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The Large Truck Crash Causation Study

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by
Daniel Blower
Kenneth L. Campbell

Center for National Truck Statistics

The University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, Michigan 48109-2150

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16. Abstract

This paper presents the approach and methodology of the Large Truck Crash Causation Study (LTCCS), undertaken jointly by the Federal Motor Carrier Safety Administration and the National Highway Traffic Safety Administration. The LTCCS is a study of a nationally-representative sample of serious and fatal heavy truck crashes occurring between 2001 and 2003. The data collected provides a detailed description of the physical events of the crash, along with an unprecedented amount of information about the vehicles, drivers, truck operators, and environment.

The LTCCS was designed to include all elements in a traffic crash—vehicle, driver, and environment. In addition, extensive information is collected about the operator of each truck involved, including details about driver compensation, vehicle maintenance, and carrier operations.

Rather than crash experts assigning causes to each crash, the LTCCS approach is based on statistical associations in the aggregate data. The crash assessment data provides information on what physically happened in the crash, including prior movements of each vehicle, the critical event in the crash, and the reason for the critical event. "Causes" can be determined through the analysis of this information, by identifying associations between vehicle, driver, and environmental characteristics, and particular crash types or modes of involvement.

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

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
rnL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	**1.8C + 32**	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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The Large Truck Crash Causation Study

Introduction

This paper provides an explanation of the approach and methodology of the Large Truck Crash Causation Study (LTCCS), undertaken jointly by the Federal Motor Carrier Safety Administration and the National Highway Traffic Safety Administration. The LTCCS is a study of a nationally-representative sample of serious or fatal heavy truck crashes that occurred between June 2001 and December 2003. The data collected provides a detailed description of the physical events of the crash, along with an unprecedented amount of information about the vehicles, drivers, truck operators, and environment.

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

The Federal Motor Carrier Safety Administration has identified four key safety areas in achieving the goal of crash reduction: commercial and passenger vehicle drivers; commercial vehicles; the roadway and environment; and motor carrier safety management practices.[1][*] The LTCCS has the potential to enhance understanding in each of the four key safety areas. The LTCCS was designed to include all elements in a traffic crash—vehicle, driver, and environment. In addition, extensive information is collected about the operator of each truck involved, including details about driver compensation, vehicle maintenance, and carrier operations.

The amount of data collected is vastly greater than any previous truck crash investigation program in the United States. The data elements were all chosen for the light they might shed on factors that affect the risk of crash involvement. The objective of the analysis is not to establish

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

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

Approaches to causation: the clinical method and statistical association

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

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

In contrast, in the "statistical" approach, "causation" is not determined at the data collection stage by researchers, however expert. In fact, the "causes" of specific crashes are not determined or assigned at any point. Instead, crash cause is defined in terms of changes in risk. Researchers attempt to collect objective data describing the crash, the environment of the crash, the vehicles, and the drivers involved. Then analysts search for associations between factors of interest and changes in the risk of crash involvement. In the "statistical" approach, cause is defined, either explicitly or implicitly, as a factor that increases crash risk.

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

Indiana expert approach

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

In the Indiana approach, a framework of causes is defined. At the top level, the causes cover vehicles, drivers, and the environment. Within each of those areas, a variety of causes is defined. For example, human direct causal factors are subdivided into critical non-performance errors, recognition errors, decision errors, and performance errors. At the most in-depth level of investigation, an interdisciplinary team of experts collected very detailed information about the crash and identified the factor(s) that caused the crash and those that contributed to its severity. In the end, about 420 traffic crashes in one county of Indiana were investigated at the "third" or most detailed level. While the Indiana tri-level approach has been considered successful, it is not often emulated because it requires heavy commitment from experts in a number of disciplines.

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

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

<u>National Transportation Safety Board case approach</u>

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

While this approach results in a thorough understanding of particular crashes, it is less useful in understanding truck crashes as a general traffic safety problem. First, the selection of particular crashes to study is the not the product of systematic sampling, but rather a matter of convenience or some other criteria. However they are selected, there is no context in which to put the NTSB-investigated crashes. If low inflation pressure is identified as the cause of the blowout that led to the crash, without a systematic sampling scheme one has no idea if this is a widespread problem or unique to the crash investigated.

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

<u>The LTCCS approach</u>

The LTCCS relies on a statistical approach to "causation," defining cause in terms of relative risk. A statistical view of causation has two elements, both of which are necessary. The first element is a statistical association between crash types and factors of interest. One analytical technique is to show that certain factors are over-represented in certain crash types. Association is not causation, however. Statistical association itself does not indicate the direction of the causal arrows, as it were. The second element necessary to establishing a "causal" relationship is some plausible mechanism to explain how the factor relates to the crash. By providing detailed information about the physical events of a crash, data in the LTCCS establishes the necessary link between the statistical association and the physical mechanism that explains the association.

