range of interventions currently considered feasible.

Sources and Variables used for the Critical Event and Critical Reason

The proposed in-depth accident database is composed of ideas and variables taken from a variety of sources. The overall concept of accident event chains is taken from Perchonok, and following him, from a methodology described by James Fell. The actual code levels for the critical event are borrowed from the National Highway Traffic Safety Administration’s General Estimates System (GES). GES includes five related variables that describe the action of the vehicle prior to the critical event; the critical event; corrective action taken; vehicle control after the corrective action, and the vehicle’s path after the corrective action. The GES code levels are comprehensive. Using these variables will allow comparisons with results from GES.

Coding for the critical reason essentially follows the framework of the Indiana *Tri-Level Study of the Causes of Traffic Accidents*. The *Tri-Level Study* groups related factors into driver, vehicle, and environment. For our purposes, the most important set of factors taken from the *Tri-Level Study* are those for the driver. The four primary categories of driver critical reasons are “critical non-performance,” recognition errors, decision errors, and performance errors.

Critical non-performance is a “catastrophic interruption in the driver’s performance,” such as blacking out, falling asleep, or a heart attack, that removes the driver from any further active participation in the accident. Recognition errors include various failures to perceive or comprehend available information in a timely fashion. Decision errors are conscious decisions on vehicle control that put the driver into a situation that he could not recover from. Some of these codes have the potential to be circular. For example, “following too closely” is another way of saying “struck lead vehicle in the rear.” But here the intent is to capture situations where a steady following distance had been established prior to the critical event, but the following distance was so short that an unexpected action of the lead vehicle immediately created a critical event. The final category, performance errors, refers to inadequate skills in controlling the vehicle.

Note that the critical reason is coded for both the truck and truck driver as well as the other vehicle and other vehicle’s driver.

The critical event refers only to the physical movement of the vehicles involved, not which vehicle had the right-of-way at the time of the accident. There will be cases where a vehicle is assigned the critical event, yet had the right-of-way at the time of the crash. For example, a vehicle turning left on a green arrow in front of on-coming traffic had the right-of-way, but also committed the critical event in that the turn put the vehicles on a collision course. In order to address these cases as well as to sort out an important element of traffic crashes, an additional variable has been added. The variable simply records which vehicle had the right-of-way at the time of the accident. Perchonok addresses the issue with the concept of “culpability.” A driver is “culpable” if he violates the expectations of a normal driver. This is reformulated here in terms of right-of-way, which can generally be determined at the scene, either from the physical configuration of the accident and its location, or established by witnesses.

Related Factors

Following the critical event and critical reason variables is a long list of “related factors.” These related factors capture important characteristics of the driver, vehicle, and environment. The items on the list are taken from previous studies of accident causation and they have either been shown to increase crash risk or there are good theoretical reasons to think that they may increase crash risk. The point here is to consider all parts of the crash, i.e., the driver, vehicle, and environment and record the presence of any of the factors.

It is important to understand that, in this section, we are recording all factors present, *regardless of whether they contributed to this specific crash or not*. In practical terms, it is often not possible to determine all factors that contributed to a particular crash. The resources required are not available or the effect of the factor itself cannot be determined after the fact. For example,

fatigue can have effects far beyond just falling asleep and running off the road. It can slow perception and reaction time, or cloud judgment. In a particular accident, fatigue *may* cause a driver to misjudge his speed or slow his perception of the movements of traffic ahead, but the evidence in a particular case is often not strong enough for the investigator to identify fatigue as causal in the crash.

At the same time, coding factors where the connection to a particular accident might not be immediately apparent allows statistical associations to be drawn. If we comprehensively collect the incidence of a factor among drivers involved in a crash, we can measure statistically whether and how much that factor increases the risk of crash involvement. We may not know that fatigue “caused” this or that crash, but we will be able to determine that fatigue raises the risk of accidents by a certain amount.

To give another example: it is clear that poor braking can contribute to traffic crashes. Some cases are very clear, as when a truck loses all braking. But there are other cases where the brakes are just out of adjustment and diminished braking capacity may or may not have contributed. It is likely that many truck drivers are aware when their truck’s brakes are not fully adjusted and compensate for the longer stopping distances. A study a few years ago by the National Transportation Safety Board showed that about 45% of the trucks on the road had misadjusted brakes at that time, yet the overwhelming majority of trucks made it to their destination safely. So, does brake adjustment affect accident risk? By collecting brake adjustment data on all trucks involved in a crash, regardless of whether braking had anything to do with the crash or the role of the truck in it, it is possible to measure the effect of brake adjustment on particular types of crashes. If trucks that are rear-ended while stopped (where their own braking capacity had nothing to do with the crash) have a lower percentage of brakes out of adjustment than trucks that are rear-ending other vehicles, that is evidence that brake out-of-adjustment increases the risk of accident involvement and we can calculate the amount of the increased risk.

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March 9, 2001

Ms. Julie Cirillo
Acting Assistant Administrator
Federal Motor Carrier Safety Administration
Room 6316
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Washington, D.C. 20590

Dear Ms. Cirillo:

The Committee for Review of the Federal Motor Carrier Safety Administration's Truck Crash Causation Study held its second meeting on January 25 and 26, 2001, at the National Research Council facilities in Washington, D.C. The enclosed meeting roster indicates the members, liaisons, guests, and TRB staff in attendance. On behalf of the committee, I want to thank the staff members of the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA) for their presentations and responses to committee questions. I believe we had a very open and productive exchange of ideas.

The meeting provided the committee with an opportunity to review the progress of the pilot study, examine preliminary crash data and information for several crashes from the four pilot study data collection sites, and respond to agency questions about committee member suggestions for changes to the data collection forms. A good part of the discussion focused on the need to reduce subjectivity in the data as much as possible within project limitations. The meeting also included discussions about FMCSA and NHTSA expectations for the study. There was an exchange of views on the analysis method being used by the agency to determine critical crash events, and several other analysis methods were suggested.

The committee met in closed session to deliberate on its findings and begin the preparation of this report, which was completed through correspondence among the members. This report summarizes key discussions and provides several recommendations to FMCSA.

Study Purpose and Agency Expectations

FMCSA and NHTSA staff reviewed what they hope to achieve with the Truck Crash Causation Study (TCCS), the most comprehensive study of truck crashes ever attempted. Staff described the TCCS as an exploratory study of 1000 truck crashes aimed at collecting data on a wide range of crash factors related to the drivers, vehicles, roads, and trucking companies involved. The study data will enable the agency to develop inferences about crash circumstances

and crash causes. The agencies expect the crash assessments to provide a basis for determining future countermeasure priorities, designing countermeasures, and developing measures of effectiveness for countermeasures.

Crash Event Assessment

FMCSA is basing the crash assessments on the Perchonok method of analyzing crash events as described in the FMCSA document provided at the committee's first meeting (see attachment). This method describes traffic crashes as the result of causal chains where events are linked to one another in a series of cause-effect relationships. Each effect serves as a cause for the next link in the chain. The approach calls for trained crash analysts to examine case documents to determine key crash factors, events, and reasons. These are coded according to a set of pre-determined definitions. While this diagnostic approach relies on the judgment of the crash analysts, its procedures have proven successful in other studies of motor vehicle crashes and will provide considerable information on a large number of crashes within the time and budget available. The agency plans to undertake additional analyses as described in a later section.

Several committee members and agency staff noted that there are slightly different versions of this method. In addition, the Perchonok method can result in differing conclusions about the critical precrash event and the reasons for the critical precrash events—the heart of the Perchonok method (Items 5 and 6 on the Crash Event Assessment form). Judgments on these items are critical to the Perchonok analysis (and, possibly, to other future analyses of the data) and there was considerable discussion during the meeting as to whether the judgments made in the presented cases were supported by the available data. As a result, the committee urged FMCSA to give considerable attention to ensuring both objectivity and consistency in the crash analyses.

First, the committee urged FMCSA to follow the procedures of the Perchonok version that is recognized as being the most objective approach to identifying key crash factors, i.e., the one that has been shown to result in the least bias toward any pre-determined outcome. This version should provide the crash analyst with the best tool for avoiding prejudging the circumstances or supporting a predetermined outcome. The choice should also be based on which method ensures the highest inter-rater and intra-rater consistency and reliability. The committee is not sufficiently familiar with the alternative methods to recommend the one that can best meet these goals. The choice will have to be made by FMCSA working with NHTSA staff and study consultants who are familiar with all versions. FMCSA should document its choice for future users of the analysis results and the data.

Second, the committee urged FMCSA to conduct two independent assessments of each crash case. (We note that independent here means making independent assessments of the critical precrash event and the reasons for the critical precrash event based on information in the collected data, not simply having one analyst review the assessments of another.) Subsequent to the meeting, the committee learned that FMCSA plans to undertake independent assessments of each of the 1000 cases. Crash assessments will be undertaken first by an experienced crash

analyst in one of the two National Zone Centers and then by the supervisor of both zone centers. In addition, early in the study, most cases will be subjected to a third independent review by a consultant who is an experienced crash investigator. The committee strongly supports this multiple assessment approach. Continuing the dual assessment throughout the entire study will greatly increase the objectivity and consistency of the findings, and the third review in the early cases should identify the need for and facilitate any training or procedural changes needed in the assessment effort.

Review of Pilot Cases

- Agency staff presented preliminary material on several pilot study crash cases to illustrate selected aspects of the crash event assessment process. While none of the case studies had been completed, the presentation nevertheless prompted considerable discussion and debate. Committee members expressed their concern about highly subjective interpretations of data and premature conclusions. While agency staff pointed out that the analysis of crashes would be based on several other data sources in addition to the data forms, many committee members strongly emphasized the need to ensure that any future presentations or discussions about the crash cases be limited to the recorded facts. Because the crash cases presented at the meeting were based solely on information from the data forms, many committee comments were directed at the items in the data forms (as discussed below). The committee requested that several complete pilot study crash case files be made available for committee review prior to its next meeting.

Alternative Analysis Methods

FMCSA staff indicated that it plans to use other analysis methods in a limited fashion following preliminary examination of the study data. The committee concurs with this decision, especially agency plans to undertake some limited exposure data analyses of specific driver- and vehicle-related factors. The committee also notes that the crash database will provide opportunities for analyses that may lead to increased insight on crash causation and risk. For example, one can hypothesize that a factor may increase the risk of certain types of crashes (e.g., poor truck brakes will result in more rear-end crashes in which the truck is the striking vehicle). One can then examine the relative risk of this factor between carefully selected subgroups in an attempt to reveal such associations (e.g., the proportion of poor brakes in trucks struck in rear-end collisions versus the proportion for trucks that are the striking vehicles in rear-end collisions). With careful planning, it may be possible to examine a number of possible “causative factors” in this manner.

In addition, the committee urges FMCSA to undertake “but-for” analyses of at least a sample of the crashes. “But-for” analysis was used in a previous crash causation study, the Indiana Tri-Level Study. The method involves a team of crash experts from several disciplines working together to identify the causal factors necessary or sufficient for the occurrence of the crash. (This could be done with the pilot study data being collected.) This method considers as many crash-related events and/or circumstances as possible and identifies those for which it can be stated “but-for the event (or circumstance), the crash would not have occurred.” The

committee believes this approach can provide additional insight into critical precrash events. In addition, FMCSA indicated that it will collect data on possible crash escape options or maneuvers available to the drivers involved in the crashes. These should facilitate this type of analysis. The team for such an analysis would require expertise in human factors, engineering, and trucking in addition to crash investigation. This team could be formed at a future date.

Case Documentation: Data Forms and Other Information Sources

General

Both FMCSA and the committee view the initial agency analyses of the data as the first of many such efforts because of the importance of truck safety and the landmark nature of this study. It is unlikely that such a data collection effort will be launched again for many years. (Most of the data will be collected by teams of trained investigators from NHTSA's National Automotive Safety Sampling System [NASS] project and FMCSA-funded truck safety inspectors.) The truck crash database being assembled will be important for many years to come. As a result, it is critical that the data collected be as accurate, objective, and complete as possible, and that they be documented in detail for future use by analysts who will not have the advantage of being involved in the data collection. Many committee member comments were based on the critical need for sound data and detailed documentation.

Data Forms

Following the first meeting, individual committee members provided written comments on the data collection and assessment forms being used in the TCCS. Agency staff provided written responses to these comments at this meeting. After some initial discussion about the comments and responses, it was clear that several issues persisted. These included the concern that some questions were not sufficiently tailored to the special circumstances of trucks and truck equipment, truck drivers, or carriers. To address this and other issues related to the forms, the committee established several task groups that met during the open session with agency staff to further discuss possible improvements in the data forms. In these discussions the committee stressed the need to reduce subjectivity in the data. The committee emphasized the need for objective, accurate, and focused crash data and information as a basis for effective assessment and determination of critical crash events. Several committee members agreed to further review selected data topics and items after the meeting and prepare additional suggestions. NASS staff indicated that they planned to complete revisions to the forms by the end of February 2001. (The committee suggested that future revisions to the data forms be identified with the revision date.)

Other Information Sources

Agency staff briefly reviewed other sources of information that form the full data set for each crash case. These sources include the following:

1. Crash Scene Drawings (prepared by the NASS crash investigator)
2. Narratives (prepared by the NASS crash investigator)

3. Motor Carrier Safety Assistance Program (MCSAP) vehicle inspection reports (prepared by state MCSAP inspector)
4. Police Report (prepared by the police who respond to the crash)
5. Interviews (conducted by the NASS crash investigator on site and/or later)
6. Photos (prepared by the NASS crash investigator)
7. Police Reconstruction (prepared by the police for a sample of crashes)
8. Medical Data (all or part of the medical records from the admitting hospital)
9. FMCSA Carrier Investigation Report (prepared by state FMCSA staff)

The committee plans to review completed examples of these forms at a future meeting.

Relational Data Base

Several committee members noted that they remained unclear as to how the various data forms relate to one another. FMCSA staff addressed this issue by briefly describing the relational database being developed for the TCCS. This database is of considerable interest to the committee and warrants further discussion at a future meeting.

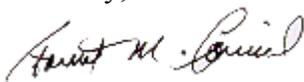
Data Availability and Data Preservation

FMCSA has indicated that the data being collected for the TCCS will be made available to other researchers after specific personal, vehicle, company, and location references are removed. As noted above, the committee supports this plan and strongly urges FMCSA to ensure that all collected data are carefully documented and preserved so that all case information is readily available and can be easily understood by future researchers. While such documentation will involve considerable effort, it is very important for future data use.

Future Meeting Plans

The committee has scheduled its next meeting for August 20 and 21, 2001 in Washington, D.C. based on the understanding that the data collection for the full study will begin at all 24 study sites on about April 1, 2001. I invite you to join us at the meeting.

Sincerely,



Forrest Council
Chairman
Committee for Review of the Federal Motor Carrier
Safety Administration's Truck Crash Causation Study

MEETING ATTENDANCE

COMMITTEE MEMBERS

Forrest Council, Chair

Michael H. Belzer

John R. Billing

Kenneth L. Campbell

James Dally (NAE)

Steven Vaughn

Frank R. Wilson

A. James McKnight

Raymond C. Peck

Lawrence A. Shepp (NAE, IOM)

Jack Stuster

Anne McCartt

Hugh W. McGee

TRB Staff

Ann Brach

Walter Diewald

Susan Garbini

LIAISONS AND VISITORS

Nancy Bondy, NHTSA

Stephen F. Campbell, Commercial Vehicle Safety Alliance

Joseph Carra, NHTSA

Ralph Craft, FMCSA

William Gay, Volpe National Transportation Systems Center

Donald Hendricks, Veridian Engineering, Inc.

Bob Ketenheim, FMCSA

Robert Lemieux, Volpe National Transportation Systems Center

Stephen Mavros, KLD Associates, Inc.

James Page, Veridian Engineering, Inc.

Richard Reed, Accident Research Analysis, Inc.

Jerry Scally, Volpe National Transportation Systems Center

Terry T. Shelton, FMCSA

Alan Smutny, Volpe National Transportation Systems Center

Gary Toth, NHTSA

Lynn Weidman, BTS

Robert Woodill, Accident Research Analysis, Inc.

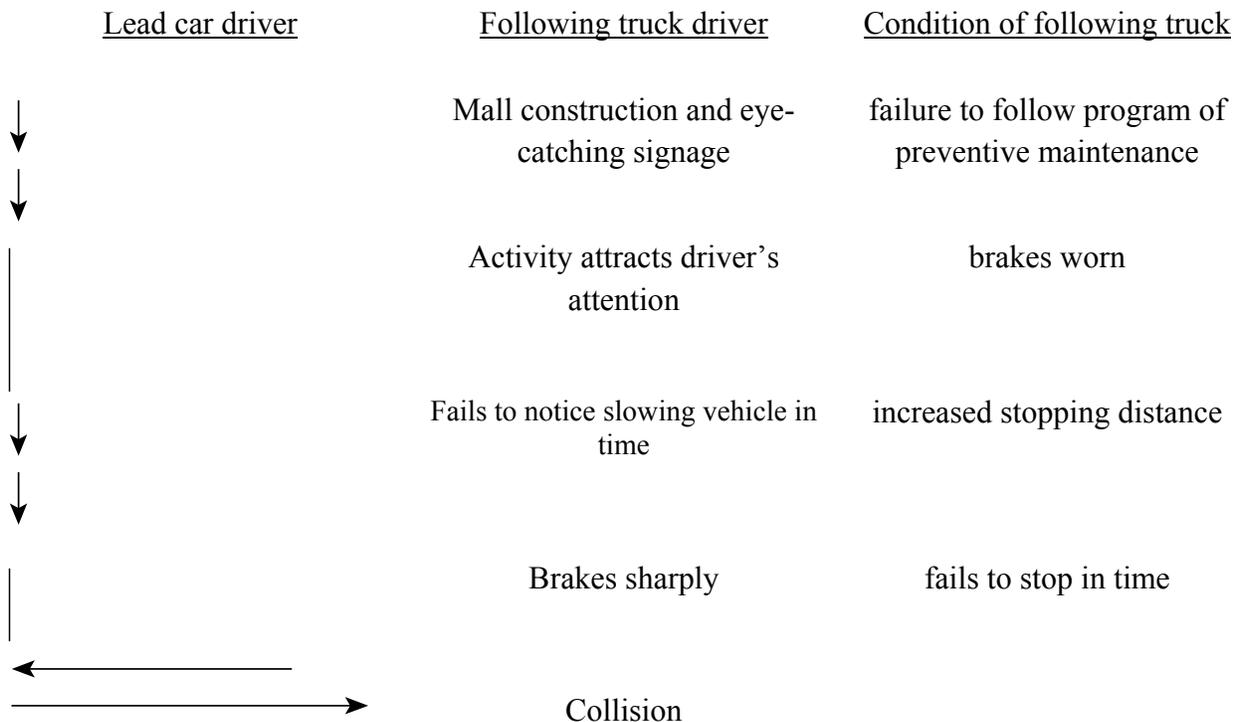
Attachment

FMCSA Statement of Approach for Coding In-depth Accident Investigation Reports

The conceptual model for the in-depth accident database is taken from Kenneth Perchonok in *Accident Cause Analysis*. Perchonok describes traffic accidents as the product of causal chains, where events are linked to one another in a cause-effect relationship. Each effect serves as a cause for the next link in the chain.

Crash Event Chains

Consider a simple rear-end collision (this example is modeled on an actual fatal crash involving a heavy truck). The lead vehicle slowed to turn left into a driveway of a store's parking lot. There was no turning flare or center-left lane, so the car was slowing in the through-traffic lane. The truck driver of the following vehicle noticed some construction to his right in a mall and a sign advertising a two-for-one special at a fast food restaurant. He did not recognize that the lead vehicle was slowing until he was too close to stop safely. He braked, but couldn't stop in time and struck the lead vehicle in the rear. Cause-effect chains can be illustrated for the driver of the lead car, the driver of the following truck, and the following car itself in the table below. The arrows show the causal direction:



Each cause is itself the effect of some other cause. And the cause-effect chain could be extended indefinitely for each of the three factors. But all of the factors listed above had to come together to produce this particular crash. If the truck's brakes had been in better shape, it may have stopped in time or at least not hit as hard. If the trucker had been paying more attention to the roadway ahead, he would have noticed the car in front slowing. If there had been no lead car, there would have been nothing for the distracted driver to crash into. If there had been a turn lane, the car would have been out of the line of traffic. If the lead driver hadn't decided to shop at that particular store, he wouldn't have gotten into the other driver's way. And so on. Some of the examples are trivial, but the point is that traffic accidents are complex events and many things have to be present at the same time for a crash to occur.

Thinking about traffic crashes in terms of multiple cause-effect chains has two principal advantages:

First, it corresponds with our intuitive understanding of traffic accidents as complex events, in which many factors can play a role. We are not trying to find a single "cause" of a traffic accident. To use the rear-end collision above again: What is the cause of this accident? Inattentiveness by the driver of the following vehicle? Following too closely? Insufficient braking capacity? Poor maintenance? Insufficient friction from the roadway? Roadway design not up to the increased flow of traffic because of the development of the mall? Poor driving technique since he didn't attempt to steer around the stopped vehicle? Slow reaction time? The distracting signs? Many factors *contributed* to the occurrence of the accident. Which one is the *cause*? Identifying the range of factors that contributed to the crash better captures what happened than simply listing "driver inattention" or "brakes out of adjustment" as the cause.

