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
Greg Radja, NHTSA
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 LTCSS

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 LTCSS 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 LTCSS 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 LTCSS 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 LTCSS 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 LTCSS file is used to estimate the national incidence of any single parameter that is measured objectively for all crashes, such as the proportion of large truck crashes that occur during daylight hours, then the 95% 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 LTCSS 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) LTCSS 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 to 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) LTCSS 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) LTCSS 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.

Night speed limit	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) LTCSS 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 accidents[1] 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

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

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:

	Certain (%)	*Certain or Probable (%)*	*Certain, Probable, or Possible (%)*
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:

Error	*Percent*
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[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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