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

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

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

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

Take, for example, a case that seems relatively clear-cut and simple: A tire blows out and a vehicle swerves into oncoming traffic where it collides with another vehicle. Is the blowout the cause of the resulting crash? Investigation reveals that the tire was defective. Is the defect the cause of this crash? The tire was under-inflated, allowing heat to build up and making failure more likely. Is maintenance the cause? The defect occurred because a worker made a mistake in manufacturing the tire. Is the worker the cause? Quality-control procedures failed to catch the defect. Is a poor system of quality-control the cause? And so on. But let us return to the critical event. The tire blew and then the driver lost control of his vehicle. Some experts believe that proper driving techniques may allow drivers to safely stop a vehicle with a blown tire. So is inadequate driving skill the real cause here? Or the failure in licensing procedures for not requiring this skill? In driver instruction for not teaching it? But let's back up again. The vehicle is of a particular design, for example, a particular model sport utility vehicle. The design of the vehicle is such that tire failures are more frequent or the vehicle is less controllable than others if a tire fails. So is the cause of this crash vehicle design?

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

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

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

With such clear-cut, well-accepted causes of crashes, why no crash? The reason is the myriad of other contingencies required to produce a crash. For crashes involving more than one vehicle, something has to get another vehicle to that same bit of the space-time continuum for a collision to occur. In the case of a stop-sign runner who escaped unscathed, fortunately there was no one on the crossing road exercising his right of way at just that instant. There easily could have been. But it just so happened that no one ten minutes before (not ten minutes and one second or nine minutes and 59 seconds, but exactly ten minutes) had to run out for a gallon of milk, or had a class to get to, or decided on a whim to go out for a ride and was feeling somewhat distracted.

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

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

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

Methodology

The LTCCS is essentially a *collision-avoidance* or *crash-prevention* study. The study is focused on pre-collision events rather than injury consequences. The purpose is to increase knowledge of the factors associated with heavy truck crashes. With greater understanding of the events and conditions that lead to crashes, it should be possible to devise strategies to decrease the frequency of heavy truck crashes.

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

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

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

The approach to both data collection and analysis is structured around the view of traffic crashes as probabilistic events. The heart of the approach is to provide a good description of the physical events that lead to crashes. In this, the LTCCS adapts the method of coding accident events outlined by Kenneth Perchonok [4]. The critical event, defined as the event that immediately precipitated the crash, is determined. The immediate failure that led to that critical event, the critical reason, is also determined. A wide variety of descriptive factors is also collected on the vehicles, drivers, and environment. At this stage, no determination is made as to whether the factors are related to the events. The data collected is purely descriptive. The factors are either present (present in a certain quantity), or absent. In fact, at no point in the coding of an individual case is the relationship between a certain factor and a particular crash determined. Instead, later statistical analysis of aggregate data will show the relationship, if any, between particular factors and particular types of crashes.

Critical Event

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

Examples:

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

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

Note that the critical event is not the "cause" of the crash.

Critical Reason

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

Examples:

- A car drifts into the opposing lane and collides head-on with a truck. The critical event is the car's movement into the truck's lane. The car driver was fatigued and had fallen asleep. The critical reason is "sleep, that is, actually asleep."

- A truck turns across the path of an oncoming car at an intersection. The critical event is the truck's turn across the path of the other vehicle. The truck had the turn arrow and observed the oncoming vehicle, which he assumed would stop. The critical reason is "false assumption of other road user's actions."

- A truck fails to slow down for slower or stopped traffic. The critical event is the failure of the truck to slow down for the traffic. Most of the truck's brakes were out of adjustment and when the driver attempted to stop, his brakes failed. The critical reason is "brakes failed." If instead, the truck was following so closely it could not stop safely even with properly functioning brakes, the critical reason would be "following too closely to respond to the actions of other road users."

The critical reason is not intended to establish the "cause" of the crash, though many of the code levels look like causes. But that is not the intent of the variable, and using the variable in that way both misconstrues the variable and can mask the range of contributing factors. In the second example above, it would be clearly inadequate to say that the cause of the crash was the truck driver's exercising his right-of-way. More plausible interventions can be suggested by factors relating to the other driver. Right-of-way is captured in the data, so this avenue can be explored. And while in the last case, brake failure seems like a satisfying cause of the crash, the design of the LTCCS methodology permits more remote factors relating to the brake problem to be evaluated. For example, brake problems might be associated with responsibility for maintenance or carrier type or vehicle type. Those factors may in turn suggest targeted interventions to reduce the incidence of brake failures and associated crashes.

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

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

Associated Factors

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

The list of factors was intended to serve two functions. The first is to provide enough information about the crash to describe it completely, permitting the range of crashes in the LTCCS to be put in the context of other crash files and allowing the selection of meaningful subsets of cases for analysis. This can be as simple as selecting crashes by maximum injury severity or testing the representativeness of the distribution of involvements in the LTCCS against other national files.