Second, approaching traffic crashes as the product of multiple chains of events gives us a broader perspective on crash prevention. Once you start thinking about crashes as the product of many factors, you can more easily identify a variety of different ways to prevent the crash or to lessen its severity. In the example above, a better brake maintenance program might have helped lessen the severity of the crash. A forward obstacle detection system might have alerted the driver in time. Defensive driving training might have improved the drivers response. Better roadway design might have moved turning traffic into a dedicate lane, improving traffic flow.

The Critical Event

Perchonok used the concept of the *critical event* to organize the coding of accidents. He defined the critical event as the event after which the collision was unavoidable. The critical event is the action or failure to act that puts the vehicles on a course so that the collision cannot be avoided given the proximity and relative velocities of the vehicles. Turning in front of oncoming traffic can be a critical event, if there wasn't time to stop or steer around the turning vehicle. Pulling out

in front of a vehicle can be a critical event, if there was no time to stop. The critical event “causes” the accident in a physical sense because, given the mechanical properties of the vehicle and roadway, there was no chance to avoid the crash after the critical event occurred.

The critical event essentially gives the researcher a place to start in analyzing a traffic accident. The idea is to start with the event after which the accident was inevitable and then build the description and related factors from that point.

The *critical reason* is the reason for the critical event. It is the “cause” of which the critical event is the result. The critical reason is the failure in the vehicle, driver, or environment that explains the critical event. For example, a driver falls asleep and runs off the road. The critical event is running off the road. The critical reason is falling asleep.

While the critical reason may be conceived of as the immediate cause of the accident, a number of other factors may be important. It is easy to imagine that for any particular critical reason, a variety of factors are related, and for each of those factors, there is another set of factors. Accordingly, a wide variety of factors are considered for in-depth accident reports.

On the other hand, it is true that the chains of events could be extended indefinitely. There is no point in the chain at which, purely from logic, all factors that conceivable could be related have been covered. So, while the list of related factors is intended to be comprehensive, it covers the current understanding of risk factors for truck crashes and the range of interventions currently considered feasible.

Sources and Variables used for the Critical Event and Critical Reason

The proposed in-depth accident database is composed of ideas and variables taken from a variety of sources. The overall concept of accident event chains is taken from Perchonok, and following him, from a methodology described by James Fell. The actual code levels for the critical event are borrowed from the National Highway Traffic Safety Administration’s General Estimates System (GES). GES includes five related variables that describe the action of the vehicle prior to the critical event; the critical event; corrective action taken; vehicle control after the corrective action, and the vehicle’s path after the corrective action. The GES code levels are comprehensive. Using these variables will allow comparisons with results from GES.

Coding for the critical reason essentially follows the framework of the Indiana *Tri-Level Study of the Causes of Traffic Accidents*. The *Tri-Level Study* groups related factors into driver, vehicle, and environment. For our purposes, the most important set of factors taken from the *Tri-Level Study* are those for the driver. The four primary categories of driver critical reasons are “critical non-performance,” recognition errors, decision errors, and performance errors.

Critical non-performance is a “catastrophic interruption in the driver’s performance,” such as blacking out, falling asleep, or a heart attack, that removes the driver from any further active participation in the accident. Recognition errors include various failures to perceive or comprehend available information in a timely fashion. Decision errors are conscious decisions on vehicle control that put the driver into a situation that he could not recover from. Some of these codes have the potential to be circular. For example, “following too closely” is another way of saying “struck lead vehicle in the rear.” But here the intent is to capture situations where a steady following distance had been established prior to the critical event, but the following distance was so short that an unexpected action of the lead vehicle immediately created a critical event. The final category, performance errors, refers to inadequate skills in controlling the vehicle.

Note that the critical reason is coded for both the truck and truck driver as well as the other vehicle and other vehicle’s driver.

The critical event refers only to the physical movement of the vehicles involved, not which vehicle had the right-of-way at the time of the accident. There will be cases where a vehicle is assigned the critical event, yet had the right-of-way at the time of the crash. For example, a vehicle turning left on a green arrow in front of on-coming traffic had the right-of-way, but also committed the critical event in that the turn put the vehicles on a collision course. In order to address these cases as well as to sort out an important element of traffic crashes, an additional variable has been added. The variable simply records which vehicle had the right-of-way at the time of the accident. Perchonok addresses the issue with the concept of “culpability.” A driver is “culpable” if he violates the expectations of a normal driver. This is reformulated here in terms of right-of-way, which can generally be determined at the scene, either from the physical configuration of the accident and its location, or established by witnesses.

Related Factors

Following the critical event and critical reason variables is a long list of “related factors.” These related factors capture important characteristics of the driver, vehicle, and environment. The items on the list are taken from previous studies of accident causation and they have either been shown to increase crash risk or there are good theoretical reasons to think that they may increase crash risk. The point here is to consider all parts of the crash, i.e., the driver, vehicle, and environment and record the presence of any of the factors.

It is important to understand that, in this section, we are recording all factors present, *regardless of whether they contributed to this specific crash or not*. In practical terms, it is often not possible to determine all factors that contributed to a particular crash. The

resources required are not available or the effect of the factor itself cannot be determined after the fact. For example, fatigue can have effects far beyond just falling asleep and running off the road. It can slow perception and reaction time, or cloud judgment. In a particular accident, fatigue *may* cause a driver to misjudge his speed or slow his perception of the movements of traffic ahead, but the evidence in a particular case is often not strong enough for the investigator to identify fatigue as causal in the crash.

At the same time, coding factors where the connection to a particular accident might not be immediately apparent allows statistical associations to be drawn. If we comprehensively collect the incidence of a factor among drivers involved in a crash, we can measure statistically whether and how much that factor increases the risk of crash involvement. We may not know that fatigue “caused” this or that crash, but we will be able to determine that fatigue raises the risk of accidents by a certain amount.

To give another example: it is clear that poor braking can contribute to traffic crashes. Some cases are very clear, as when a truck loses all braking. But there are other cases where the brakes are just out of adjustment and diminished braking capacity may or may not have contributed. It is likely that many truck drivers are aware when their truck’s brakes are not fully adjusted and compensate for the longer stopping distances. A study a few years ago by the National Transportation Safety Board showed that about 45% of the trucks on the road had misadjusted brakes at that time, yet the overwhelming majority of trucks made it to their destination safely. So, does brake adjustment affect accident risk? By collecting brake adjustment data on all trucks involved in a crash, regardless of whether braking had anything to do with the crash or the role of the truck in it, it is possible to measure the effect of brake adjustment on particular types of crashes. If trucks that are rear-ended while stopped (where their own braking capacity had nothing to do with the crash) have a lower percentage of brakes out of adjustment than trucks that are rear-ending other vehicles, that is evidence that brake out-of-adjustment increases the risk of accident involvement and we can calculate the amount of the increased risk.

References

Fell, J., *A Motor Accident Causal System: The Human Element*. Research and Development, Office of Statistics and Analysis, NHTSA, DOT-HS-801-214, July, 1974.

Perchonok, K., *Accident Cause Analysis*. Cornell Aeronautical Laboratories, Inc., July, 1972.

Treat, J, et al., *Tri-Level Study of the Causes of Traffic Accidents: Final Report*. Institute for Research in Public Safety, School of Public and Environmental Affairs, DOT HS-034-3-535-77-TAC, March, 1977.

November 15, 2000

Ms. Julie Cirillo
Acting Assistant Administrator
Federal Motor Carrier Safety Administration
Room 6316
400 7th Street, SW
Washington, D.C. 20590

Dear Ms. Cirillo:

The Committee for the Review of Federal Motor Carrier Safety Administration's Truck Crash Causation Study (the Review Committee) held its first meeting on September 7 and 8, 2000 at the Holiday Inn, 2010 Wisconsin Avenue, Washington, D.C. The enclosed meeting roster indicates the members, liaisons, guests, and TRB staff in attendance. On behalf of the committee, I want to thank you for attending the meeting and providing background on the Truck Crash Causation Study (TCCS). I would also like to thank the staff members of the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA) for their presentations and responses to committee questions.

The TCCS is a congressionally mandated study of causes of truck-involved crashes resulting in fatality or serious injury, i.e., serious crashes. The results of the study will be used to design and select cost-effective measures for reducing the number and severity of serious crashes involving large trucks. The study consists of in-depth investigations of a nationally representative sample of large truck crashes. These investigations will be performed by teams of trained investigators from NHTSA's National Automotive Safety Sampling System (NASS) project and FMCSA-funded truck safety inspectors. (See the Appendix for details of the ongoing NASS activity.) FMCSA and NHTSA have developed data forms and procedures and are currently testing them at four pilot study sites. After the pilot study is completed and appropriate adjustments are made to the data collection forms and procedures, the full study is expected to begin at twenty-four data collection sites in 2001.

The Review Committee was convened by the National Research Council to review and provide guidance on progress on major TCCS milestones. The first meeting of the committee focused on study design, proposed sample size and approach, data collection forms, and data collection procedures. The original plan for the Review Committee's activities called for its first meeting to take place in early 2000 prior to the proposed initiation of the full pilot study in July, 2000. Both the meeting and the initiation of the full pilot study were delayed. The committee plans to meet again in early 2001, prior to the start of data collection at all TCCS sites, to review preliminary results of the pilot

study. That meeting will examine whether the pilot study results suggest the need for changes in the data collection methodology, data collection forms, sampling design or analysis techniques and procedures.

The meeting began with a series of presentations from FMCSA and NHTSA staff in an open session. Staff presented an overview of the TCCS goals and objectives and provided a brief history of truck crash causation studies at FMCSA and its predecessor organization, the Office of Motor Carriers of the Federal Highway Administration. Brief presentations then followed on several important study components—study design, data forms, data collection plans, and data processing. The Review Committee met in closed session to deliberate on its findings and begin the preparation of this report which was completed through correspondence among the members.

General Comments

The TCCS is a valuable undertaking because crash causation is important to highway safety and a key concern to policy makers, the commercial motor carrier industry, highway safety and law enforcement officials, and highway users. More knowledge about truck crash causation can help focus future truck safety inspection programs and other enforcement efforts, truck safety regulation, and the design and implementation of appropriate vehicle, motor carrier, highway, and driver safety countermeasures. It is clear that the TCCS cannot possibly answer every question about truck safety, or even truck crash causation. However, its results, when combined with other past and current research, should yield valuable information on truck crash causes, both in terms of truck-related causes and non-truck-related causes. Study success requires that the TCCS be performed on a sound scientific basis with methods, data, and procedures that are thoroughly documented and reviewed for sensitivity for diagnosing causes, reliability (including consistency and repeatability), and validity for measuring the causal factors selected to the focus of the study.

The committee identified several critical issues that warrant consideration by FMCSA before the initiation of the full study. These issues fall into three broad categories: (1) choice of study methodology, (2) specific issues related to the methodology, and (3) concerns about data items, data collection, and causal analysis procedures. Some committee concerns in this latter category might stem from the committee's lack of familiarity with the detailed accident investigation forms and other documents being used to summarize each crash investigation. The documents given to the committee at the meeting could not be thoroughly reviewed and discussed in the time available. Even though the committee was assured that several of its concerns are being addressed in the pilot study, all such concerns, except those related to the data forms, are noted below. FMCSA agreed to report to the committee when actions are taken on these items. In addition, issues related to study implementation, which cannot be addressed in the absence of results from the pilot study (e.g., effectiveness of crash notification procedures, whether the estimated time for follow-up investigation is sufficient), are not addressed in this letter but will be considered at the committee's next meeting.

The roles of FMCSA and NHTSA were discussed in general terms at the meeting. Nevertheless, the committee believes that FMCSA should prepare a statement for the record that clarifies the roles of the agency and NHTSA in the study, including which agency will be responsible for analyzing the data. The agency should also indicate the roles that contractors will be expected to play in the study. Such a statement would be helpful to the committee and others interested in the TCCS.

Choice of Methodology

Much of the committee's discussion focused on the case analytic methodology FMCSA has chosen for the study. This approach uses accident reconstruction methodology to identify crash causes, such as vehicle and highway defects and driver errors. It can yield considerable information about crash causes for the sample of crashes studied, e.g., driver fell asleep, ran-off-the-road, and struck a pole. However, accident reconstruction does not address less direct contributors or related factors such as driver sleep schedule. The roles of these contributors are better identified by comparing their occurrence in a crash sample with their occurrence in the population-at-risk. Since several of these indirect factors are included in the data collection forms, FMCSA should carefully document both its rationale for choosing the reconstruction methodology and how it plans to make inferences concerning the contribution of these indirect causes to crashes. The committee would like to review such documentation at its next meeting.

The committee believes there is a clear need for a thorough analysis plan that documents agency plans for interim and final analyses for the study. Such a plan can help determine if all key data elements are being collected, provide guidance on how crash data should be interpreted by the NASS crash cause analysts, and help assess the adequacy of the TCCS study design. Regardless of methodology, data collection must be based on the research questions being addressed and the analysis to be undertaken.

The analysis plan should include a list of basis questions concerning crash causation FMCSA is attempting to answer together with the data elements that correspond to these questions. The analysis plan should also include a description of the types of statistical analyses that will be used for estimating parameters, testing hypotheses, examining subpopulations, etc. The plan should document how FMCSA will minimize inter-analyst variability, especially where the procedures rely on analyst judgment. Finally, FMCSA's schedules for releasing its data for general research use and for publishing causal analyses should be highlighted. There is considerable interest in the TCCS from the highway safety field and the trucking industry as well as policy makers and public officials at all levels of government, and the general public. Such schedules can help allay concerns and may reduce the pressure on FMCSA for unduly accelerated results.

Specific Methodological Issues

Sample Size and Selection

The TCCS as presently structured will be based on in-depth investigations of 1000 truck-involved crashes. A sample of 1000 truck-involved crashes is very small in light of the large number of potential truck-involved crashes, the many potential causal factors, and the eventual need to partition the data for analysis. (In 1998 nearly 94,000 truck-involved crashes resulted in fatalities or serious injury.) In-depth investigations of the type being undertaken are costly and the sample size is understandably constrained by the project budget. However, the small sample size will provide challenges to data analysis. The committee would like to know more about the basis for the selected sample size and the statistical considerations involved. Because results of previous studies suggest that the sample will yield fewer than 500 cases in which a crash cause can be attributed to a truck, the committee is interested in whether FMCSA plans to screen out potentially unproductive investigations in the crash selection process (e.g., collect only minimum data on crashes in which non-trucks are the primary cause). If so, the committee would like to know more about the screening method and how screening might affect the intended representative sample. If not, then the committee would be interested in FMCSA's reaction to whether approximately 500 cases can give them all the causal information they need to make truck-related treatment decisions.

To select crashes for the nationally representative sample of truck-involved crashes, FMCSA is relying on a sampling plan based on NASS data for all highway crashes, not just truck-involved crashes. TCCS project staff indicated that they could document that the sampling plan based on all vehicle crashes is suitable for TCCS. The committee strongly recommends that FMCSA document that the sampling plan will not compromise the ability to draw inferences about causality of truck-involved accidents. It is particularly important that differences between various regions be taken into account in the sampling plan; for example, some states although not necessarily large in size or population, are border or corridor states, with considerably large truck traffic flows. These states can experience proportionally greater exposure compared to other states of similar size and population that are not border or corridor states. The committee plans to review the document and comment as appropriate.

Definition and Determination of Cause

Fundamental to crash causation studies are *the definition of cause and the method chosen to determine crash causation*. Although FMCSA described in broad terms how it plans to determine crash causation, the agency provided no details for the approach. As a result, the committee remains unclear how causality will be determined, including how potential multiple causes will be evaluated, weighted, and summarized, and how these determinations will be tested to ensure objectivity, and reliability of results. It is also unclear how the NASS crash analysts who will make the cause determinations will be trained, monitored, and reviewed to achieve reliability across analysts.

Since crash causation is the focus of this study and the method of crash cause determination is a potential topic of future criticism when results are published, FMCSA should prepare a detailed description and justification of the fundamental approach it plans to use to determine and analyze cause. Such documentation should be written to be clearly understandable by all interested parties. The committee notes that following the

meeting FMCSA distributed a resource paper that the agency has used as the basis for its internal discussions and plans. After reviewing the document, the committee will prepare comments and forward them to you in a separate letter.

Expert Knowledge

Several committee members noted that the study crash investigators and the NASS crash analysts determining the causes of each crash need to be knowledgeable about trucking company business operations and truck vehicle dynamics to assist them in conducting their investigations. Such knowledge will be of particular value when the investigators examine crash sites and the trucks involved and when they interview truck drivers and truck company representatives. Lacking such knowledge, the crash investigators will be limited in their understanding of what they see and hear and their ability to question the truck driver and the motor carrier, and so may be likely to overlook specific details about key facts. In addition, the committee believes the NASS causal analysts who will determine crash causation need to be knowledgeable about highway design and truck driver human factors so that items in these categories are adequately considered and understood in the determinations of crash causes. This is particularly important because much of the NASS work has focused on non-truck-related human factors rather than truck-related human factors and has addressed roadway effects in a limited fashion. The committee suggests that the issue might be addressed by having the conclusions of the causal analysts checked by a panel of human factors and highway design experts.

Definition of Trucks for the TCCS

FMCSA's regulatory responsibilities extend to all trucks with a gross vehicle weight of 10,000 lbs. and more. This is a wide range of trucks including pickup trucks, delivery trucks, and vans. The committee recognizes that in choosing a definition of trucks for this study FMCSA must address not only methodological but also policy issues. However, the committee believes the TCCS should focus on crashes involving single unit trucks with three or more axles and all combination trucks and not consider smaller trucks. Using such a definition will yield a larger sample of crashes involving larger trucks, and the information gained from this sample will be more valuable than the information lost by not including crashes involving smaller trucks. This suggestion is based on the increasing number of combination trucks in the total truck fleet, their importance in serious truck crashes, and the potential for high payoffs if more is known about crashes involving these large trucks. This revised definition also incorporates the

vehicles of most concern to highway safety advocates, highway users and policy makers concerned with truck safety. It also reflects how FMCSA deploys most of its resources.

Other Issues

Specific Variables

In light of the limited opportunity for thorough review and discussion of the data collection forms and individual data items, the committee plans to review these documents and prepare a separate report to the agency.

In-Vehicle Recording Devices

Some trucks and passenger cars are currently equipped with in-vehicle recording devices. The committee urges FMCSA to collect as much information as possible from such equipment on vehicles involved in the crashes investigated. While the portion of the vehicle fleet equipped with such devices is too small for the devices to be used for primary data collection, those that are in the sample of crash-involved vehicles might provide data helpful for validating the data that is manually collected.

Alternative Data Collection Method

One committee member supports an alternative method of data collection for the TCCS. It involves installing continuous-loop video cameras in a sample of trucks and extracting the data from cameras on trucks involved in crashes. The committee did not discuss this proposal and has not endorsed it. The proposal will be discussed at the committee's next meeting.

Future Meeting Plans

The committee has scheduled its next meeting for January 25 and 26, 2001 in Washington, D.C. I would like to invite you to join us at the meeting.

Sincerely,

Forrest Council
Chairman
Committee for the Review of Federal Motor Carrier
Safety Administration's Truck Crash Causation Study

MEETING ATTENDANCE

COMMITTEE MEMBERS

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Katrina Knight, Volpe National Transportation Systems Center
Robert Lemieux, Volpe National Transportation Systems Center
Tim Lynch, Motor Freight Carriers Association
Stephen Mavros, KLD Associates, Inc.
Dave Osiecki, American Trucking Association Foundation
James Page, Veridian Engineering, Inc.
Andy Schindel, Central Analysis Bureau
Terry T. Shelton, FMCSA
John Siebert, Owners-Operators-Independent Drivers Association
Marvin Stephens, NHTSA
Gary Toth, NHTSA

Disclosure Statement

As is standard policy for NRC committees, the members of this committee meet in executive session at the outset of each meeting to discuss any potential or perceived conflicts of interest that might have arisen for any of them. The committee has agreed to abide by TRB policies for dealing with conflicts of interest that may arise in the bidding for or winning of FMCSA contracts by firms or organizations with which members are associated. In the interest of full disclosure, we note the following FMCSA-related activities.

Michael H. Belzer's current research on driver pay and safety and an assessment of costs and benefits of the Federal Motor Carrier Safety Administration's proposed hours of service regulations is funded by the Federal Motor Carrier Safety Administration. Kenneth L. Campbell currently manages the Trucks Involved in Fatal Accidents (TIFA) data file. This file supplements data on fatal truck crashes that are reported to the federal government as part of the Fatal Analysis Reporting System. The Federal Motor Carrier Safety Administration and the National Highway Traffic Safety Administration provide substantial financial support for TIFA, which also receives funding from state and private sources.

APPENDIX

NATIONAL AUTOMOTIVE SAMPLING SYSTEM (NASS)¹

The National Automotive Sampling System (NASS) was established in 1978 within the National Center for Statistics and Analysis of the National Highway Traffic Safety Administration. NASS has two major operating components:

1. The General Estimates System (GES) which collects data on an annual sample of approximately 55,000 police traffic crash reports; and
2. The Crashworthiness Data System (CDS) which collects additional detailed information on an annual sample of approximately 5,000 police reported traffic crashes involving a towed passenger car, van or truck that is less than or equal to 10,000 pounds GVW

The purpose of NASS is to provide nationally representative data on fatal and nonfatal motor vehicle traffic crashes for use in better understanding the vehicle-trauma experience and to determine the national crash trend experience. This helps NHTSA develop an understanding of both the relationship between vehicle crash severity and occupant injury, and the scope of the highway safety problem.

NASS CDS has detailed data on a representative, random sample of thousands of minor, serious, and fatal crashes. There are 24 field research teams that study about 5,000 crashes a year involving passenger cars, light trucks, vans, and utility vehicles. Trained

crash investigators obtain data from crash sites, studying evidence such as skid marks, fluid spills, broken glass, and bent guardrails. They locate the vehicles involved, photograph them, measure the crash damage, and identify interior locations that were struck by the occupants. These researchers follow up on their on-site investigations by interviewing crash victims and reviewing medical records to determine the nature and severity of injuries.

Interviews with people in the crash are conducted with discretion and confidentiality. The research teams are interested only in information that will help them understand the nature and consequences of the crashes. Personal information about individuals - names, addresses, license and registration numbers, and even specific crash locations - are not included in any public NASS files.

NASS data have been electronically coded in computerized data files for statistical analysis since 1979. NASS CDS has investigated and collected detailed data on a representative, random sample of more than 119,000 minor, serious, and fatal crashes. Custom software incorporating automated quality control is used for data entry.

¹ Based upon information provided by the National Highway Traffic Safety Administration.

Separate contractors perform extensive quality control reviews of field case sampling procedures and non-automated data such as scene diagrams and vehicle damage sketches. Additional case data, such as vehicle photographs and scene diagrams, are retained for detailed analysis by the agency and the highway safety community. Contractor staff are trained in NASS investigation procedures at the Transportation Safety Institute in Oklahoma City, Oklahoma. Performance of contractor staff is carefully monitored against defined goals to assure accuracy and completeness of crash sampling and data collection.

Police reports used as the source for GES data are collected by CDS teams adjacent to GES sites or by part-time contractor personnel at remote GES sites. Data are converted to a common format and coded to the electronic file at one central contractor location. All CDS and GES data are carefully controlled to protect the privacy of involved persons. NASS data are available in electronic data files and in annual reports for selected years. These data are essential to a variety of regulatory and enforcement initiatives. Currently NASS data are supporting rulemaking in light truck side impact and vehicle rollover crash protection, head injury protection, and occupant ejection, and fuel system integrity. Other uses of NASS data include in-depth engineering analyses of crashes involving automatic occupant protection systems such as air bags and evaluation of pre-crash avoidance maneuvers for the problem definition stage of Intelligent Transportation Systems (ITS) specifications to improve the man/machine interface in crash events.

The data collected by the CDS research teams become permanent NASS records. This information is used by NHTSA for a variety of purposes, including:

- Assessment of the overall state of traffic safety, and identification of existing and potential traffic safety problems.
- Obtaining detailed data on the crash performance of passenger cars, light trucks, vans, and utility vehicles.
- Evaluation of vehicle safety systems and designs.
- Increasing knowledge about the nature of crash injuries, as well as the relationship between the type and seriousness of a crash and its injuries.
- Assessment of the effectiveness of motor vehicle and traffic safety program standards.
- Evaluation of alcohol and safety belt use programs.
- Evaluation of the effect of societal changes, such as increased traffic flow and increased large truck traffic.



Bounds on effectiveness of driver hours-of-service regulations for freight motor carriers

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Abstract

Crash rates for trucks depend in part on the length of time drivers have been operating their vehicles. This paper investigates bounds on the reduction in crash rates due to the imposition of hours-of-service regulations, which limit the number of hours drivers operate their vehicles. Methods for analyzing probability distributions for trip length, and odds ratios for crashes (as a function of hours driven) are developed. We also produce bounds on the economic costs of truck-involved collisions, and estimate changes in these costs due to changes in hours-of-service rules. The study is a first step toward a broader cost/benefit analysis of regulations, based on analysis of data from the fatal accident reporting system (FARS). © 2007 Elsevier Ltd. All rights reserved.

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1. Introduction

Safety is a critical concern for the freight industry. The National Highway Traffic Safety Administration reported in its annual 2002 traffic safety report that tractor-trailers constitute only 3% of the registered vehicles operating in the United States but are involved in almost 10% of all fatal vehicle crashes. Fatigue, alcohol abuse, human negligence, and sleep deprivation are some of the chief causes for truck crashes, but no single factor stands out above all others.

This research creates methods for bounding the effect of driving hours of service (HOS) regulations on crash and fatality rates for truck-involved crashes. HOS regulations permit drivers to operate their vehicles and be on duty (i.e., working either as a driver or in some other related activity) for a stipulated amount of time per shift as well as over seven and eight day periods. Because truck drivers spend a majority of their work time behind the wheels of their vehicles, truck safety can be gauged by analyzing HOS regulations. All trucking organizations must comply with HOS rules, and any change in these HOS rules also affects the oper-

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ations of the truck operators. As a step toward understanding the costs and benefits of HOS regulations, this paper computes upper bounds on the number of lives saved due to imposition of HOS constraints.

2. Background

Although economic efficiency, quality of service, and reliability are goals for any freight system, safety is also a critical requirement, particularly for trucks, which share the roads with passenger vehicles, pedestrians and cyclists. Trucks are the most commonly used vehicles for the movement of goods measured as a percentage of shipments transported, and are used for a least a portion of most freight shipments.

Driver hours-of-service (HOS) regulations are intended to ensure that fatigue does not reduce safety. The importance of these regulations has been highlighted in the work of the Federal Motor Carrier Safety Administration (FMCSA), which has estimated that 100% adherence to HOS regulations would produce approximately \$1 billion in annual economic savings due to reductions in crashes (FMCSA, 2003).

HOS rules were implemented in the United States in 1939, and remained largely unchanged until 1962. Under the original rules, a truck driver could operate a vehicle for a maximum of 10 h, after which a minimum 8-h period was required as off-duty (i.e., not working). A truck driver could be on duty for a maximum of 15 h, followed by a mandatory 8 or more hours off-duty. Finally, a driver could operate a vehicle for no more than 60 h in a 7-day period or 70 h in an 8-day period.

In January, 2004, a new set of rules was implemented, limiting a driver to no more than 11 h followed by a minimum 10 h rest period. Also, the driver could remain on duty for a maximum of 14 h, after which a break of 10 or more hours was required. Additional changes were implemented pertaining to driving restrictions over 7 and 8-day periods. In addition, truck drivers are allowed to split their on-duty time between rest and driving by using sleeper berths (i.e., a pair of drivers alternates between sleeping and driving in a truck). Drivers can accumulate the equivalent of 10 consecutive hours off-duty by taking two periods of rest in the sleeper berth, provided that neither period is less than 2 h, driving time in the period immediately before and after each rest period when added together does not exceed 11 h, and the driver does not operate after the 14th hour.

Vehicular – especially truck – crashes always involve the damage and destruction of property and sadly sometimes that of life itself. Different factors contribute to the occurrence of crashes. Attenuation of human functions, machine failure, changes in the surrounding environment and various other factors are responsible for crashes. Fatal crashes involve the loss of life and are of serious concern to transportation related governing bodies in the United States. The National Highway Traffic Safety Administration (NHTSA) maintains a central database termed the Fatality Analysis Reporting System (FARS) to track such crashes. FARS is a census of all fatal crashes that occur on public roadways. It is considered to be the most reliable national crash database, although it only contains fatality related data. Our work relies on the FARS database for its empirical analyses.

The remainder of this paper is directed at developing and applying probabilistic models that bound the reduction in crashes due to the imposition of hours-of-service regulations. Section 3 reviews related literature. Section 4 develops and demonstrates probabilistic models, and Section 5 provides conclusions.

3. Literature review

The relationship between driving patterns and crash risk has been an active field of research. Much of this literature is surveyed in Orris et al. (2005), published as a research synthesis study of the Transportation Research Board. The authors' review found that sleep deficits, night driving, reduced sleep, and fatigue are associated with a variety of risk factors, including dangerous events, reduced performance, and falling asleep while driving. Looking more directly into the literature, Kaneko and Jovanis (1990) examined crash risks for consecutive and multiple driving days. Using a data set provided by a national less-than-truckload (LTL) carrier, a non-linear binary logistic regression was used to model crash risks. Through cluster analysis, the authors found that crash risks were highest during night and early morning driving. The authors also found that driving at different times of the day within 1 day, and over several days were associated with different

levels of crash risk. Over 7 day driving periods, the highest crash risk occurred during daytime and early evening hours. Night and early morning driving posed the least risk to truck drivers.

Harris and Mackie (1972) found significant changes in truck and bus driver performance after about ten hours of driving, relative to drivers who had driven less time. Drivers committed more errors and were physically less aware of external stimuli the longer they kept on driving continuously. Mackie and Miller (1978) found that driver performance errors significantly increase with longer hours of driving. Cumulative fatigue effects also show up with multi-day driving schedules. A time dependent logistic regression model was estimated by Lin et al. (1993), which showed that the likelihood of a crash increased significantly after the 4th hour of driving and kept on increasing significantly along with longer driving hours.

A study by the National Transportation Safety Board (NTSB) in 1995 examined the role of driver patterns of duty and sleep in single vehicle crashes. Through multivariate statistical analysis, results showed that the duration of the last sleep period, total hours of sleep in the 24 h prior to the crash, and split sleep patterns were important predictors of fatigue-related crashes. Moreover, truck drivers involved in crashes had slept an average of only 5.5 h, nearly 2.5 h less than the 8 h of sleep for drivers who were not involved in crashes. The study indicated that driving at night with a sleep deficit appeared to be more critical in predicting fatigue-related crashes than just nighttime driving.

A study by Wylie et al. (1997) investigated the degree of recovery afforded to truck drivers by rest periods. A group of five drivers who had driven for four 13-h periods with night starts were given a 36-h period off and then allowed to drive for four more consecutive 13 h night driving periods. Another group of 20 drivers who drove four 13-h day trips with daytime starts were exposed to four different conditions. The first group of three drivers was allowed no off-duty periods; the second group of five drivers was allowed a 36-h period off and then worked for four additional days; the third group of six drivers was given 36 h off and then worked an extra day. The final group of six drivers was given a break of 48 h and then allowed to work an additional day. The analysis showed that night drivers performed worse than their daytime counterparts. The subjects who had no off-duty hours displayed a significant decline in their driving performance. Truck drivers with break periods of 36 h showed a minimal decline in driving performance, while those with a 48 h break had no decrement in their driving performance.

Mackie and Miller (1978) determined that truck drivers operating on irregular schedules received less sleep and showed signs of fatigue prior to drivers operating on regular schedules, even when both sets of drivers were allowed to sleep for the same period of time. Due to the sleep debts accumulated by the irregularly scheduled drivers, drivers performed less reliably than their regular counterparts. Hertz (1988) and Jovanis et al. (1991) observed a stronger likelihood of crashes with nighttime driving. A Swedish study by Kecklund and Akerstedt (1995) found that the crash risk for trucks was 3.8 times higher between 3 a.m. and 5 a.m. when compared to the crash risk associated with daytime driving.

Jones and Stein (1987) investigated the connection between driving hours and crashes. They compared a sample of 332 tractor-trailer crashes to randomly selected trucks on the same road segment and at the same time of day as the crashes, sampled 1 week after the crash. The authors found out that the relative risk for drivers who had driven for more than 8 h was almost twice that of drivers who drove for fewer hours. Moreover, they found that drivers violating logbook regulations, drivers aged 30 and under and interstate operators had a higher crash risk. The study suggested that longer driving hours led to increased crash risks. This result was upheld in Kaneko and Jovanis (1990) and Wylie et al. (1997).

In long-distance trucking, carriers frequently use sleeper/driver teams, so that vehicles can keep moving while drivers alternately sleep and driver. Mackie and Miller (1978) found that this type of driver tends to display greater driver fatigue and worse performance than single drivers who drove along the same route. Sleeper drivers showed poorer driving skills, increased lane tracking variability, and more critical events that are indicative of drowsiness. In a majority of these cases, the sleeper drivers had undergone shorter driving times than their single counterparts. Sleeper drivers obtained less sleep than single drivers before commencing their driving operations, and sleeper drivers experienced disrupted sleep and lower arousal levels that culminated in degraded driving performance. In a similar study, O'Hanlon (1981) found that drivers usually displayed a decline in their performance at some point during their 4–5 h driving operations, but the effects are more pronounced in night driving, especially around midnight. Sleeper drivers are more prone to such decline in driving conditions and are unable to respond to situations effectively during late night and early morning driving.

Unlike the previously mentioned studies, Hertz (1988) found similar crash risks for sleeper drivers and single drivers. However, Hertz found that crash risks did not arise due to disturbance in sleep from truck motion, but due to the splitting of sleep into two periods. Drivers who split their sleep periods and relieved each other tended to face decreased driving performance and increased fatigue and subsequently higher crash risk levels. Dingus et al. (2003) reported that single LTL drivers were more frequently involved in critical incidents than their team counterparts. Team drivers were more able to manage their fatigue levels and critical incident involvement than single drivers. Single drivers were four times more likely to be involved in a critical incident than team drivers.

Beyond setting rules, compliance is an issue. In Braver et al. (1992), 73% of their 1249 surveyed tractor-trailer drivers reported that they had violated hours-of-service rules. Thirty-one percent of the violators reported driving more than the legal limit of 60 h in 7 days or 70 h in 8 days; more than 25% of these violators stated that they worked 100 h or more per week and 19% said that they had fallen asleep at the wheel one or more times during the previous month while operating a tractor-trailer. The study showed that drivers violated HOS rules due to irregular route driving, low pay rates, penalties for late arrivals and delays in services, carrying perishable commodities and being assigned unrealistic delivery deadlines. Over half of the drivers who violated the HOS regulations believed that they should be allowed to drive more than 10 h a day and have more flexibility in their work schedules.

Clearly many factors related to driver work hours affect truck safety. Hours-of-service regulations do not address all of these, but do act (if imperfectly) to constrain the length of driver trips. In the following section, we will concentrate on the relationship between crash rates and driver hours-of-service, as reflected in trip length (measured in time). We do not address the issue of cumulative fatigue, which would require analysis of the inter-relationship among driving tours over sequences of work shifts. Our focus here is on a single shift.

4. Bounding methodology

Past literature on truck safety has shown that longer driving hours are statistically linked to higher crash risks. A reduction in driving hours would consequently reduce the chance of a crash occurring. This reduction in risk can be predicted using probability distributions and a statistical framework. Probability distributions are created in this section to compare drivers who have had a crash after being on the road for more than x hours against those drivers who have had no crashes after time x . These distributions are truncated to produce bounds on the change in crash risks due to the imposition of HOS constraints.

4.1. Analysis of probability distributions

In this section, we develop and analyze probability distributions, which are then used to evaluate reductions in crash rates under a set of scenarios involving different HOS constraints. Probability distributions are specifically used to predict the proportion of crashes that happen after a certain time x as well as the reduction in crashes due to adherence to modified HOS constraints. The distributions are defined as

- $P(x)$ is the probability that a randomly selected truck on the road will have a *total trip length* greater than x hours and $g(x)$ is its assigned probability density function.
- $F(x)$ is the probability that a randomly selected truck on the road has an *elapsed trip time* of more than x hours *at the time it is selected*.
- $H(x)$ is the probability that a *crash involved* truck has driven for more than x hours at the time of the crash.

X is defined as the trip length in hours and is a random variable. It can be stated that $F(x) = \int_x^\infty g(z)P(T > x | z)dz$, where T is the elapsed time for a randomly selected truck on the road, and thus:

$$F(x) = \int_x^\infty g(z) \left(\frac{z-x}{z} \right) dz \quad (1a)$$

$$= \int_x^\infty g(z) dz - x \int_x^\infty \frac{g(z)}{z} dz \quad (1b)$$

Hence, $F(x) = P(x) - x \int_x^\infty \frac{g(z)}{z} dz$, and therefore $F(x) \leq P(x)$.

Let the crash rate per unit time be denoted as $a(x)$, where x denotes the time traveled since departure. The total crashes for vehicles that have driven more than x can be quantified as

$$\text{Total crashes beyond time } x = \int_x^{\infty} f'(z)a(z)dz \quad (2)$$

where,

$$f'(x) = -\frac{dF(x)}{dx}, \text{ or}$$

$$f'(x) = g(x) + \int_x^{\infty} \frac{g(z)}{z} dz - g(x) = \int_x^{\infty} \frac{g(z)}{z} dz \quad (3)$$

Now, to determine the proportion of crashes for vehicles that have driven greater than x , the distribution $H(x)$ is created.

$$H(x) = \frac{\int_x^{\infty} f'(z)a(z)dz}{\int_0^{\infty} f'(z)a(z)dz} \quad (4)$$

The reduction in crashes due to HOS regulations can be computed as the difference between the above function, $H(x)$, and the number of fatalities transferred to shorter trips (trips with fewer driving hours), as explained below. This can be summarized as

$$\text{Reduction in crashes} = H(x) - \text{Transference to shorter trips} \quad (5)$$

The term “transference to shorter trips” represents the transfer of risk from the ends of long trips to substituted shorter trips. For instance, if a trip that would otherwise take 10 h is truncated to 8 h, the deleted 2 h of duty must be covered in another trip of shorter length. The hours-of-service constraint reduces total crashes if the crash risk for the final 2 h of duty is larger than the crash risk for the substituted hours. The transference value must be non-negative, and therefore $H(x)$ is an upper bound on crash reduction.

An example of how the functions $F(x)$ and $H(x)$ can be obtained from a given $P(x)$ distribution and crash rate $a(x)$ is described below. For illustration, $P(x)$, the probability that a randomly selected trip length is greater than x hours, is assumed to be exponential. $g(x)$ is its assigned probability density function and the mean of the given distribution is denoted by $1/\lambda$, measured in hours. $F(x)$, the probability that a randomly selected truck on the road has driven for more than x hours at the time it is selected, is calculated as follows. Given:

$$P(X > x) = e^{-\lambda x}$$

$$\text{and, } g(x) = \lambda e^{-\lambda x} \quad (6)$$

$F(x)$ is calculated as,

$$F(x) = e^{-\lambda x} - x \int_x^{\infty} \frac{\lambda e^{-\lambda z}}{z} dz$$

$$\text{or, } F(x) = e^{-\lambda x} - \lambda x \int_x^{\infty} \frac{1}{z} e^{-\lambda z} dz \quad (7)$$

Integrating the right-hand side results in:

$$F(x) = e^{-\lambda x} - \lambda x \left(\ln |z| + \sum_{i=1}^{\infty} \frac{(-\lambda z)^i}{i * i!} \right) \Big|_x^{\infty} \quad (8)$$

For illustration, if the average trip length is 4 h, $F(7)$ (probability that a randomly selected truck has driven more than 7 h) is calculated as follows:

$$F(x) = e^{-0.25 \times 7} - 1.75 \int_7^\infty \frac{1}{x} e^{-0.25x} dx \tag{9}$$

or, $F(x) = 0.173805 - 0.121605 = 0.0522$

Hence, the probability that a randomly selected truck on the road has driven for more than 7 h at the time it is selected, given a mean total trip time of 4 h, is 0.0522, or about 5%.

$H(x)$ can next be derived by combining $F(x)$ with information on crash rates. First, by differentiating $F(x)$, we obtain $f'(x)$:

$$f'(x) = -\frac{dF(x)}{dx}, \text{ or} \tag{10a}$$

$$f'(x) = \int_x^\infty \frac{g(z)}{z} dz = \lambda \int_x^\infty \frac{1}{z} e^{-\lambda z} dz \tag{10b}$$

or, $f'(x) = \lambda \left(\ln |z| + \sum_{i=1}^\infty \frac{(-\lambda z)^i}{i * i!} \right) \Big|_x^\infty$

Next, for illustration, suppose that the crash rate is the logarithmic function $a(z) = b(\ln(z) + c)$, where z is the elapsed driving hours. Hence, the distribution $H(x)$ can be expressed as follows:

$$H(x) = \frac{\int_x^\infty f'(z)a(z)dz}{\int_0^\infty f'(z)(a(z))dz} \tag{11}$$

or, $H(x) = \frac{\int_x^\infty (\lambda \int_x^\infty \frac{1}{z} e^{-\lambda z} dz)b(\ln z + c)dz}{\int_0^\infty (\lambda \int_x^\infty \frac{1}{z} e^{-\lambda z} dz)b(\ln z + c)dz}$

The distribution for $H(x)$ can be obtained by dividing the integrals. Using the same example as earlier, and now assuming a crash rate $a(z) = 10^{-4}(\ln(z) + 1.5)$, the probability $H(x)$ that a crash involved truck has driven for more than 7 h is calculated as follows:

$$H(x) = \frac{\int_7^\infty (0.25 \int_x^\infty \frac{1}{z} e^{-0.25z} dz)(\ln x + 1.5)dx}{\int_0^\infty (0.25 \int_x^\infty \frac{1}{z} e^{-0.25z} dz)(\ln x + 1.5)dx} \tag{12}$$

or, $H(x) = 0.15055$

Hence, the probability that a crash involved truck has driven more than seven hours is 0.151 or 15%, which is an upper bound on crash reductions by imposing a 7-h HOS constraint. Note that the probability that a crash involved truck has driven more than seven hours is much higher than the probability that a random truck has driven more than seven hours, reflecting the higher crash rates for longer trips in the function $a(z)$. However, keep in mind that the actual reduction in crashes is $H(x)$ minus the proportion of crashes that are transferred to shorter trips (i.e., $H(x)$ is an upper bound).