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

Analysis of the data

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

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

<u>Distributions of events and factors</u>

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

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

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

Table 2 Factor present for the driver MSP FACT data	
Condition	**%**
Alcohol	0.97%
Illegal drugs	1.93%
Fatigue	2.90%
Unfamiliar with area	1.21%
Driver inexperience	2.66%

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

Table 3 Carrier type FACT data	
Carrier type	**%**
LTL	7.1
Truckload	41.5
Private	38.7
Other	5.3
Unknown	7.4
Total	100.0

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

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

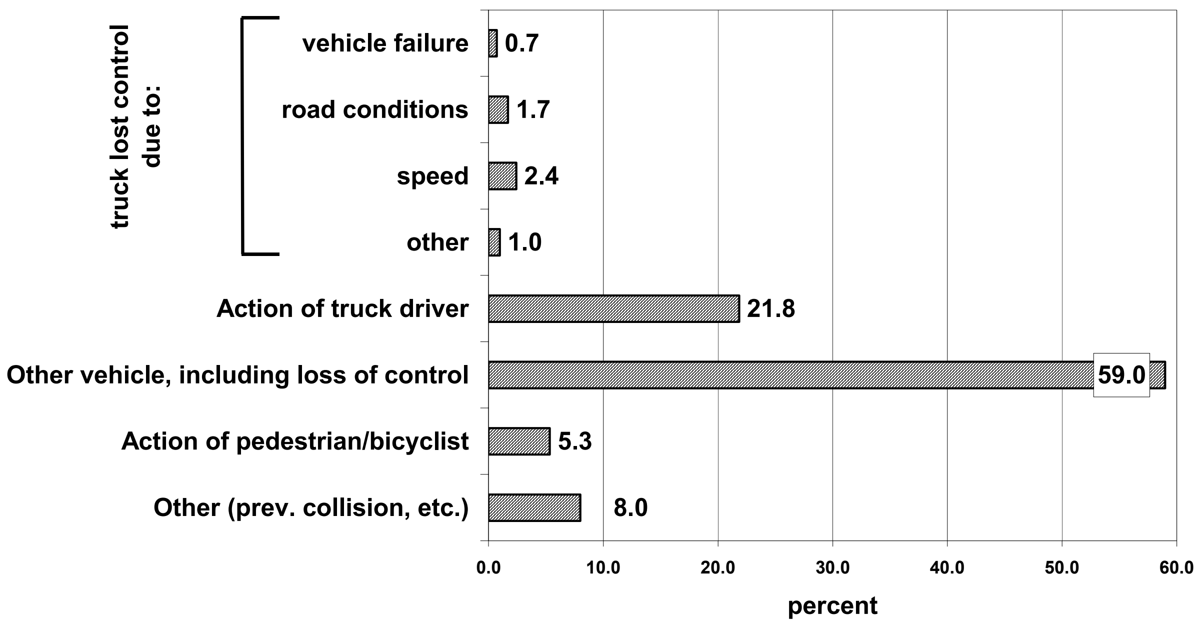

Figure 1 Critical Event FACT data

<u>Relative risk: involvement ratios</u>

The most interesting way these data can be used is in testing hypotheses through conditional probability calculations. A primary component of the LTCCS methodology is to establish a relatively detailed picture of what physically happened in the crash. By incorporating this detail into the analysis, it is possible to test hypotheses that certain factors are associated with increased risk. Most of the factors of interest operate through particular mechanisms. Thus, they are more likely to be found in some crash types than others. Using the LTCCS data, one can essentially calculate conditional probabilities to measure the relative risk of involvement of driver or vehicles with certain properties in crashes where those properties should pose additional risks as compared to other vehicles/drivers without those properties.

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

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

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

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

Table 4 Brake violations and braking-critical crashes MSP FACT data			
Brake violations	**Other braking critical**	**Truck braking critical**	**Total**
None	68	24	92
One or more	23	20	43
Total	91	44	135
None	74.3%	54.5%	68.2%
One or more	25.7%	45.5%	31.2%
Total	100.0%	100.0%	100.0%

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

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

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

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

Limitations to the LTCCS approach

Though the purpose of this note is to argue for the usefulness of the LTCCS approach, it is important to recognize its limitations and to contrast the LTCCS approach with other methods.

Each has particular strengths and weaknesses. Each can answer certain types of questions and is not suited to others.

<u>Absolute risk using VMT or some measure of exposure</u>

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

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

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

<u>Alternative approaches with LTCCS data</u>

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

Justification: Why take this approach rather than some other?

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

When completed, the LTCCS will provide a good description of the landscape of serious heavy truck crash involvements. It will provide vastly more detail in virtually every area than is now available about truck crashes. We will know much more about the types of motor carrier operations represented in traffic crashes, the mechanical condition of the trucks, the status of the drivers, and the types of crashes they are involved in. This will provide a good roadmap to further research, in some cases using the case materials collected for the LTCCS. For example, in the crash types in which brake condition was found to contribute, all those cases could be examined to determine the nature of the braking problem, whether slack adjustment, maintenance, air pressure, or some other factor.

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

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

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

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

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