This example can be modified to account for different types of distributions for $P(x)$ and different functions for the crash rate $a(x)$. While $P(x)$ was assumed to be exponential, other distributions, such as uniform, log-normal or gamma can be used to obtain results. The same holds true for the crash rate $a(x)$, such as linear, exponential, quadratic or even a constant, can be applied for the crash rate to explore other scenarios. Later, we draw insights from empirical data on truck-involved fatal crashes.

4.2. Analysis of odds ratio

In this section, we use the concept of ‘‘odds ratio’’ to develop a more precise estimate of the reduction in crash risks due to HOS constraints. We define the odds ratio as

$$\text{Odds_ratio}(x) = \frac{a(x)}{a(0)}, \tag{13}$$

where,

$a(x)$ is the crash rate per unit time and x denotes the elapsed time since departure. $a(0)$ is the crash rate per unit time when $x = 0$.

This concept was utilized by Park et al. (2005) to demonstrate that a sample of truck drivers had a greater likelihood of being involved in crashes as driving time increases (Fig. 1). At the end of 9 h of driving, the odds of a crash have doubled from the start. This implies that the driver is twice as likely to be involved in a crash in the 9th hour as in the 1st hour. The data in Fig. 1 were used to model the odds ratio as a function of elapsed driving time through logarithmic regression analysis, resulting in:

$$\text{crash_odds} = 1.149 + 0.374 \ln(x) \tag{14}$$

The R^2 value for this fit is 0.8426.

We now approximate the proportional reduction in crashes due to HOS constraints under an assumed condition that HOS constraints have the effect of truncating the distribution $P(x)$. An exponential distribution for driving time, as in Fig. 2, is used as illustration. For instance, if trip length has a mean of four hours, and the crash odds is as shown in Eq. (13):

$$\begin{aligned} F(x) &= 1 - e^{-0.25x} \\ F(\text{HOS}) &= 1 - e^{-0.25 \times 10} = 1 - e^{-2.5} = 0.9179 \\ F'(x) &= \frac{F(x)}{F(\text{HOS})} = \frac{1 - e^{-0.25x}}{0.9179} \\ \text{Odds_ratio(O.R.}(x)) &= 1.149 + 0.374 \ln x \end{aligned} \tag{15}$$

Then we can calculate the proportional reduction in crashes from the following ratio:

$$\text{Reduction} = 1 - \frac{\int_0^{10} \frac{d(F'(x))}{dx} \text{O.R.}(x) dx}{\int_0^{\infty} \frac{d(F(x))}{dx} \text{O.R.}(x) dx} \tag{16}$$

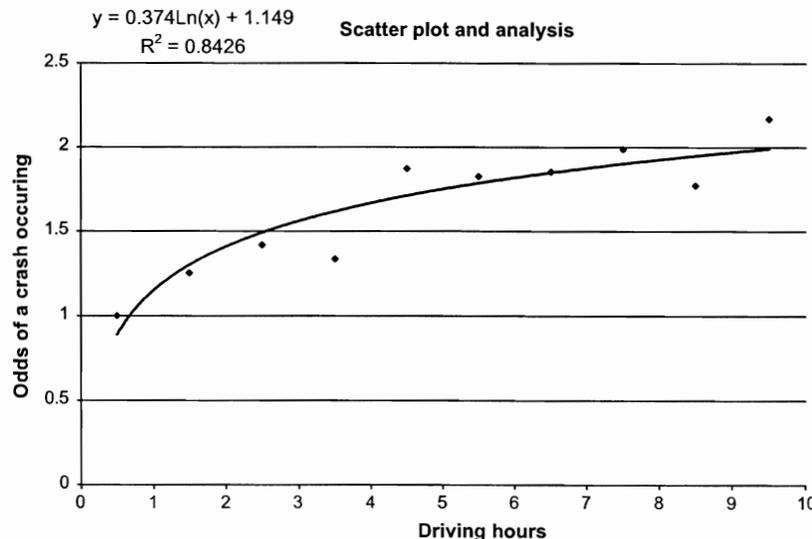


Fig. 1. Logarithmic regression for odds ratio.

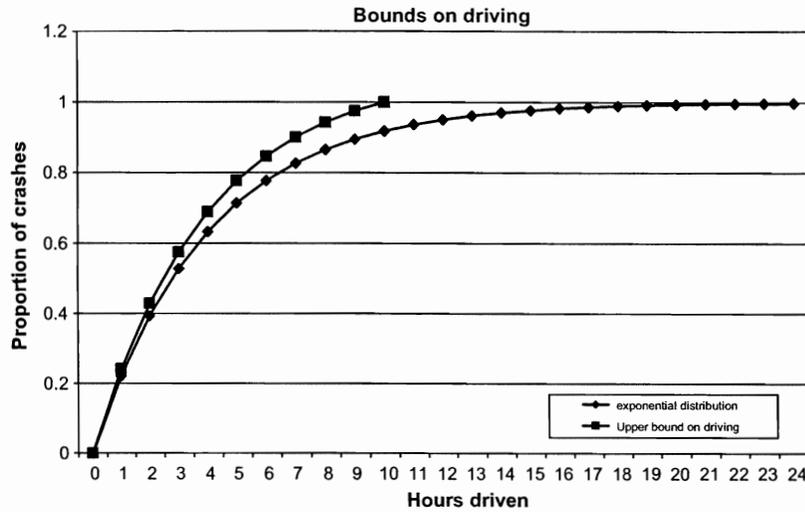


Fig. 2. Truncated exponential distribution.

$$\text{Reduction} = 1 - \frac{\int_0^{10} \frac{d(1-\frac{e^{-0.25x}}{0.9179})}{dx} (1.149 + 0.374 \ln x) dx}{\int_0^{\infty} \frac{d(1-\frac{e^{-0.25x}}{0.9179})}{dx} (1.149 + 0.374 \ln x) dx}$$

$$\text{Reduction} = 1 - 1.089 \frac{\int_0^{10} (1.149e^{-0.25x} + 0.374e^{-0.25x} \ln x) dx}{\int_0^{\infty} (1.149e^{-0.25x} + 0.374e^{-0.25x} \ln x) dx} \tag{17}$$

or, Reduction = 1 – 0.958222 = 0.041778

Hence, the reduction was computed to be 4.2%. Following the same method, the reduction in crashes is shown in Table 1 for HOS constraints of 6, 7, 8, 9, 10, 11 and 12 h, and mean driving times of 2, 4, 6 and 8 h.

The same truncation method may be used to estimate the reduction of crashes due to HOS constraints for other probability distributions. We will use the normal distribution as an example, with coefficient of variation (CV) values of 0.15 and 0.3, mean trip lengths ranging from 2 to 8 h, and upper bounds ranging from 6 to 12 h. But first, we use a mean driving time of 8 h and a standard deviation of 2.4 h (CV = 0.3) for illustration (Fig. 3).

If the trip length is restricted to no more than 10 h, then

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^x e^{-(x-\mu)^2/(2\sigma^2)} dx$$

$$F(\text{HOS}) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{10} e^{-(x-8)^2/(2 \times (0.24)^2)} dx = 0.797671 \tag{18}$$

$$F'(x) = \frac{F(x)}{F(\text{HOS})}$$

$$\text{Odds_ratio(O.R.)} = 1.149 + 0.374 \ln x$$

Table 1
Reduction in crashes due to upper bounds on driving time: exponential distribution

	Upper bound on hours							
Mean driving time	μ	6	7	8	9	10	11	12
	2	3.2%	2.0%	1.3%	.80%	.50%	.31%	.20%
	4	11%	8.3%	6.6%	5.2%	4.2%	3.3%	2.6%
	6	16%	13%	11%	9.6%	8.2%	7.0%	6.0%
	8	20%	17%	15%	13%	12%	10%	9.0%

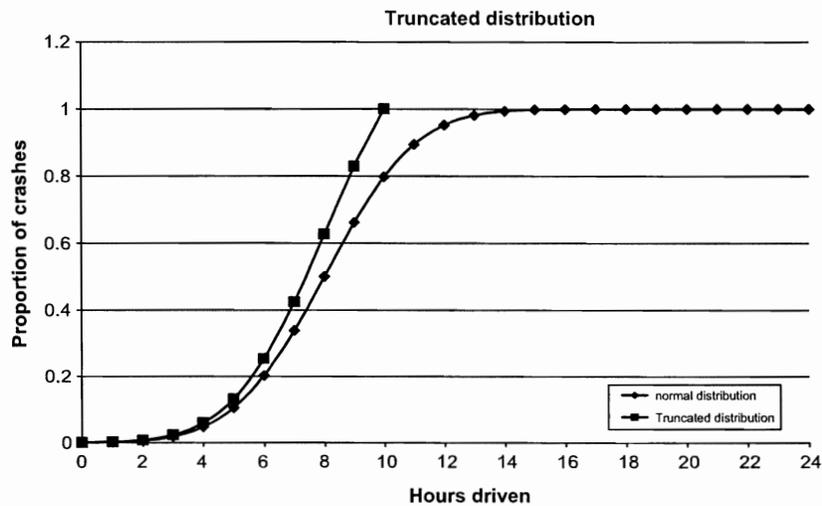


Fig. 3. Upper bounds on driving hours (normal distribution).

The reduction in crashes can be expressed through the equations below.

$$\text{Reduction} = 1 - \frac{\int_0^{10} \frac{d(F'(x))}{dx} \text{O.R.}(x) dx}{\int_0^{\infty} \frac{d(F(x))}{dx} \text{O.R.}(x) dx} \tag{19a}$$

$$\text{Reduction} = 1 - 1.2536 \times \frac{\int_0^{10} \frac{d(\int_{-\infty}^x e^{-(x-8)^2/(11.52)} dx)}{dx} (1.149 + 0.374 \ln x) dx}{\int_0^{\infty} \frac{d(\int_{-\infty}^x e^{-(x-8)^2/(11.52)} dx)}{dx} (1.149 + 0.374 \ln x) dx} \tag{19b}$$

$$\text{Reduction} = 1 - 0.9801 = 0.0199$$

Thus, crashes are reduced by 1.99% when HOS constrains driving to no more than 10 h. Table 2 shows the reduction of crashes for other parameter values. Unfortunately, the exact driving time distribution for trucks is unknown. However, a study carried out by FMCSA in 2003 found that the average trip length is about 6 h. Keeping this in mind, calculations were carried out by varying both the mean and the upper bound to get a wide spectrum of plausible scenarios. In Table 2, the maximum reduction (7%) occurs when the mean driving time is 9 h, with an upper bound of 8 h, and assuming a normal distribution with a CV of 0.3.

4.3. Preliminary analysis of FARS data

FARS, an acronym for Fatality Analysis Reporting System, was implemented by the National Highway Traffic Safety Administration (NHTSA), and is maintained by the National Center for Statistics and Analysis (NCSA). NCSA maintains an exhaustive set of data collected from its own internal data sources as well as data from other governmental agencies. FARS is one such data set. FARS contains data on a census of fatal traffic crashes occurring within the 50 states, Washington, DC, and Puerto Rico. For data to be recorded in

Table 2a
Reduction in crashes due to upper bounds on driving time: normal distribution ($\sigma = 15\%$ of μ)

$\sigma = 15\%$ of μ	Upper bound					
Mean driving time	μ	8	9	10	11	12
	6	0.0924%	0.003%	0%	0%	0%
	7	0.868%	0.1787%	0.017%	0%	0%
	8	2.36%	0.985%	0.27%	0.0437%	0.0031248%
	9	4.067%	2.31%	1.08%	0.373%	0.085%

Table 2b
Reduction in crashes due to upper bounds on driving time: normal distribution ($\sigma = 30\%$ of μ)

$\sigma = 30\%$ of μ	Upper bound					
Mean driving time	μ	8	9	10	11	12
	6	1.428%	0.5%	0.17%	0.04%	0.007%
	7	3.17%	1.739%	0.8%	0.339%	0.11%
	8	5.104%	3.33%	1.99%	1.08%	0.5%
	9	7%	4.99%	3.405%	2.19%	1.318%

FARS, a crash must involve a motor vehicle that has been traveling on a public roadway and the crash must result in the death of a person (vehicle driver, occupant or pedestrian). FARS data are divided into four categories – crashes, persons, vehicles and drivers. FARS provides the crash time, date, day, month, year, age of person, number of hours driven and the trip type are used in the analysis of crash risks, as well as other data. The last two variables are not directly linked to the FARS data, but are obtained from a different survey data set called Trucks Involved in Fatal Accidents (TIFA).

TIFA has been collected since 1980 by University of Michigan Transportation Research Institute (UMTRI) Center for National Truck and Bus Statistics in conjunction with NCSA. In addition to the FARS data, an extra set of variables was produced by TIFA, collected from police reports and surveys. TIFA data provide the elapsed time that drivers had been driving at the time of the crash. The driving times are obtained from the driver surveys collected by TIFA, as well as through police reports or from operator logs. This time is a lower bound for hours of service at time of crash, as the driver may have completed a prior trip in the same duty period. In many instances, however, the two times are the same. Due to the absence of data on hours-of-service at time of crash, the following analysis is based on driving time at time of crash as a proxy.

We now turn to the FARS data sets from the years 2000 until 2003, which provide a basis for determining the distribution $H(x)$, the probability that a crash involved truck has driven more than x hours. A histogram of the data sets is provided in Figs. 4 and 5 provides the cumulative distribution for driving hours at time of crash, or the $1 - H(x)$ distribution, for all three data sets.

In a previous section, reduction in crashes was computed by using the equation $\text{Reduction} = H(x) - \text{Transference to shorter trips}$. Thus, an upper bound for reduction in fatal crashes is $H(x)$, as shown in Table 3. For example, in the 2001 data set, the mean driving time at time of crash is 3.33 h. For instance, if drivers were restricted to no more than 9 h, the number of fatal crashes would decline by no more than 1.78%. It can be noted that an absolute constraint on trips of no more than 8 h would at most reduce fatalities by 3–5% com-

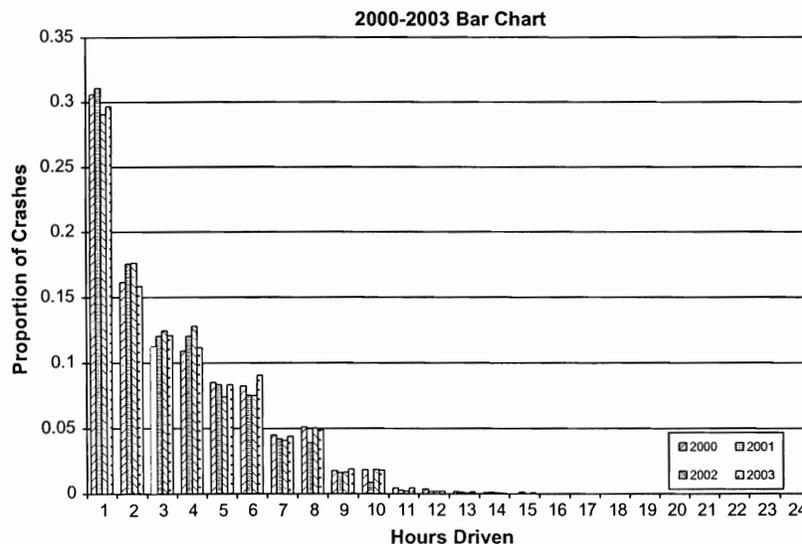


Fig. 4. Bar chart – proportion of crashes for years 2000–2003.

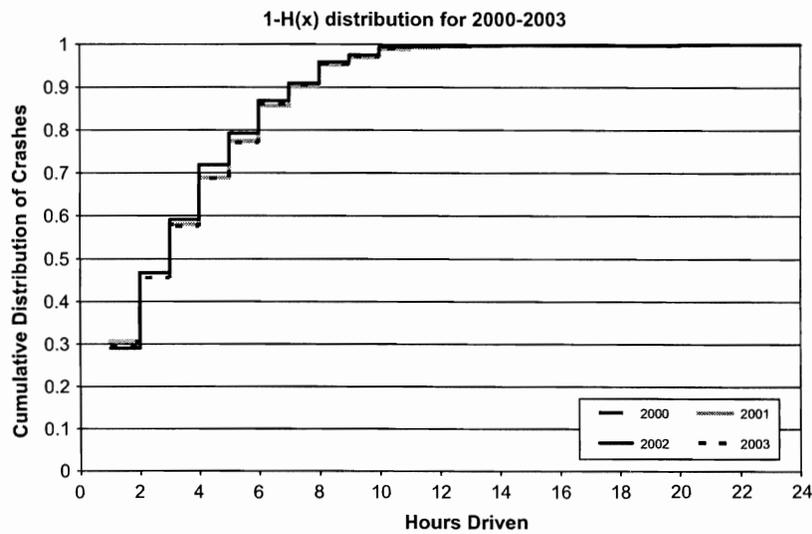


Fig. 5. $1 - H(x)$ distributions for years 2000–2003.

Table 3
 $H(x)$ empirical distributions for years 2000–2003

Driving hours	Mean driving time = 3.544 h	Mean driving time = 3.33 h	Mean driving time = 3.453 h	Mean driving time = 3.5478 h
	Year 2000	Year 2001	Year 2002	Year 2003
1	0.694255	0.689204	0.709677	0.70344
2	0.532619	0.513631	0.53331	0.545088
3	0.420318	0.393312	0.408836	0.424233
4	0.311263	0.272992	0.280856	0.312674
5	0.226225	0.189749	0.206872	0.229315
6	0.143784	0.114504	0.131837	0.138829
7	0.098994	0.072701	0.091164	0.095135
8	0.048036	0.033806	0.041024	0.046483
9	0.03051	0.017812	0.024544	0.02758
10	0.012334	0.009088	0.005961	0.009606
11	0.008114	0.006543	0.004208	0.005268
12	0.004544	0.004726	0.002454	0.003409
13	0.002921	0.003635	0.002104	0.002169
14	0.001947	0.002545	0.001403	0.001859
15	0.001947	0.001454	0.001403	0.00124
20	0.000649	0.000364	0.000701	0

pared to the present. This would depend on perfect enforcement, combined with an assumption of no transference of fatalities to shorter trips.

4.4. Mean hours until crash

In addition to affecting crash rates, HOS constraints can affect the mean driving hours at time of crash. HOS constraints have the effect of truncating the distribution of time until crash and, hence, reducing its mean value. To examine this effect, Table 4 provides the proportion of crashes at each given hour. The mean hours was determined by computing the summed product of the individual driving times and their respective probabilities, and then dividing the result by the sum of the probabilities.

For example, if a driver can drive for a maximum of 4 h, the mean total trip length is the sum of the individual probabilities from 1 to 4 h, multiplied by their respective driving times, then divided by the sum of the

Table 4
Probability values for proportion of crashes

Driving hours	Mean driving time = 3.544 h	Mean driving time = 3.33 h	Mean driving time = 3.453 h	Mean driving time = 3.5478 h
	Year 2000	Year 2001	Year 2002	Year 2003
1	0.305745	0.310796	0.290323	0.29656
2	0.161636	0.175573	0.176367	0.158352
3	0.112301	0.120319	0.124474	0.120855
4	0.109055	0.12032	0.12798	0.111559
5	0.085038	0.083243	0.073984	0.083359
6	0.082441	0.075245	0.075035	0.090486
7	0.04479	0.041803	0.040673	0.043694
8	0.050958	0.038895	0.05014	0.048652
9	0.017526	0.015994	0.01648	0.018903
10	0.018176	0.008724	0.018583	0.017974
11	0.00422	0.002545	0.001753	0.004338
12	0.00357	0.001817	0.001754	0.001859
13	0.001623	0.001091	0.00035	0.00124
14	0.000974	0.00109	0.000701	0.00031

Table 5
Expected number of driving hours at time of crash

Upper bounds on driving	Expected number of driving hours			
	Year 2000	Year 2001	Year 2002	Year 2003
4	2.035813	2.068999	2.125303	2.068982
5	2.361578	2.370122	2.393459	2.386007
6	2.711904	2.678571	2.705171	2.765741
7	2.92507	2.873383	2.897376	2.970204
8	3.196728	3.079759	3.164167	3.226843
9	3.301637	3.176165	3.262761	3.339069
10	3.424907	3.236242	3.38871	3.459953
11	3.457135	3.256131	3.402109	3.492835
12	3.487772	3.272094	3.417227	3.508704
13	3.503256	3.282746	3.420588	3.520499

probabilities. This method uses the weighted mean concept and provides a reasonably accurate estimate of the average elapsed driving hour when a crash occurs. For example:

$$E(X|X \leq 4) = \frac{1 \times 0.305 + 2 \times 0.161 + 3 \times 0.112 + 4 \times 0.109}{0.305 + 0.161 + 0.112 + 0.109}$$

or, $E(X|X \leq 4) = 2.035$

This means that the average elapsed driving time at time of crash is 2.035 h, given that 4 h is the upper bound for driving times. Table 5 provides the mean driving times for different HOS constraints. Note that the mean time until crash increases at a less than linear rate, approaching an upper bound that represents the time observed in the FARS data.

4.5. Economic assessment

We now turn to an economic assessment of the benefits of HOS constraints, combining the bounds created earlier with available data on the costs of truck-involved collisions in the United States. This will enable us to bound the economic savings, in reduced truck collisions, due to HOS constraints. These constraints naturally add to the costs of operating truck fleets, as described in Mukherjee and Hall (2006), because drivers cannot be

used as efficiently on short tours as on long. The costs of HOS constraints are more difficult to calibrate and are therefore omitted from this paper.

Savings in crash costs were estimated by applying data on the costs of truck crashes from Zaloshnja et al. (2000) to our bounding data, assuming that distributional data for trip lengths of fatal truck crashes are representative of all truck crashes. Miller and Spicer accounted for medical costs, emergency costs, property damage, lost productivity and monetized quality adjusted life years (QALYs). We adjusted their data to estimate costs in 2004 dollars, accounting for changes in annual vehicle kilometers traveled by trucks and inflation. The final cost values are shown in Table 6, which shows a total cost due to truck crashes of approximately \$30.1 billion in 2004. Monetized QALYs account for the largest cost share, with a value of \$16.2 billion. Total lost productivity followed with a value of \$10.8 billion, and the rest was split among medical costs, emergency and property damages.

We now turn to the reduction in costs that result from constraining driving hours. In Section 4, bounds on reduction in crashes were created from four probability distributions, three theoretical (based on exponential and normal distributions), and the fourth empirical, based on FARS data. We have applied these calculated bounds to the total economic costs of truck-involved crashes in Mukherjee and Hall (2006). Examples are provided in Figs. 6 and 7, and in Table 7 for the FARS data. For the FARS data, we provide multiple graphs,

Table 6
Total crash costs in millions by truck type (in 2004 dollars)

Truck type	Medical costs	Emergency costs	Property damages	Lost productivity	Total lost productivity	Monetized QALYs	Total
Straight truck no trailer	507	27	747	2164	3729	5054	10,064
Straight truck with trailer	60	4	87	241	578	1006	1735
Straight truck unknown with trailer							
Bobtail	24	2	50	155	203	156	435
Truck-tractor, 1 trailer	538	36	942	2562	5754	8969	16,239
Truck-tractor, 2–3 trailers	24	2	32	83	451	962	1,470
Truck-tractor, unknown # of trailers	2	0.2	6	8	13	13	33
Medium/heavy truck, unknown if with trailer	5	0.4	12	30	42	31	89
All large trucks	1160	71	1875	5243	10,769	16,190	30,066

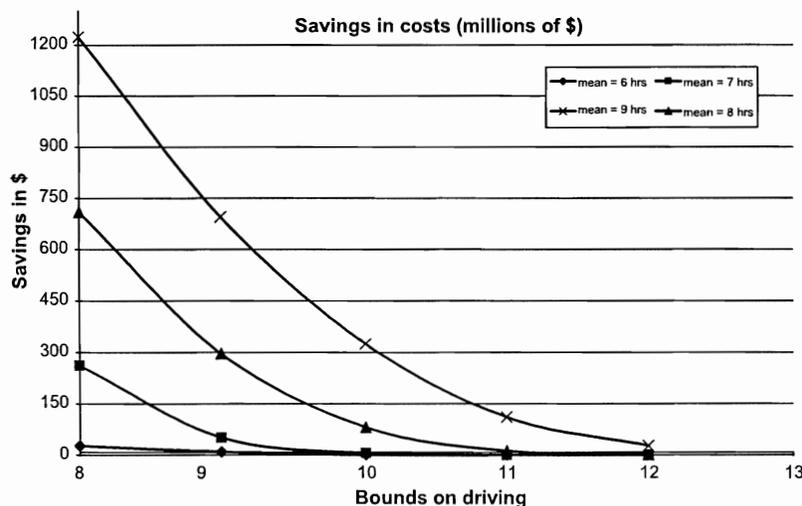


Fig. 6. Savings in cost for normal distribution (SD = 15% of mean).

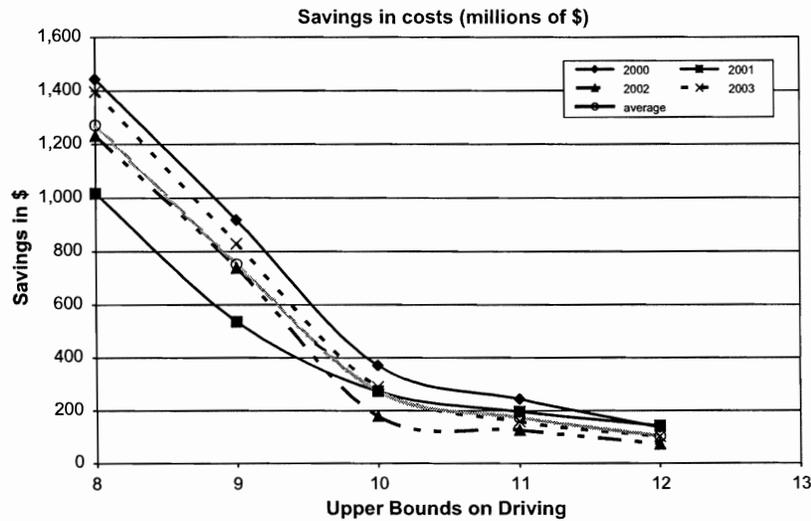


Fig. 7. Savings in cost for empirical distribution.

Table 7
Average reduction in costs for empirical distribution (millions of dollars)

Truck type	Bounds on driving				
	8	9	10	11	12
	Reduction percentage				
	4.23%	2.48%	0.91%	0.58%	0.35%
	Total savings in cost				
Straight truck no trailer	\$426	\$252	\$92	\$58	\$35
Straight truck with trailer	\$73	\$43	\$16	\$10	\$6
Bobtail	\$18	\$11	\$4	\$3	\$2
Truck-tractor, 1 trailer	\$687	\$406	\$148	\$94	\$56
Truck-tractor, 2–3 trailers	\$62	\$37	\$13	\$9	\$5
Truck-tractor, unknown # of trailers	\$1	\$1	\$0	\$0	\$0
Medium/heavy truck, unknown if with trailer	\$4	\$2	\$1	\$1	\$0
All large trucks	\$1272	\$752	\$274	\$174	\$104

each derived from the empirical distribution for a different year. We also provide a graph representing the average data among all of the examined years. One point to note, before discussing the results, is that the figures predict a savings, even for HOS values that exceed the current limit. This is because our graphs assume perfect compliance, when in reality some crashes occur beyond the legal limit.

We observe the following:

- The greatest savings occur both when the mean driving time is long, and when the variability is large. This is because more trips would otherwise exceed the bound imposed by the HOS constraint.
- The savings increase as the HOS constraint is tightened. Of the examples, the greatest savings occur with an exponential trip length distribution with a mean of 8 h and an HOS constraint of 6 h, in which case the potential savings is no more than \$6 billion per year.
- As a more realistic estimate, an 8-h HOS constraint could provide up to \$1.2 billion in annual savings, as derived from the empirical distribution, or with a normally distributed trip length of 9 h with a standard deviation of 1.35 h.
- The total achievable economic savings, while significant, is quite small relative to the size of the United States economy (a factor on the order of 0.01%).

5. Conclusions

In this research, methods were developed for analysis of probability distributions to determine the effect of HOS rules on driving hours. By plotting exponential and normal distributions for driving times and applying bounds on driving hours, we found that the reduction in crash rates was no more than 12–15% and 2–5%, respectively. A crash rate function was developed using data from LTL trucking companies and this crash rate was used in conjunction with the probability distributions to estimate the reduction in crashes. Driving hours from the FARS/TIFA data set were also used to estimate the reduction in crashes. By constraining driving hours, fatalities can be reduced by no more than about 3–5% compared to the present. This also means that drivers could only drive for a maximum of 8 or 9 h, 2 h lesser than the current HOS guidelines. A 3–5% reduction in crashes is only possible with perfect enforcement of HOS rules, and an assumption that no fatalities are transferred to shorter trips.

From an economic perspective, very stringent HOS rules, limiting drivers to perhaps six hours per day, would reduce the cost of crashes by no more than about \$1.2 billion per year. This number is consistent with prior FMCSA analyses, which estimated the annual cost of fatigue related crashes to be \$2.3 billion per year.

Acknowledgement

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OPINION.

Ezra Hauer, October 23, 2003

1. Introduction.

Congress asked the CDC Injury Center to evaluate the adequacy of the research design for the Large Truck Crash Causation Study (LTCCS). By 'research design' one usually means:

- a statement of the research questions to be answered;
- a description of the kind of data needed to answer them and of the amount of data necessary to do so;
- a plan for collecting the requisite data;
- information about the methods of analysis by which answers to the research questions will be extracted from the collected data.

The problem is that a document describing the LTCCS research design did not exist before the data collection effort commenced and does not exist now. What I know to exist are three documents giving clues about the DOT plans for the analysis of the data.

- a statement of how the sample data will be expanded to represent the continental U.S (Bondy, April 2003)
- A "Statement of Approach for Coding" (FMCSA, Undated) defining and describing the 'critical event' and 'critical reason' concepts.
- A paper by Blower (December 2001) describing a statistical approach to data analysis which defines 'causation' as being the same as 'relative risk'.

In addition, there exist two papers written for the TRB Committee, but these are more in the nature of external advice than internal plan. These fragments of approach to data analysis do not amount to a research design. Therefore, since a research design did not and does not exist, one cannot comment on its adequacy. The most telling observation to be made at this point is that the data collection for the LTCC Study was not guided by a research design and that during the two years of data collection no comprehensive plan for the analysis of the data has emerged.

At the time this opinion is written, the data collection phase is substantively complete. It is not useful anymore to ask what data should have been collected to answer which research question. We now face a fishing expedition—here is the data we have, see what can be found in it.

2. The Aims of the LTCCS.

The congressional charge for the LTCCS (Section 224 of the Motor Carrier Safety Improvement Act of 1999) was clear. It provides that: *"The study shall be designed to yield information that will help the Department and the States identify activities and other measures likely to lead to significant reductions in the frequency, severity, and rate per mile traveled of crashes involving commercial motor vehicles..."* Thus, Congress hoped for a study that will focus on countermeasures to reduce the frequency and severity of crashes involving trucks. For reasons that remain unstated in the documents that I have read, there has been a shift of terminology. The focus shifted from 'countermeasures' to 'causation'. Even the name- LTCCS- speaks of causation, not of countermeasures. Lurking in the background is the undeclared and unexamined belief that knowledge of causes is a necessary precondition for the determination of countermeasures'. Thus, e.g., in a rare statement of what the LTCCS is about, Croft and Blower, write (late in 2001?) that the study *"will determine contributing factors to fatal and serious injury truck crashes, allowing FMCSA to implement effective crash countermeasures."* How one is to translate 'causes' or 'contributing factors' into the *"activities and other measures likely to lead to significant reductions in the frequency, severity"*, which Congress is interested in, has somehow fallen of the table; only causation remained.

At this point it is not necessary to have an agreement about whether knowledge of 'cause' is necessary for the development of efficient countermeasures². Not is it necessary to agree on whether knowledge of 'cause' is usually a good starting point for countermeasure development. It is only necessary to restate that the final aim is development of countermeasures; that crash causation is only an *instrument* to be used towards this aim; that is, causation derives its importance solely from its possible success in pointing out efficient countermeasures³. This leads to several conclusions:

C1⁴.The LTCCS will be incomplete if it does not clarify the link between what it identifies as 'causes' (or 'reasons', or 'contributing factors') and the

¹ It is perhaps not idle to note here that, in contrast to the lay public, the notion of cause is the source of consternation and difficulty to scientists and philosophers over many centuries. Furthermore, for statisticians who attempt to extract information from data, the distinction between cause and association has been difficult to make (except, perhaps, in randomized trials).

² Dan Blower, the architect of the statistical approach for LTCCS, says (2001) that: Ultimately, the goal of the LTCCS is to support the search for countermeasures to reduce the number of trucks involved in traffic crashes. . . In fact, **the most effective countermeasures may not be related to causes.** (Emphasis added).

³ A countermeasure is efficient if it is attractive in terms of the achievable reductions in crash frequency or severity and the overall cost of its implementation.

⁴ The conclusions I reach will be numbered as C1, C2, etc.

countermeasures to which these lead. Are 'causes' a good way to identify efficient countermeasures? Do they lead to new countermeasures, ones that were not already otherwise evident? Are there efficient countermeasures that are cannot be identified using the 'causes' suggested by the LTCCS? In what way should the DOT and the States use the results of LTCCS in developing countermeasures? Can one use the LTCCS 'causes' to speculate about countermeasure effectiveness, about setting priorities?

C2. Inasmuch as the approaches to the analysis of the collected data are at this time still fluid, it is possible to adopt the following as general guidance for the development of data analysis approaches:

The attraction of an approach to the analysis of the LTCCS data should be judged by its contribution to the ultimate aim which is the development of efficient countermeasures.

In what follows I will adhere to this guidance hoping that it will help to reduce some of the confusion that comes from preoccupation with the elusive notion of cause.

3. Critical Event and Critical Reason.

In the documents I have, much space is devoted to the notions of 'Critical Event' and 'Critical Reason' inherited from an old study by Perchonok (1972). Thus, e.g., the FMCSA Statement of Approach (undated) defines the Critical Event as:

"...the event after which the collision was unavoidable . . . The critical event "causes" the accident in a physical sense because, given the mechanical properties of the vehicle and roadway, there was no chance to avoid the crash after the critical event occurred."

The same document states that:

"The critical reason is the reason for the critical event. It is the "cause" of which the critical event is the result. The critical reason is the failure in the vehicle, driver, or environment that explains the critical event."

What Critical Event and Reason are in a crash is determined by 'crash coders'. That is, after all the data for a crash has been collected, it is shipped to the 'zone centers' where experienced staff called 'crash coders' determine what for that crash was its 'Critical Cause' and what its "Critical Reason". The determination of Critical Cause and Reason is

not the judgement-free conversion of field data to numeric code; it is an interpretation about which opinions may differ.

Another document speaking about Critical Event and Critical Reason and written from inside the FMCSA is by Blower (2001). He explains the same two concepts in similar words but asks us to *"Note that the critical event is not the "cause" of the crash"*. Later he asserts that:

"The critical reason is not intended to establish the "cause" of the crash, though many of the code levels look like causes. But that is not the intent of the variable, and using the variable in that way both misconstrues the variable and can mask the range of contributing factors."

We can rightly be confused; are they a cause or are they not?. It appears that within the FMCSA there is no agreement about the nature of what seems to be a key organizing principle. For our purpose the question is not so much whether the Critical Event or Reason is to be considered as 'cause'; the important question is what use is to be made of these concepts in data analysis?

The documents I have read do not answer to this question. Thus, while Critical Event and Reason are written about as if they were the backbone of the objective approach to the data organization and perhaps of analysis, it remains unclear how and what for these two notions will be used. Will one tabulate frequencies of critical events or reasons? Is the intent that someone else in the DOT or the States to examine these tabulations at a later time and derive from them an inspiration about what might be attractive countermeasures? Will the tabulation be taken as an indication for the setting of priorities amongst countermeasures? Can or should such tabulations be used to spot or to prioritize countermeasures? Is this how these notions have been used in the past? Was this kind of 'past use' considered a success?

To these questions and similar questions I found no documented answers. While the TRB committee had persistent misgivings about the specific way in which Critical Event and Reason were determined by the crash coders, it is impossible to know how important these misgivings are. It is another instance of the problem recognized at the outset. To comment intelligently about the adequacy of a research design, a research design must exist. Similarly, to make useful comments about the Critical Event and Reason approach, one must know how these notions are to serve. When this is unstated, the commentator is reduced to speculation.

My speculation is that the intent is to provide in the LTCCS report some tabulations of the frequencies of critical events and of critical reasons and that these tabulations will be used (later and by others) as inspiration or justification for various countermeasures. The question is whether such a use would be sensible. To answer this question I will go back to the source (Perchonok, 1972) to see what use he made of Critical Event and Reason. Following that I will examine what kinds of countermeasures are identifiable by Critical Event or Reason, which countermeasures usually escape attention, and which can never be reached.

3.1 What Perchonok did.

Perchonok (1972) begins by saying that: *"A brief review of studies of accident causation suggests little to recommend it as an area beneficial to highway safety."*(p.3). His intent was to check whether the study of accident causation could be made profitable by erecting a *"solid systematic framework"* in which the chain of events preceding accidents is described objectively and coded, so that it can be the subject of computerized quantitative analysis. His objectives were mainly two¹: *"1. Examine the causal structure of accidents to analyse the accident process,"* and to *"2. Analyse elements of the causal structure together with the accident context to determine relationships between them."* The development of countermeasures or their prioritization was not his objective. However, he says that: *"It is clear that these objectives (1 and 2 above) cannot directly yield solutions to the accident problem. Rather, they point to problem areas requiring solution. But then, what better place to start?"* (p.5)

Perchonok says that the Critical Event is, *"...the cornerstone of the causal structure (and) was thought of as the last cause. ... While the critical event described the activity which produced, or allowed the critical condition, the critical reason described why the unit did so."* The Critical Event and Reason *"carried to most useful information in the causal structure"* (p.9). Indeed, opening the RESULTS section (p.21) are tables of the frequency of Critical Reasons (Table 5) and of Human, Vehicular and Environmental Reasons for Critical Events (Table 6). About these Perchonok says that:

"... a determination of the relative contribution to accidents by the human, the vehicle and the environment was determined by analyzing critical reasons." (p.23).

While later researchers may have reservations about Perchonok's unabashedly causal interpretation given to Critical Reason, for him it was the essence of the approach. Thus,

¹ Actually there were three objectives, but the last objective is not directly relevant here.

e.g., if in 57% of the Critical Reasons were found to be "Human" (driver breakdown, primary control, sensing ...) this was deemed to be the contribution of the human elements to accident causation.

In discussing the results of his research Perchonok returns to the issue of central interest here, namely, whether Critical Cause and Reason can lead us to countermeasures. He says (p. 63) that:

"... one topic, as yet, has not been treated; viz., accident prevention. Although this study was specifically addressed to accident causation; although the two topics, while related, are not the same; and although increased knowledge of accident causation can't help but enhance accident prevention; the question remains: Do any of the findings herein suggest routes for accident prevention? Perhaps so."

To illustrate some cases in which accident causation may lead to countermeasures, Perchonok mentions older drivers and what are called their 'recognition' and 'projection' problems found in his study to be of some importance. On this basis he says that this may call for better older driver testing. Regarding 'information failures' in general (which accounted for more than 40% of the critical reasons for culpable drivers) he says that "it is not likely that any great strides will be made by arming drivers with this fact" and the "drivers need help". In short, having completed the analysis of the data, Perchonok's position is that better understanding of the accident causation process is bound to be of general benefit, but that it remains unclear whether the findings of causation research are of much use in suggesting routes to prevention.

3.2 Which Countermeasures Can and Cannot be Identified using the Critical Reason?

The Critical Event is a useful notion in that all subsequent events are pre-ordained. Therefore, one should not look for countermeasures after the critical event occurred. On the other hand, the usefulness of Critical Reason for countermeasure development requires scrutiny.

Strong convictions and entrenched position that often mar discussions on road safety. To sidestep these, consider an example set in a more different context. A candle was placed on the windowsill. A draft caused the flame to flicker and the curtain caught fire. The fire spread to the sofa and chairs filling the apartment with smoke. The smoke-alarm battery was dead and there was no sprinkler system in the apartment. The occupants woke up, groped their way to the door through the smoke but the door was locked and they could not find the key. From here on the sad result was inevitable. Thus,

the door being locked or the key being difficult to find are the Critical Event. The reasons for locking the door or the reason for the difficulty to finding the key is then the Critical Reason. Is this Critical Reason particularly informative about what could have prevented the outcome? I think not. Many countermeasures that could have prevented the conflagration and its consequences come to mind. Only few of these have much to do with the Critical Event or Reason. One thinks of countermeasures such as allowing to sell only candles the flame of which is protected from drafts, using fire retardants for curtains and sofas, mandating sprinkler systems in apartments, requiring keyless locks on doors, etc.. The moral of the story is that focus on the Critical Reason points the searchlight on a subset of countermeasures and leaves other countermeasures in the dark, outside the scope of our attention. The two groups of countermeasures – those illuminated by Critical Reasons and those left in the dark – tend to be systematically different. The nature of their difference is best explained by a picture¹.

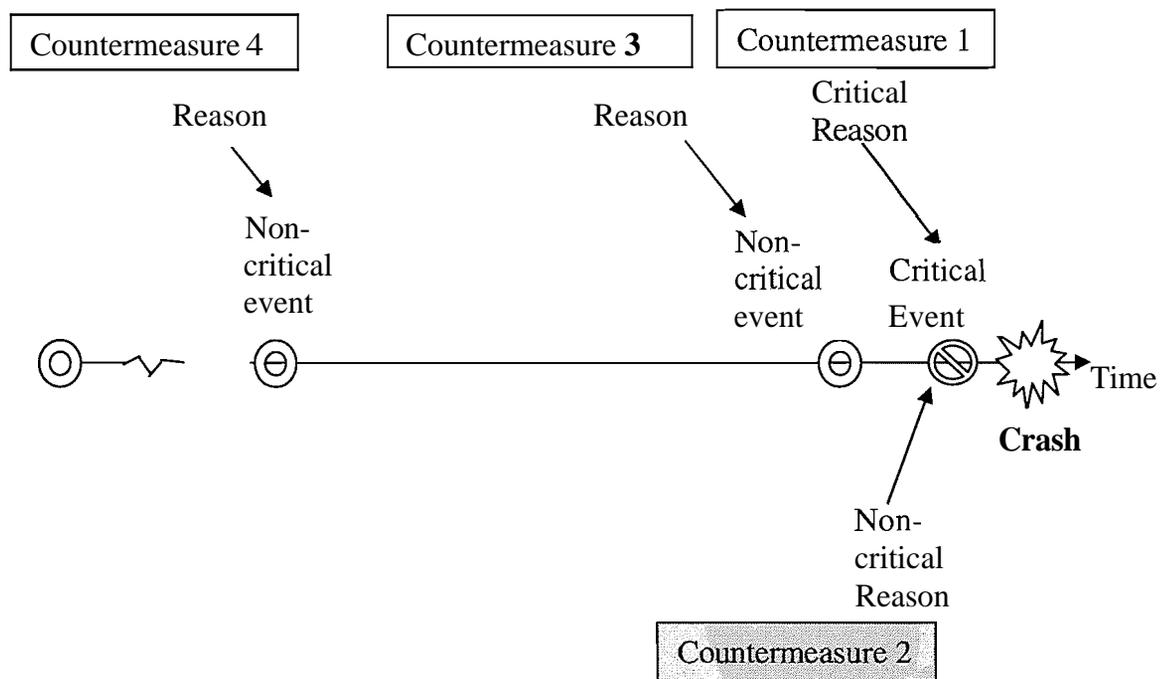


Figure 1

¹ The picture will be constructed using the Perchonok model of crashes being the end of a chain of 'events' such that each event has its 'reasons' , with reasons being the subject of 'countermeasures'. While better representations may exist, this one is sufficient for the present purpose.

The critical event is proximate to the crash. The critical reason is why the crash could not be avoided - the brakes could not possibly stop the vehicle, the driver was asleep and therefore did not brake or steer to avoid the crash etc. Countermeasure #1 is the action that could have altered the critical reason. It could have taken place sometime in the past (brakes could have been adjusted before the trip; the driver could have been assured of a proper rest etc.). Still it must be a measure to alter the reason for an event very close in time to the crash. This leaves in the dark countermeasures the could have altered a non-critical reasons (#2) for the critical event and countermeasures aimed at altering reasons for events or circumstances occurring or prevailing long before the critical event has occurred (#3 and #4). To make this argument more tangible, consider the example in the FMCSA Statement of Approach (undated) of a chain of events preceding a crash:

"Consider a simple rear-end collision (this example is modeled on an actual fatal crash involving a heavy truck). The lead vehicle slowed to turn left into a driveway of a store's parking lot. There was no turning flare or center-left lane, so the car was slowing in the through-traffic lane. The truck driver of the following vehicle noticed some construction to his right in a mall and a sign advertising a two-for-one special at a fast food restaurant. He did not recognize that the lead vehicle was slowing until he was too close to stop safely."

It appears that *"Fails to notice slowing vehicle in time"* was taken to be the Critical Reason in this crash. In discussing the crash the document says that *"If the truck's brakes had been in better shape, it may have stopped in time or at least not hit as hard."* This then could be the 'non-critical reason' in Figure 1. Since this is not a critical reason, countermeasure #2 in Figure 1 would not feature in a tabulation of critical reasons. The FMCSA documents proceeds to discuss events and circumstances further removed from the time of the crash and says; *"If there had been a turn lane, the car would have been out of the line of traffic."* This then is a non-critical event or reason to which countermeasures such as #3 or #4 in Figure 1 would apply. But, of course, reasons of this kind, being further removed from the critical event will not show up in a tabulation of critical reasons. Therefore, if the critical reasons are to be the inspiration for countermeasures, some countermeasures are less likely to be spotted and some are unreachable.

Critical Reason will lead us to think of countermeasures that could alter events associated with the movement of the vehicle just before the crash (condition of brakes, inflation of tires, securing of load, etc.) and events associated with the actions or the state of the driver just before the crash (lateness of perception, sleep, drugs or alcohol in blood,

etc.). Reasons related to vehicle design (number of trailers, type of train coupling the trailers, roll threshold, off-tracking, etc.) are not likely to be critical reasons. Driver-related characteristics (prior convictions and accidents, seniority, diabetes, etc.) are not likely to be critical reasons. Firm related characteristic (firm size, existence of safety management program, etc.) are not likely to be critical reasons. Road related characteristics (presence of driveway, absence of turning lane, signal without dilemma zone pre-emption, etc.) will never surface as critical reasons. Reasons related to planning and regulation (size and weight regulations, location of trucking terminals, truck-rail mode split) will never be critical reasons. Thus, the use of Critical Reason as an inspiration for countermeasure development is flawed. It points attention to a small subset of countermeasures and there is no assurance that the countermeasures noted by this device are more promising than the countermeasures missed by it.

The FMCSA Statement of Approach explicitly acknowledges that the crash described earlier has many factors when it says:

“What is the cause of this accident? Inattentiveness by the driver of the following vehicle? Following too closely? Insufficient braking capacity? Poor maintenance? Insufficient friction from the roadway? Roadway design not up to the increased flow of traffic because of the development of the mall? Poor driving technique since he didn't attempt to steer around the stopped vehicle? Slow reaction time? The distracting signs? Many factors contributed to the occurrence of the accident. Which one is the cause? Identifying the range of factors that contributed to the crash better captures what happened than simply listing "driver inattention" or "brakes out of adjustment" as the cause.

The FMCSA also acknowledges that countermeasures may be many when saying that:

” . . . approaching traffic crashes as the product of multiple chains of events gives us a broader perspective on crash prevention. Once you start thinking about crashes as the product of many factors, you can more easily identify a variety of different ways to prevent the crash or to lessen its severity. In the example above, a better brake maintenance program might be helped lessen the severity of the crash. A forward obstacle detection system might have alerted the driver in time. Defensive driving training might have improved the driver's response. Better roadway design might have moved turning traffic into a dedicate lane, improving traffic flow.

Given this recognition each crash is the result of a long chain of events and that countermeasures can apply at any link of this chain, one might expect that in the LTCCS

approach no single event or reason will be elevated into overriding prominence; that some rational system would have been developed to address the reality of potential countermeasures being attached to reasons all along the event chain. It is therefore puzzling to see the notions of critical event and reason are being described as some kind of organizing principle.

The advocates of the Critical Event and Reason approach emphasize its objective nature in the sense that, in defining these concepts, there is less scope for judgement than in the Indiana Tri-Level study which required considerable judgement to be exercised by experts. Admittedly, reliance on expert judgement was a weak aspect of the otherwise sensible approach of the Indiana Tri-Level study. Because the Indiana approach was sensible its conclusions and data base were widely used. The problem is that the appearance of objectivity, the selling point for the Critical Event and Reason concepts, is bought at the expense of good sense. I may have missed some point that is obvious to others. However, if I did not, then for the purpose of developing countermeasures, the use of Critical Reason and Event makes no good sense.

We are now in a position to summarize. The object of the LTCCS is to support the development of efficient countermeasures for crashes involving trucks. No indication was given about how Critical Event and Reason are to be used for this purpose. No reasons were given to show that the notions of Critical Event and Reason can serve this purpose well. An argument has been made to show that the notion of Critical Reason will leave many a promising countermeasure in obscurity. Therefore, in my opinion,

C3. The notions of Critical Event and Reason should not be used as a basis for frequency tabulations in the LTCCS final report.

3.3. Use of data.

Craft and Blower say that:

"The LTCCS will provide more information about truck crashes in richer detail than is available anywhere else. The study will supply unprecedented detail about the types of motor carriers, methods of payment to drivers, incidence of fatigue, recent sleep schedule, medical condition of drivers, mechanical condition of vehicles, roadways, and other factors. Much of the data will come from on scene data collection, and the crashes will be a representative national sample of truck-involved serious crashes. In addition the data will be coded, with the help

of descriptions and reconstructions provided by field staff, into a relatively detailed picture of what physically happened in the crash.

This much is certainly true. The hope is that in the hands of competent researchers this unique data set will lead to a rich harvest. None of the earlier criticism of Critical Cause and Reason should be taken to mean that the collected data cannot be profitably used. I am less certain about the next statement by Craft and Blower:

"Merely tabulating the prevalence of many variables will be instructive. What is the comparative presence of alcohol, drugs, fatigue, and medical conditions among truck and other drivers involved in these crashes? How often are mechanical problems of the vehicles associated with the crashes? Do roadway design and adverse weather conditions show up prominently in the data?"

The tenor of this statement runs counter to the spirit of the Relative Risk notion (to be discussed later) on which much of Blower's statistical approach to the data analysis rests. Thus, e.g., should it turn out that truck drivers in crashes have less alcohol in their blood than car drivers will that mean that companies do not need to insist on alcohol-free driving? Should one find a surfeit of mechanical problems on trucks in crashes does this mean that a remedial program is called for even if the same kind of mechanical problems are found just as frequently in trucks not in crashes? Should that fact that few roadway variables were coded mean that no effort should be made to make roads more truck friendly?

It is certainly feasible to do 'data mining' and perhaps some unexpected associations will be found. However, the "*Merely tabulating*" activity is seldom a reliable guide for countermeasure development. In the hands of non-experts and decision-makers tabulations of this kind often lead to ill conceived programs and the attendant misallocation of resources.

There is, however, a use of the data that I did not see emphasized in the reports I read. Whenever a potential countermeasure is contemplated, one needs to know to how many crashes it may apply. Thus, e.g., if one considers a countermeasure aimed at overturning crashes on the ramps of rural interstates one may want to know their number. One may also want to know the distribution of roll-over threshold of as-loaded trucks on such roads and ramps. In this manner, the assembled database may prove of direct use to countermeasure development.

4. Relative Risk.

In his thoughtful paper, Blower (2001) says that: *"The LTCCS relies on a statistical approach to "causation," defining cause in terms of relative risk."* (emphasis added)' Thus the elusive 'cause' is replaced by the sensible notion that there are many factors that affect the risk of crash occurrence and that the assembled data is to be used for detecting for such factors. Blower explains:

"Since the way the crash physically occurred is known, statistical tests can show if a particular "risk increasing factor" was overinvolved in the kind of crash where the physical mechanism could be expressed. For example, the LTCCS data will provide information about the condition of the trucks' braking system. Crash type coding can be used to distinguish rear-end crashes in which the truck was the striking vehicle from those in which the truck was struck. Hypothesis: trucks with poor braking are overinvolved in rear-end crashes in which the truck was the striking vehicle. Using the LTCCS data, this hypothesis can be tested ..."

The test statistic in this case is the ratio: (proportion of striking trucks with bad brakes)/(proportion of struck trucks with bad brakes). This ratio is called the Relative Risk (RR). If $RR > 1$, trucks with bad brakes are 'overinvolved' and therefore one can say that bad brakes cause accidents in the sense that, were the brakes better adjusted, fewer or less severe accidents would have occurred.

My comments about the statistical approach to causation and the corresponding analysis of the LTCCS data as described both Blower (2001) and Hedlund (2003) are in three parts. First I will discuss the relationship between that task of countermeasure development and the statistical approach to causation. Second, I will examine the danger of confounding that is associated with the data-set assembled in the LTCCS. Third, I will comment on what I think is a conceptual problem in Blower's examples and the implication thereof for the analysis of the data.

¹ He demotes Critical Reason to its proper role saying that the "... analysis of the data is not completed by an enumeration of the critical reasons assigned. Instead, the critical reason should be used as another bit of evidence of what happened in the crash."(p. 12)

4.1 Overinvolvement and Countermeasures.

The statistical analysis approach suggested by Blower(2001)) as the mainstay of LTCCS approach to data analysis is a search for factors that can be shown to be associated with overinvolvement'. Hedlund (2003) thinks of the same statistical approach is a part of 'Problem Identification' – the finding of factors that substantially increase crash risk². The question is whether only those factors that are associated with overinvolvement are legitimate targets of countermeasures. This question can be asked in two parts:

- A. Is the existence of overinvolvement usually a good motivation for interventions?
- B. Is the absence of overinvolvement usually a good reason for non-intervention?

Ad A. Under certain conditions one can say and believe that if a factor is associated with overinvolvement then, a change in that factor will cause a change in crashes. Thus, e.g., motorcycle riders have a higher relative risk of severe or fatal injuries than car drivers. Compared to car drivers they are overinvolved. The change in this 'factor' (being a motorcycle rider) would involve making motorcycle riders into car drivers, or somehow giving them a comparable protection against injury. Thus, while this overinvolvement points to a cause (lack of protection against injury), to have a countermeasure one also has to have the ability to influence that cause. The possibility of exerting influence over a cause is in no way indicated by the presence or degree of overinvolvement. Therefore,

C4. Only factors the levels of which can be practically influenced or altered need to be examined for overinvolvement.

Ad B. Some successful countermeasures (e.g. those aimed at drinking and driving) do have overinvolvement as a part of their motivation. Other countermeasures (e.g. occupant protection by seat belts) were not motivated by overinvolvement (although, post-factum it can be shown that unbelted occupants have a higher risk of fatality than belted occupants). The point is, that a successful countermeasure need not be aimed at reducing overinvolvement. All that is necessary for success is to have a factor that influences risk in many circumstances (even if not at a level causing overinvolvement) and the possibility to alter the level of that factor cheaply. Thus, e.g., to reduce night-time crashes it makes sense to illuminate a freeway with 100,000 vehicles per day before illuminating

¹ As noted earlier, overinvolvement and relative risk >1 considered synonymous.

² 1) The other part of Hedlund's 'Problem Identification' is the task of finding factors involved in a substantial number of crashes.

a two-lane road with 5,000 vehicles per day, even if the relative risk of travel on the latter is much higher than on the former. It is the number of target-crashes that matters, not overinvolvement. Similarly, even if triple-trailers were found over-represented in some kind of crash relative to semi-trailers, the contemplation a vehicle countermeasures should be significantly influenced by the fact that the semis are more than a thousand times more numerous than triples.

To sum up this part of the argument, use of the LTCCS data to estimate relative risk for some factors is promising. However, efficient countermeasures can be developed for target accidents and factors that do not exhibit overinvolvement. Therefore,

C5. the existence of overinvolvement must not exert an unduly large influence in the quest for efficient countermeasures.

4.2 Relative Risk and Confounding

Consider again the example of relative risk estimation discussed in several documents:

"...So, does brake adjustment affect accident risk? By collecting brake adjustment data on all trucks involved in a crash, regardless of whether braking had anything to do with the crash or the role of the truck in it, it is possible to measure the effect of brake adjustment on particular types of crashes. If trucks that are rear-ended while stopped (where their own braking capacity had nothing to do with the crash) have a lower percentage of brakes out of adjustment than trucks that are rear-ending other vehicles, that is evidence that brake out-of-adjustment increases the risk of accident involvement and we can calculate the amount of the increased risk."

In this example, trucks that are rear-ended while stopped are the 'comparison crashes' relative to which the factor (brake adjustment) for the rear-ending trucks is assessed. At first glance, this miniature 'study design' seems sensible. The question is whether there are plausible ways in which this choice comparison group can lead to incorrect conclusions.

Confounder A: Trucks that are rear-ended are usually stopped at intersections. Most intersections are in urban areas. Truck driven in urban areas may not have the same degree of brake adjustment as truck in rural areas. Trucks driven on freeways may not have the same brake adjustment as trucks driven on arterials. Three-axle units may differ from four-axle semis. If a separate analysis is not done for 'urban' and 'rural', freeway and arterial, single-unit and semis, the results obtained may reflect differences by area or road type, or truck type, rather than brake adjustment. A similar scenario is the following:

Vehicles with well adjusted brakes are found in large fleets with good maintenance programs, well paid, well trained, senior drivers. In contrast vehicles with poorly adjusted brakes tend to be driven by less well paid or trained drivers, who are in more of a rush etc. Thus, the difference in relative risk may not be due to the brakes but due to the seniority, training, pay etc.

This brings to the surface a generic issue. The danger of confounding is usually minimized by matching (in case-control studies) or by stratification (estimating separately for urban-arterial,-single rural-freeway-semi, etc.) It may not be possible to sufficiently stratify a sample of 1000 cases (of which only a portion will fit the 'rear-ended' or 'rear-ending' categories) without making the results so statistically imprecise as to be useless. This point is made convincingly by Hedlund (2003)

Confounder b: The first vehicle in the queue at a signalized intersection often has to make a decision to stop on amber or continue. That decision may depend on what the driver knows about his brakes. Therefore, the first stopped vehicle may have better than average brakes. Not accounting for this would lead to a biased estimate of relative risk. A similar bias will be at work in the following circumstance: A truck brakes unexpectedly and rapidly and is hit from behind. It must have good brakes and the inclusion of this vehicle in the comparison group will again lead to the same kind of bias. Biases of this kind cannot be easily accounted for by stratification.

Thus, what at first glance seemed to be a reasonable choice for a comparison group may not withstand closer scrutiny. The problem is that when a study is being designed, thought is usually given to potential confounders. If the danger of confounding can be reduced by matching and stratification, the possibility to do so is built into the study design. In the LTCCS not much prior thought was given to the questions to be asked nor to the design that will allow answering them. As a result, there now may be few opportunities for relative risk estimation and no practical way to guard against confounding. As noted by Hedlund (2003):

"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 where the feature being examined has no effect." (Emphasis added).

The question is for how many factors a suitable control group can be found. The brake adjustment factor is the one most frequently mentioned in the documents I have read and even in this case legitimate questions can be raised about the suitability of the 'control group of crashes'. The other example mentioned in passing by is the examination of the Hours of Service (HOS) violations. Blower (2001) says that:

"...if 30% of drivers in single vehicle crashes at night had HOS violations, compared with 20% for multiple-vehicle crashes at night, that would be consistent with the notion that HOS violations played a role in the crashes."

This example seems to be a much further stretch than the brake-adjustment example. Do we know that fatigue plays a lesser role in multi-vehicle crashes than in single-vehicle crashes? Were we find no difference in relative risk would that mean: 'no effect' or perhaps 'equal effect'? Also, the problems of confounding are here very pronounced. The proportion of single-vehicle crashes depends dramatically on rural-two-lane versus urban-multilane and perhaps on many similar unknown stratifications.

It appears therefore that there are not many obvious examples where one can find a solid 'suitable group of control crashes'. It is, of course, possible that when the full data is examined, ingenious researches will find many more opportunities to devise 'suitable control groups of crashes'. However, since the LTCCS was not designed to facilitate the estimation of relative risk for a set specific set of factors selected beforehand, the opportunities for confident estimation of relative risk are not likely to be many.

There will be a strong temptation to make extensive use of the expensive LTCCS data for relative risk estimation. To ensure that the relative risk estimates are credible I suggest that:

C6. The estimation of every relative risk will have to be preceded by a study that examines plausible sources of confounding and quantifies their threat to the validity of the results.

4.3 When can a confounder be disregarded?

In discussing an earlier example of relative risk estimation for the 'brake capacity' factor, Blower (2001) discusses the possibility of confounding thus:

"Cases where the braking capacity of the truck was critical in the crash were 1.8 times more likely to have a brake violation. ... One explanation for this result could be that "at-fault" trucks are poorly operated and maintained and therefore

the association of brakes and "at-fault" in the crashes reflects poor operations rather than the mechanical association that is hypothesized."

Having recognized the danger of confounding, Blower examines whether the possibility of confounding can be ruled out. To do so, he checked whether there is an association between 'inspection categories (log violations, suspension violations etc.) and between violating the right-of-way in "brake-related crashes. Blower concludes that:

"The relationship of each of inspection categories ...was tested against violating the right-of-way in "brake-related" crashes. None of the items showed any statistically significant association. Log violations showed a similar magnitude of effect, but there are insufficient cases for the association to be significant.

Since none of the associations testes proved to be statistically significant, Blower concludes that:

"... the analysis shows that brake violations are statistically associated with being the "at-fault" vehicle in crashes where braking is important. ... The LTCCS will support precisely this type of analysis."

This example is an illustration of the following general approach to relative risk estimation. The relative risk estimate for factor X (here X=braking capacity) is statistically significantly different from 1. However, there is a suspicion that this may be partly due to another factor Y that is associated with X. To assess the danger of confounding by Y, test the hypothesis that X and Y are not correlated. If the hypothesis of no correlation cannot be rejected, take this to mean that the hypothesis is true(X and Y are truly not correlated). Conclude that there is no reason to worry about the confounding due to factor Y and that the elevated relative risk is can be attributed to factor X.

The problem with this general approach is that failure to reject the statistical hypothesis that the correlation between X and Y is zero should not be taken to mean that X and Y are not correlated. Failure to reject this null hypothesis only means that, there is insufficient data to say with confidence that the correlation is not close to zero. This, I suspect, will be the typical circumstance encountered in the relative risk analysis of the LTCCS data. That is, typically one will have insufficient data to say whether the estimated relative risk for factor X is or is not confounded by factor Y. This conclusion is the opposite of the conclusion stated by Blower. Therefore, when examining the influence of a confounding factor

C7. The absence of a statistically significant association between the factor of interest and a potential confounding factor may not be automatically taken to mean that there is no danger of confounding or that it is small. Means other than a statistical test of the hypothesis that there is no association should be sought to assess the danger and perhaps magnitude of the confounding effect.

If the analyst wishes to remain within the usual framework of testing a statistical hypothesis for the danger of confounding, a more sensible procedure might be as follows:

Step1. Examine and determine what level of correlation between factors X and Y (r_{XY}) is sufficient to undermine the attribution of relative risk to factor X.. Call this correlation $r_{critical}$.

Step2. Check whether the hypothesis $r_{XY} > r_{critical}$ can be rejected at a chosen level of significance.

Step3. Repeat for all plausible confounders Y. If the hypothesis can be rejected for all plausible Y, attribute the relative risk mainly to factor X.

Alternatively, a Bayesian approach to the checking of the danger of confounding could be developed.

5. Discussion.

A new data set containing information about truck crashes will be available. I do not think that the examination of Critical Reasons will prove to be a productive device for the development of efficient countermeasures. The creative examination of Relative Risk for as many factors as is feasible is a promising direction. However, in my opinion, the number of factors that can be examined in this manner will prove to be small for two reasons. First, because for many factors it will be difficult to find a suitable comparison group of crashes in which that factor certainly plays no role. Second, because of the limitations of sample size it will often be difficult have confidence in the estimate of relative risk and impossible to rule out the influence of confounders. If this assessment is correct then, unless additional approaches to analysis will be found, the new data set will not produce results that are commensurate with the hope and money invested in it. It follows that, even though it is late in the game, it is not too late to think again and to think hard about how the assembled data set can be used to develop efficient countermeasures for the reduction of crashes involving trucks.

The focus of this new effort should be on prevention, not causation; the aim should be the identification of efficient countermeasures and not the discovery of new

and unknown ones. That is, the kind of question to be answered using the LTCCS data set and additional means is: "How many crashes involving trucks (and other road users) are likely to be prevented or reduced in severity by a certain countermeasure?" If there are methods or approaches that can help to answer this question, they should be identified and examined. With this aim in mind the FMCSA should

- explicitly refocus the aim of LTCCS from causation to prevention;
- provide a conceptual framework for the development of efficient countermeasures and state what are the requisite elements of knowledge for implementing it;
- Use the LTCCS data set to provide some of these requisite elements and seek ways to fill the remaining gaps;
- If feasible, develop a provisional set of efficient countermeasures.

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**WORK SCHEDULES OF LONG-DISTANCE TRUCK DRIVERS
BEFORE AND AFTER 2004 HOURS-OF-SERVICE RULE CHANGE**

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ABSTRACT

Objectives: Federal rules regulate work hours of interstate commercial truck drivers. On January 4, 2004, a new work rule was implemented, increasing daily and weekly maximum driving limits and daily off-duty requirements. The present study assessed changes in long-distance truck drivers' reported work schedules and reported fatigued driving after the rule change. Associations between reported rule violations, fatigued driving, and schedule as well as other characteristics were examined.

Methods: Samples of long-distance truck drivers were interviewed face-to-face in two states immediately before the rule change (November-December 2003) and about 1 year (November-December 2004) and 2 years (November-December 2005) after the change.

Results: Drivers reported substantially more hours of driving after the rule change. Most drivers reported regularly using a new restart provision, which permits a substantial increase in weekly driving. Reported daily off-duty and sleep time increased. Reported incidents of falling asleep at the wheel of the truck increased between 2003 (before the rule change) and 2004 and 2005 (after the change); in 2005 about one-fifth of drivers reported falling asleep at the wheel in the past month. The frequency of reported rule violations under the old and new rules was similar. The percentage of trucks with electronic on-board recorders increased significantly to almost half the fleet; only a few drivers were using automated recorders to report rule compliance. More than half of drivers said that requiring automated recorders on all large trucks to enforce driving-hour limits would improve compliance with work rules. Based on the 2004-05 survey data, drivers who reported more frequent rule violations were significantly more likely to report fatigued driving. Predictors of reported violations included having unrealistic delivery schedules, longer wait times to drop off or pick up loads, difficulty finding a legal place to stop or rest, and driving a refrigerated trailer.

Conclusions: Reported truck driver fatigue increased after the new rule was implemented, suggesting the rule change may not have achieved the goal of reducing fatigued driving. Reported violations of the work rules remain common. Because many trucks already have electronic recorders, requiring them as a means of monitoring driving hours appears feasible.

Keywords: Large trucks, hours-of-service, fatigue, violations, trucking

INTRODUCTION

In 2006, 4,812 deaths occurred in highway crashes involving large trucks; this represented 11 percent of all crash deaths. Sixteen percent of these deaths were occupants of large trucks; the others were occupants of passenger vehicles, motorcyclists, or other road users. Anticipated increases in truck travel, coupled with increases in highway congestion and travel speeds, likely will push this toll higher during the next decade. Truck driver fatigue is a known crash factor, although precise quantification is difficult. The federal government has estimated that truck driver fatigue is a factor in 15 percent of truck crashes involving deaths or serious injuries (Federal Motor Carrier Safety Administration, 2000).

Fatigued driving results from truckers' arduous work schedules. Studies have found increased crash risk among drivers operating large trucks for more than 8-10 hours (e.g., Campbell, 1988; Campbell and Belzer, 2000; Jones and Stein, 1987; Lin et al., 1993, 1994). Studies also have found a relationship between long driving hours and reported falling asleep at the wheel of a large truck (Braver et al., 1992; McCartt et al., 1997; McCartt et al., 2000) or reported fatigued driving (Friswell and Williamson, 2008) and have documented widespread violations of US federal work rules and falsifications of paper logbooks used for rule enforcement (e.g., Braver et al., 1992; Hertz, 1991; McCartt et al., 1997).

A number of factors have been shown to contribute to rule violations including tight delivery schedules (Beilock, 1995, 2003; Beilock and Capelle, 1987; Braver et al., 1992); payment amounts (Braver et al., 1992) and methods (e.g., payment by the mile, nonpayment for nondriving work) (Belzer, 2000; Braver et al., 1992); carrying a perishable commodity (Beilock, 1995, 2003; Beilock and Capelle, 1987; Braver et al., 1992); solo vs. team driving (Beilock, 1995, 2003); and various other job and schedule characteristics.

Since 1939, US federal work rules have regulated how much time interstate commercial truck drivers spend on the road and on duty. These rules are enforced primarily through roadside safety inspections conducted by state enforcement personnel. In 1995, Congress directed the US Department of Transportation to open rulemaking on work rules to reduce truck driver fatigue and fatigue-related crashes. On April 28, 2003, the Federal Motor Carrier Safety Administration (FMCSA) issued a new

rule. The rule was implemented on January 4, 2004, but FMCSA requested that states begin full enforcement on March 1, 2004, after 2 months of “soft enforcement.”

The new rule was a substantial change (Table 1). Daily and weekly maximum driving limits and daily off-duty requirements were increased. Although the rule initially proposed in 2000 included a requirement that all trucks have electronic on-board recorders (EOBRs) to monitor driving hours, handwritten logbooks were retained for monitoring compliance in the final rule.

In response to a lawsuit filed by safety organizations, in July 2004 the US Court of Appeals for the District of Columbia vacated the rule because it did not take into account the health and safety of drivers. The court also criticized the absence of scientific evidence to support several key provisions of the new rule. In September 2004, Congress intervened to keep the new rule in place until federal regulators addressed the court’s concerns or until September 30, 2005, at the latest. On August 19, 2005, FMCSA issued a new rule to take effect October 1, 2005. Changes included some exceptions for short-haul operators and changes to the sleeper berth exception to off-duty requirements (Table 1); other provisions of the rule implemented in January 2004 remained intact. Full enforcement of the new provisions began January 1, 2006. In July 2007, the US Court of Appeals for the District of Columbia vacated the 2005 rule, finding that FMCSA had not provided adequate justification for the increases in daily and weekly driving limits. Effective December 27, 2007, FMCSA issued an interim final rule, identical to the 2005 rule, and provided additional justification for the increased driving limits. As of February 2008, final resolution of the hours-of-service rule had not been reached.

With regard to EOBRs, in September 2004 FMCSA returned to the beginning of the regulatory process with an advance notice of proposed rulemaking. In January 2007, the agency proposed a rule that would require recorders for only a small fraction of carriers that were the worst habitual violators of the work rules. A final rule has not yet been published.

To assess the effects of the rule implemented in January 2004 on long-distance truck drivers’ work schedules and reported fatigued driving, surveys of on-the-road truck drivers were conducted in two states in late fall 2003 (immediately before the rule change took effect) and late fall 2004 (about 1 year after). To examine longer term effects of the 2003 rule change, the survey was repeated in late fall 2005

(about 2 years after the rule change). Data from the 2004 and 2005 surveys were used to examine the association between reported rule violations and fatigued driving and the association between driver, carrier, and schedule characteristics and reported rule violations.

METHOD

Interviews were conducted with samples of drivers of large trucks passing through roadside commercial vehicle weigh stations on interstate highways in western Pennsylvania (eastbound Route I-80) and northwestern Oregon (eastbound Route I-84). In Pennsylvania, surveys were conducted during November 18-22, 2003, November 16-20, 2004, and November 17-21, 2005; in Oregon, surveys were conducted during December 3-6, 2003, December 1-4, 2004, and November 30-December 5, 2005.

Weigh stations were operated on most days and at various times of the day and night to enforce federal limits on truck weights. Given the heavy volume of truck traffic on these roadways, a steady stream of vehicles were weighed when the stations were open. In Pennsylvania, all trucks were required to drive over the scales. Oregon, like many states, had an automatic commercial vehicle identifier program that allowed precertified participating vehicles equipped with transponders to bypass designated weigh stations, port-of-entry facilities, and other enforcement stations. Trucks in Oregon's "green light" program were weighed by an electronic scale as they approached the weigh station, and trucks in compliance were allowed to bypass the station. Approximately one-quarter of the truck traffic was "green lighted" during the survey periods and, thus, not part of the survey sample. According to Oregon inspection staff, trucks participating in the green-light program were primarily local rather than long-distance carriers.

Interviews were conducted when weigh stations were open; this included weekdays and at least one weekend day, and both daylight and evening hours. When an interview was completed, inspection staff directed the next truck passing a predetermined reference point on the approach ramp to a parking lot. Trucks that were overweight, inspected, or known local trucks were excluded, but this occurred infrequently. When approaching drivers, interviewers explained they were researchers conducting a study and not enforcement staff. Drivers were asked to participate if they regularly made trips requiring them to

spend at least one night away from home. To increase survey participation and elicit accurate responses, anonymous person-to-person interviews were conducted by trained interviewers, drivers were offered \$10 to participate, and interviews were described as research to determine truck drivers' schedules and opinions about the hours-of-service rule. The questionnaire was informally tested at private truck stops and formally tested at the Pennsylvania site.

Descriptive findings are presented separately for each state and for each survey year. Some questions about work schedules, rule violations, and fatigued driving were asked in all three survey years, and differences between the 2003 versus 2004 and 2004 versus 2005 responses were examined. Some carrier and job characteristics varied by state. In addition, the distributions of sampled drivers by cargo type (private carrier, for-hire carrier, owner-operator/other) and trailer type in the 2003 and 2004 samples varied significantly in at least one state, and cargo type varied between 2004 and 2005 in at least one state. Therefore, differences between the 2003 and 2004 results were tested using the Cochran-Mantel-Haenszel chi-square statistic ($p < 0.05$) after stratifying by state, cargo type, and trailer type. Similarly, differences between the 2004 and 2005 results were tested after stratifying by state and cargo type. The Cochran-Mantel-Haenszel chi-square statistic tests whether significant differences exist between the years for at least one of the strata. To gather additional information on changes in work schedules after the rule change, drivers interviewed in 2004 and in 2005 who had worked under the pre-2004 rules were asked to compare their daily and weekly work schedules under the current and pre-2004 rules.

Odds ratios ($p < 0.05$) were computed to examine the strength of associations between reported fatigued driving and reported frequency of rule violations, using data from the 2004 and 2005 surveys. Odds ratios also were computed to examine the strength of associations between reported rule violations and carrier, job, and driver characteristics. Analyses were conducted for each state and for the states combined (again using the Cochran-Mantel-Haenszel procedure). Results for each state were consistently in the same direction, so odds-ratios for the states combined, adjusted for state and year of survey, are presented.

RESULTS

A total of 1,921 drivers participated during the three waves of interviews. Approximately 350 drivers were interviewed in each state in 2003 and in 2004; smaller samples of 236 drivers in Pennsylvania and 287 in Oregon were interviewed in 2005 due to inclement weather. Participation rates in each state were high in each survey year (range 88 to 98 percent). Nonparticipating drivers were primarily those who were hurrying to complete their trips or unable to speak fluent English.

Interviewed drivers held their commercial driver's licenses from a broad cross-section of states, and this was consistent across the three years. For example, in the 2005 survey 16 percent of drivers were licensed by Pennsylvania or Oregon, 31 percent were licensed by bordering states, 50 percent were licensed by other states, and 3 percent were licensed in Canada. Few drivers interviewed were female (1 percent in Pennsylvania and 6 percent in Oregon in 2003, 4 percent in both states in 2004, 2 percent in Pennsylvania and 7 percent in Oregon in 2005). Driver age and years of experience varied little by state or year (Table 2); the majority of drivers were 40 or older and had been driving a large truck for more than 10 years.

As noted above, some carrier and job characteristics varied by state but there also were many similarities (Table 2). Drivers reported logging many miles; more than 4 in 10 drivers in each state in each year said they expected to drive at least 125,000 miles during the year in which the interview occurred. Drivers reported they regularly had trips requiring long absences from home. For example, in 2005, 27 percent of drivers in Pennsylvania and 36 percent of drivers in Oregon reported trips typically lasting more than 2 weeks. When asked if they were sharing the driving on the current trip, 8-9 percent of drivers in Pennsylvania and 19-20 percent of drivers in Oregon said they were. As noted above, in at least one state the distribution of sampled drivers by cargo type (private carrier, for-hire carrier, owner-operator/other) and trailer type varied significantly between the 2003 and 2004 samples, and cargo type varied significantly between 2004 and 2005.

Few drivers were carrying hazardous materials in any state in any survey (5 percent or less in either state in all three surveys) or pulling two or more trailers (1 percent in all three years in

Pennsylvania and 5-7 percent in Oregon) (tables not shown). Consistently, about 9 in 10 drivers were paid either by the mile or by percentage of the load (table not shown).

Work Schedules

Drivers interviewed in 2004 and 2005 were asked to describe their current typical work schedules and their typical schedules under the pre-2004 work rule (Table 3). Excluded were drivers who began driving a truck after the 2004 work rules were implemented.

The new rule increased the limit on daily driving from 10 to 11 hours. In both 2004 and 2005, about one-fifth of drivers said they were driving more hours daily under the new rule. The large majority (72-76 percent in 2004 and 69-70 percent in 2005) said their current daily driving times were about the same as before the rule change. Based on drivers' estimates of pre-2004 daily driving and their current daily driving, a higher percentage of drivers' daily schedules in 2004 and 2005 included more than 10 hours of driving than schedules before the rule change. Most drivers said their daily schedules included about the same number of hours of nondriving work prior to and following the 2004 work rule change (table not shown).

The rule implemented in 2004 increased the daily off-duty requirement from 8 to 10 hours; a provision allowing this time to be split into two periods (each at least 2 hours) in a sleeper berth was retained. The 2005 rule modified the sleeper berth exception to require one period of at least 8 hours in the sleeper berth. In the 2004 survey, about 1 in 4 drivers said they typically split their off-duty periods (Table 3); this proportion was much smaller in both states in the 2005 survey. The majority of drivers in 2004 and in 2005 said their current daily off-duty times were about the same as before the rule change. In 2004, 31 percent of drivers in Pennsylvania and 24 percent in Oregon reported their current daily schedules included more off-duty time than their pre-2004 schedules; the percentages were comparable among drivers interviewed in 2005. Based on reported current off-duty time and recollections of off-duty time before the rule change, a much higher percentage of drivers were taking at least 10 hours off-duty in 2004 than before the rule change. However, the proportion of drivers who reported at least 10 hours off-duty was lower in 2005 than in 2004 (74-78 percent vs. 62 percent). In 2005, 38 percent of drivers in

each state reported they typically took fewer than the required 10 hours off duty, and the majority of these drivers typically took fewer than 8 hours off duty. In the 2004 and 2005 surveys, a sizable percentage of drivers in both states reported they typically got more daily sleep under the new work rule than under the old rule.

Weekly driving limits of 60/70 hours in a 7/8-day period were retained in the new rule implemented in 2004. However, under a restart provision, when the weekly limit is reached (even if reached in fewer than 7 or 8 days) drivers can resume driving toward a new 60/70-hour limit after taking 34 hours off duty. More than 90 percent of drivers interviewed in 2004 and 2005 reported they had ever used the restart provision (Table 4). At least 72 percent said the restart was part of their regular schedules. Between 9 and 16 percent of drivers said they took off fewer than 34 hours before beginning a new weekly shift; 20-24 percent said they took off exactly 34 hours, and 62-71 percent said they took off more than 34 hours.

Fatigued Driving

The percentage of drivers interviewed in Pennsylvania who said they drove their trucks while sleepy at least once during the past week increased from 43 percent in 2003 to 48 percent in 2004 and then declined to 43 percent in 2005 (Table 5). In Oregon, the percentage was 36 percent in 2003 and 2004 and 41 percent in 2005. The percentage who reported dozing at the wheel of a truck on at least one occasion during the past month increased over time in each state, and the percentage increase from 2004 to 2005 was statistically significant. In 2003, 13 percent of drivers in Pennsylvania and 12 percent of drivers in Oregon reported falling asleep at the wheel; in 2005, 19 percent of drivers in Pennsylvania and 21 percent of drivers in Oregon reported doing so.

Compliance with Work Rule

Reported rule violations were common before and after the 2004 rule change. For example, the percentage of drivers in Pennsylvania who said they worked longer than the rules permitted in the past

month was 25 percent in 2003, 28 percent in 2004, and 29 percent in 2005. Among drivers in Oregon, the percentage was 30 percent in 2003, 32 percent in 2004, and 24 percent in 2005.

Although patterns were not always consistent from year to year, in general the prevalence of violations was not statistically different between 2003 and 2004 and between 2004 and 2005 (Table 5), but there were exceptions. For example, drivers interviewed in 2004 were more likely than drivers interviewed in 2003 to report they never exceeded the weekly driving limit (the restart provision allows drivers to begin a new weekly driving clock after 34 hours off duty). A substantially larger percentage of drivers interviewed in 2005 than in 2004 said they never omitted hours worked in their logbooks.

On-Board Technologies and Perceived Enforcement

Between 2003 and 2005, there were large increases in the percentage of drivers with EOBRs (Table 6). The percentage of drivers with EOBRs increased from 19 to 43 percent in Pennsylvania, and from 17 to 49 percent in Oregon. Almost all drivers with EOBRs said they also maintained paper logbooks for inspection purposes. Drivers in the 2005 survey were asked their views on an on-board recorder requirement for large trucks (tables not shown). About 6 in 10 drivers in each state were aware of proposals to require recorders on all large trucks. Fewer than one-quarter of drivers supported a requirement. Sixty-one percent of drivers in Pennsylvania and 54 percent of drivers in Oregon said a recorder requirement would increase drivers' compliance with the work rules.

In the 2004 survey, drivers who had worked under both the old and new rules were asked whether the current level of enforcement of the work rules through roadside inspections was more, less, or about the same as the level before the rule change (table not shown). Forty percent of drivers in Pennsylvania and 28 percent of drivers in Oregon said enforcement had increased; 6 percent in each state said enforcement had declined.

Association between Reported Rule Violations and Fatigued Driving

Using data from the 2004 and 2005 surveys, analyses examined the association between reported frequency of work rule violations and the measures of fatigued driving. Adjusted odds ratios and 95

percent confidence intervals for a given exposure variable represented the increase or decrease in the odds of dozing at the wheel at least once during the prior month or the odds of driving while sleepy at least once during the past week, after accounting for effects of state differences and year of survey. Exposures of interest included reportedly working longer than the rules permitted during the past month (yes/no), omitting hours worked in the logbook (often/sometimes vs. rarely/never), violating the daily 11-hour driving limit (often/sometimes vs. rarely/never), violating the daily 14-hour duty limit (often/sometimes vs. rarely/never), taking fewer than the required 10 hours off duty (often/sometimes vs. rarely/never), and driving more than the weekly 60/70-hour driving limit (often/sometimes vs. rarely/never). All measures of frequency of reported rule violations were associated with a higher likelihood of dozing at the wheel of a truck and a higher likelihood of driving while sleepy (Table 7). In general, more frequent reported violations of the work rules were associated with approximately a twofold increase in the odds of reported fatigued driving.

Association between Driver, Carrier, Truck, and Schedule Characteristics and Rule Violations

A similar set of analyses focused on the extent to which various driver, carrier, truck, and schedule characteristics were related to more frequent reported rule violations (often/sometimes vs. rarely/never). For most types of rule violations, the odds of often/sometimes violating the work rules was higher for more frequent unrealistic delivery schedules, not sharing the driving on the current trip, longer typical drop-off or pickup times, and trouble finding parking spots. Compared with hauling a dry box or bulk trailer, hauling a refrigerated trailer significantly increased the odds of reported violations for all six measures; hauling a flatbed trailer versus a dry box/bulk trailer also increased the odds of more frequent reported violations of the daily off-duty and 14-hour work rule and omitting hours worked in the logbook. More years as a commercial driver significantly increased the odds of reportedly violating the rules in the prior month, the odds of often/sometimes driving more than 11 hours, and the odds of driving after being on duty 14 hours. Nonsignificant carrier, truck, or schedule characteristics (not shown in Table 8) included estimated miles driven during the past year, hauling private carrier cargo versus for-hire cargo,

whether the driver was an owner-operator, and whether the driver used the sleeper berth exception to split the daily off-duty period.

DISCUSSION

Truck driver fatigue is an important risk factor in serious and fatal crashes. The work rule change implemented in January 2004 followed nearly a decade of rulemaking undertaken after a Congressional directive to reform the work rule to reduce truckers' fatigued driving and fatigue-related crashes. Effects of the rule change on crashes can be determined only through scientific study examining crashes involving trucks from affected motor carriers over a sufficient period of time and controlling for other potential crash factors such as economic trends and travel patterns. At this juncture, pertinent information to assess the effects of the rule change is evidence of changes in drivers' schedules, fatigued driving, and compliance with the work rules. The present study provides such evidence. Although the evidence is based on drivers' self-reports, interviews were conducted anonymously so that drivers would be willing to report violations without fear of legal or other repercussions. High participation rates were obtained, and the method of sampling sought to ensure that the samples of drivers interviewed generally would be representative of the population of long-haul drivers.

Results indicate that drivers reported driving more hours after the rule change implemented in 2004, and reports of falling asleep while driving were more common than before the rule change. The 2004 rule change was opposed by most safety organizations and remains highly contentious, but there is little disagreement that the current enforcement system is inadequate. Numerous studies reported that the prior rule was widely flouted and logbooks frequently falsified (e.g., Braver et al., 1992; McCartt et al., 1997). In the research reported here, about 30-40 percent of drivers believed enforcement increased after the rule change. However, reported noncompliance with the new rule remained widespread and at levels similar to those under the old rule.

Consistent with surveys of drivers working under the old rule (Braver et al., 1992; McCartt et al., 1997), more frequent reported violations of the work rules were associated with reported dozing at the wheel and reported driving while sleepy. Also consistent with these earlier surveys, a number of schedule

and carrier characteristics were predictive of more frequent reported violations, including longer wait times to pick up or drop off loads.

Between 2003 and 2005, the percentage of drivers with EOBRs increased substantially even though these systems are not required by law. However, EOBRs rarely were used to show compliance with the rules. The widespread lack of compliance with the work rules and the growing availability of EOBRs suggest that requiring them on all large trucks will improve rule compliance without undue economic hardship for carriers. Because the data from these devices are a more reliable source of information on hours of driving than drivers' self-reports, these data also could be used in research that examines the effects of different work and rule patterns on reported fatigued driving and crash involvements.

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Table 1
Old (pre-2004) and New (2004) Work Rules for Long-Distance Commercial Truck Drivers

	Old rule	New rules
Daily driving limits	10 driving hours after 8 off duty; up to 16 hours driving per 24-hour period	11 driving hours after 10 off duty; up to 14 hours driving per 24-hour period
Daily off-duty requirements	After driving 10 hours or working 15 hours, driving is not allowed again until after taking 8 hours off duty; may log off duty for breaks to extend 15-hour on-duty shift	After driving 11 hours or if 14 hours have passed since driver started duty, driving is not allowed again until after taking 10 hours off duty; may not log off duty during 14 hour on-duty shift
Sleeper berth exception	May split required 8 hours off duty into 2 periods in a sleeper berth (period must be 2 hours or more)	May split required 10 hours off duty into 2 periods in a sleeper berth (period must be 2 hours or more). Revised effective October 1, 2005, so that at least 8 consecutive hours must be taken in a sleeper berth, plus 2 consecutive hours either in sleeper berth, off duty, or any combination of the two.
Restart provision	No provision	May restart official work week after 34 consecutive hours off
Weekly driving limits	60 hours in 7 days or 70 hours in 8 days	60 hours in 7 days or 70 hours in 8 days, but restart provision allows up to 77 hours in 7 days, 88 hours in 8 days
Work-hour limits	No daily work hour limits; no weekly work hour limits	No change
Monitoring for compliance with rules	Handwritten logbooks; voluntary use of automated recorders permitted	No change

**Table 2
Driver, Truck, Carrier, and Schedule Characteristics of Survey Samples by State and Year (Percent)**

	Pennsylvania			Oregon		
	2003 (N=354)	2004 (N=356)	2005 (N=236)	2003 (N=338)	2004 (N=350)	2005 (N=287)
Driver age (years)						
21-29	5	7	7	11	9	7
30-39	22	22	22	22	20	15
40-49	36	31	34	33	35	38
50-59	28	28	29	27	24	27
60+	10	11	8	7	13	13
Years driving large trucks						
≤1	7	9	6	10	8	10
>1 to 4	12	13	13	16	13	18
>4 to 10	21	21	25	21	22	15
>10	60	57	57	54	56	57
Miles driven in current year (03-04)*						
<100,000	19	18	12	19	15	16
100,000-124,000	38	33	35	34	30	38
125,000-149,000	25	27	27	17	18	22
≥150,000	18	22	26	29	37	24
Days usually on road at a stretch (03-04)*						
≤5	44	40	38	26	22	27
6-7	18	16	19	17	18	15
8-14	14	16	16	19	19	22
≥15	24	28	27	38	42	36
Operator type						
Less than truckload	6	9	10	6	6	6
Full truckload	81	71	69	77	74	74
Both	13	20	21	17	20	20
Cargo hauling(03-04)* (04-05)*						
Private carrier	18	13	10	10	8	10
For-hire carrier	75	83	82	72	88	82
Owner-operator/Other	8	3	9	18	4	8
Number of trucks in fleet						
0-10	21	18	18	29	26	20
11-50	22	19	30	22	21	19
51-100	10	10	9	12	8	10
101-500	22	22	18	8	18	12
>500	26	31	26	29	27	39
Trailer type (03-04)*						
Dry box or bulk	50	62	57	47	38	45
Refrigerator	19	16	20	30	41	32
Flatbed	17	10	10	17	10	14
Tanker	5	4	5	2	3	2
Other	9	8	8	5	8	7
Sharing driving today with another driver	8	8	9	20	19	20
Unrealistic delivery time from dispatcher or shipper						
Often	12	11	15	15	14	13
Sometimes	14	15	15	18	13	17
Rarely	32	27	26	27	32	25
Never	43	47	45	40	41	46

(03-04)* denotes that Cochran-Mantel-Haenszel chi-square test indicates 2003 vs. 2004 differences are significant in at least one state ($p < 0.05$).

(04-05)* denotes that Cochran-Mantel-Haenszel chi-square test indicates 2004 vs. 2005 differences are significant in at least one state ($p < 0.05$).

Table 3
Typical Schedule Before 2004 Work Rule Change and Currently by State and Survey Year (Percent)

	2004				2005	
	Pennsylvania (N=323)		Oregon (N=319)		Pennsylvania (N=216)	Oregon (N=239)
Drive more or fewer hours in daily shift now vs. before 2004 rule change						
More	22		17		18	19
Fewer	6		7		13	11
About the same	72		76		69	70
Number of hours of driving in daily shift	Old rule	Present	Old rule	Present	Present	
≤10 hours	77	62	68	58	64	62
10.1-11 hours	11	30	18	29	30	31
>11 hours	11	8	14	13	6	7
More or fewer nondriving work hours in daily shift now vs. before 2004 rule change						
More	4		4		4	3
Fewer	7		3		14	7
About the same	89		93		82	90
More or fewer off-duty hours in daily shift now vs. before 2004 rule change						
More	31		24		29	22
Fewer	8		5		9	8
About the same	60		71		62	70
Number of hours off-duty in daily shift (04-05)*	Old rule	Present	Old rule	Present	Present	
<8 hours	24	21	17	16	36	33
8-9.9 hours	21	5	19	6	2	5
≥10 hours	55	74	64	78	62	62
Percent who split daily off-duty rest time (04-05)*	25		28		16	13
More or fewer hours of sleep in daily shift now vs. before 2004 rule change						
More	35		21		31	22
Fewer	7		4		4	11
About the same	58		75		65	67
Number of hours of sleep in daily shift	Old rule	Present	Old rule	Present	Present	
<8 hours	51	39	47	41	36	35
8-9 hours	41	41	41	41	42	44
>9 hours	9	21	13	19	23	21

(04-05)* denotes that Cochran-Mantel-Haenszel chi-square test indicates 2004 vs. 2005 differences in current schedule are significant in at least one state ($p < 0.05$), after controlling for state, year, and cargo hauling.

Table 4
Use of Restart Provision and Typical Off-Duty Time
between Weekly Shifts by State and Survey Year (Percent)

	2004		2005	
	Pennsylvania (N=356)	Oregon (N=350)	Pennsylvania (N=236)	Oregon (N=287)
Number of hours off duty before begin new weekly shift, on average				
<34 hours	9	16	13	9
34 hours	20	22	22	24
34.1-47.9 hours	31	21	20	18
≥48 hours	40	41	45	48
Ever use restart rule	93	93	94	93
Restart provision part of regular schedule	83	72	82	79

Table 5
Reported Fatigued Driving and Violations of Work Rules by State and Survey Year (Percent)

	Pennsylvania			Oregon		
	2003 (N=354)	2004 (N=356)	2005 (N=236)	2003 (N=338)	2004 (N=350)	2005 (N=287)
Drove sleepy at least once in past week	43	48	43	36	36	41
Dozed at wheel at least once in past month (04-05)*	13	16	19	12	14	21
Drive more than 10 hours (2003) or 11 hours (2004 and 2005) before taking required off-duty time (03-04)*						
Often	5	7	8	11	13	10
Sometimes	14	15	18	14	15	11
Rarely	25	26	25	19	20	22
Never	56	53	49	56	52	58
Drive after being on duty 14 hours (04-05)*						
Often	—	6	6	—	8	5
Sometimes	—	12	8	—	11	10
Rarely	—	19	18	—	16	12
Never	—	63	68	—	65	73
Take fewer than 8 hours (2003) or 10 hours (2004 and 2005) off duty						
Often	9	12	12	10	11	9
Sometimes	15	15	14	14	14	14
Rarely	22	21	18	17	16	13
Never	55	52	56	59	60	64
Drive more than weekly limit before taking required off-duty time (03-04)*						
Often	6	4	4	9	7	7
Sometimes	9	7	6	10	9	5
Rarely	22	15	18	22	17	13
Never	63	74	72	59	68	74
Omit hours worked in logbook (04-05)*						
Often	12	17	13	19	21	12
Sometimes	18	13	14	17	15	12
Rarely	18	21	17	21	19	18
Never	52	50	56	43	45	58
Worked longer than rules permitted during last month	25	28	29	30	32	24
Logbooks generally accurate for most drivers	32	38	35	35	38	39

(03-04)* denotes that Cochran-Mantel-Haenszel chi-square test indicates 2003 vs. 2004 differences are significant in at least one state, after controlling for state, year, cargo hauling, and trailer type ($p < 0.05$)

(04-05)* denotes that Cochran-Mantel-Haenszel chi-square test indicates 2004 vs. 2005 differences are significant in at least one state, after controlling for state, year, and cargo hauling ($p < 0.05$)

Table 6
Presence of Global Positioning Systems or Electronic On-Board Recorders
on Truck by State and Survey Year (Percent)

	Pennsylvania			Oregon		
	2003 (N=354)	2004 (N=356)	2005 (N=236)	2003 (N=338)	2004 (N=350)	2005 (N=287)
Global positioning system (GPS) (03-04)* (04-05)*	36	46	38	37	44	40
Electronic onboard record or other onboard computer (03-04)* (04-05)*	19	41	43	17	36	49
If yes, also keep paper logbook (04-05)*	91	93	92	91	93	87

(03-04)* denotes that Cochran-Mantel-Haenszel chi-square test indicates 2003 vs. 2004 differences are significant in at least one state, after controlling for state, year, cargo hauling, and trailer type ($p < 0.05$)

(04-05)* denotes that Cochran-Mantel-Haenszel chi-square test indicates 2004 vs. 2005 differences are significant in at least one state, after controlling for state, year, and cargo hauling ($p < 0.05$)

Table 7
Adjusted* Odds Ratios (95% Confidence Intervals) for
Reported Falling Asleep at the Wheel and Reported Driving while Sleepy
by Reported Rule Violations

	Fell asleep at the wheel in past month	Drove while sleepy in past week
Violated work rules in past month (yes vs. no)	1.78 (1.31, 2.43)	1.67 (1.30, 2.15)
Omit hours from logbook (often/sometimes vs. rarely/never)	1.75 (1.28, 2.39)	2.10 (1.63, 2.71)
Drive more than 11 hours before taking required off-duty time (often/sometimes vs. rarely/never)	2.18 (1.58-2.99)	1.82 (1.39, 2.38)
Drive after being on duty 14 hours (often/sometimes vs. rarely/never)	1.68 (1.17,2.41)	1.82 (1.34,2.47)
Take fewer than 10 hours off duty (often/sometimes vs. rarely/never)	2.06 (1.50, 2.83)	1.78 (1.37,2.32)
Drive more than weekly limit before taking required off-duty time (often/sometimes vs. rarely/never)	1.65 (1.10, 2.47)	1.93 (1.36,2.74)

*Adjusted for state and year of survey.

Table 8
Adjusted* Odds Ratios (95% Confidence Intervals) For More Frequent Reported Work Rule Violations
by Driver, Carrier, Truck, and Schedule Characteristics

	Violated rules in past month	Sometimes/often drive more than 11 hours daily	Sometimes/often take fewer than 10 hours off duty daily	Sometimes/often drive after 14 hours on duty	Sometimes/often drive more than weekly limit	Sometimes/often omit hours in logbook
Years driving truck						
≤ 1	1.00	1.00	1.00	1.00	1.00	1.00
> 1 to 4	1.44 (0.77, 2.68)	1.30 (3.66, 2.57)	1.09 (0.59, 2.01)	1.21 (0.54, 2.70)	0.62 (0.27, 1.46)	1.65 (0.88, 3.07)
> 4 to 10	2.51 (1.40, 4.47)	2.77 (1.48, 5.18)	1.65 (0.93, 2.91)	2.62 (1.27, 5.40)	1.19 (0.57, 2.45)	3.18 (1.76, 5.74)
> 10	1.96 (1.15, 3.34)	2.04 (1.13, 3.67)	1.45 (0.87, 2.43)	2.04 (1.04, 4.02)	1.38 (0.72, 2.66)	2.20 (1.28, 3.79)
Trailer Type						
Dry box or bulk	1.00	1.00	1.00	1.00	1.00	1.00
Refrigerator	1.80 (1.33, 2.44)	1.59 (1.15, 2.19)	2.00 (1.45, 2.75)	1.51 (1.04, 2.18)	1.68 (1.13, 2.49)	1.37 (1.01, 1.85)
Flatbed	1.26 (0.83, 1.94)	1.31 (0.84, 2.06)	1.76 (1.14, 2.70)	2.13 (1.34, 3.37)	0.95 (0.51, 1.77)	1.89 (1.27, 2.81)
Tanker	1.23 (0.64, 2.36)	1.64 (0.85, 3.18)	1.72 (0.90, 3.27)	1.81 (0.89, 3.71)	1.39 (0.60, 3.24)	1.26 (0.66, 2.38)
Other	0.98 (0.59, 1.62)	1.41 (0.86, 2.32)	1.29 (0.77, 2.14)	0.72 (0.36, 1.45)	0.45 (0.18, 1.15)	0.79 (0.47, 1.32)
Fleet size						
0-10 trucks	1.00	1.00	1.00	1.00	1.00	1.00
11-50 trucks	1.13 (0.78, 1.65)	1.57 (1.07, 2.31)	1.13 (0.77, 1.64)	1.13 (0.73, 1.74)	2.18 (1.32, 3.61)	1.37 (0.94, 1.99)
51-500 trucks	0.90 (0.63, 1.29)	0.94 (0.64, 1.38)	0.68 (0.46, 0.99)	0.89 (0.59, 1.36)	1.06 (0.62, 1.79)	0.75 (0.52, 1.09)
>500 trucks	0.64 (0.44, 0.92)	0.48 (0.32, 0.73)	0.47 (0.32, 0.69)	0.53 (0.34, 0.83)	0.72 (0.41, 1.26)	0.79 (0.55, 1.13)
Parking spots full (sometimes/often vs. rarely/never)	1.78 (1.29, 2.45)	2.21 (1.55, 3.15)	2.20 (1.55, 3.11)	2.05 (1.37, 3.07)	3.02 (1.78, 5.11)	1.96 (1.42, 2.70)
Unrealistic delivery time (sometimes/often vs. rarely/never)	2.92 (2.23, 3.82)	3.75 (2.83, 4.96)	3.01 (2.29, 3.96)	3.31 (2.43, 4.52)	5.60 (3.90, 8.02)	2.91 (2.23, 3.81)
Share driving (no vs. yes)	2.83 (1.80, 4.45)	2.32 (1.47, 3.67)	1.68 (1.11, 2.56)	2.63 (1.49, 4.63)	1.70 (0.97, 2.95)	1.42 (0.97, 2.07)
Pick-up wait time						
30 minutes or less	1.00	1.00	1.00	1.00	1.00	1.00
31 minutes to 1 hour	0.82 (0.55, 1.23)	0.81 (0.53, 1.23)	0.74 (0.49, 1.12)	1.00 (0.62, 1.61)	0.77 (0.43, 1.38)	0.97 (0.66, 1.43)
61 minutes to 2 hours	1.62 (1.13, 2.32)	1.35 (0.92, 1.99)	1.40 (0.96, 2.03)	1.25 (0.80, 1.95)	1.34 (0.81, 2.22)	1.40 (0.97, 2.01)
>2 hours	1.58 (1.11, 2.24)	1.60 (1.12, 2.31)	1.58 (1.11, 2.27)	1.75 (1.16, 2.65)	1.84 (1.15, 2.94)	1.70 (1.20, 2.40)
Drop-off wait time						
30 minutes or less	1.00	1.00	1.00	1.00	1.00	1.00
31 minutes to 1 hour	1.56 (1.08, 2.24)	1.15 (0.78, 1.70)	0.94 (0.64, 1.38)	1.14 (0.73, 1.78)	1.09 (0.63, 1.88)	1.40 (0.98, 1.99)
61 minutes to 2 hours	2.12 (1.48, 3.03)	1.75 (1.21, 2.53)	1.66 (1.16, 2.37)	1.49 (0.97, 2.28)	1.61 (0.97, 2.68)	1.81 (1.27, 2.57)
>2 hours	2.55 (1.78, 3.64)	2.03 (1.41, 2.93)	2.05 (1.44, 2.94)	2.21 (1.47, 3.32)	3.13 (1.97, 4.98)	2.22 (1.57, 3.15)

Note: Results in highlighted cells are statistically significant

*Adjusted for state and year of survey.