INVESTIGATIVE ANALYSIS OF LARGE TRUCK ACCIDENT CAUSATION

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The cost in damage, injury, and life resulting from accidents[0] 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 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 recommendations for the use of methods that will help assure that the results of the effort are of the greatest possible value in the prevention of large truck crashes.

Large Truck Crash Causation Study

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

LTCSS Data

The elements of data being collected in the LTCSS can be viewed in the various data collection forms. These include (1) general descriptions and diagrams of the crash, (2) descriptions and sketches of the vehicles and damage involved, (3) assessments of non-motorists (e.g. pedestrians and cyclists), (4) information gained from drivers concerning their characteristics, events surrounding the crash, and its consequences, (5) information gathered from motor carriers concerning drivers, vehicles, the trip and the carrier itself. The forms are sent to one of the two NASS zone centers, Buffalo, N.Y. and San Antonio, TX, where the data are coded and entered into a data 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 Pre-crash event," which is the event immediately preceding the crash, including something causing loss of

[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.

control, motion of a vehicle, another vehicle in or encroaching on the same lane, pedestrians, pedalcyclists, other non-motorists, animals, objects or "other." Underlying these are a host of "Related Factors" including those involving characteristics of drivers, vehicles and the environment? While not specifically labeled causes, many of the factors would seem to fall into that category, "Failed to look far enough ahead," "Brakes failed," or 'Slick roads."

The analyses being carried out with the LTCSS does not, and is not intended to identify and classify causes in a manner that will necessarily guide all forms of preventive activity. No one analysis can be expected to do that. What it does do is provide a data base from which researchers 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. Those concerned with maintenance can focus test and inspection on parts and components whose failure most results in crashes. Training of drivers can focus upon preventing those shortcomings that most frequently contribute to crashes. Testing of mental and physical abilities can focus upon those showing the greatest relative crash risk. And, 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 either 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 crashes causes, but emphasizes their preliminary nature and 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. There are realms in which the circumstances under which accidents occur are so well recorded, through on-board or remote equipment, that causes are completely and unequivocally revealed. Truck crashes are rarely among them. Rather causes must be inferred from the information that is available after the crash has occurred. The inferential processes can be divided into two basic methods which, for want of other terms, we'll label "investigative" and "statistical." The effort to identify causes of large truck accidents being undertaken by FMCSA is employing and investigative approach and this paper will focus upon use of that approach. A parallel effort using a statistical approach will be briefly summarized.

Investigative analysis

An investigative method draws casual inferences through the collection and analysis of facts about the circumstances under which a crash occurred. The validity of causal inferences depends greatly upon the nature and amount of accurate data available. Some accidents reveal no clues as to cause. In most, however, reasonable inferences can be made as to some of the contributors. 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.

In accident investigation, inferences as to the causes of accidents are drawn largely from information gathered at the scene through observations, measurements and information supplied by parties to the accidents as well as observers. In motor vehicle crashes involving injury or extensive damage, investigations are initially conducted by police called to the scene. 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 emphasizing 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 highest 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 accident-related factors. At the highest level, teams of officers trained in accident reconstruction, as well as technical specialists and professionals, look into pre-crash conditions, establish sight distances, vehicle deformation to calculate crash forces.

Statistical Analyses

The greatest limitation of the investigative approach is that the further back on 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 method frequently employed involves statistical comparisons between the characteristics of people, things or conditions involved in accident cases with control samples from the population at large that are similar to the cases in all regards except for the particular characteristics under study.

Perhaps the best known applications of the “case-control” method in motor vehicle crash research involve alcohol. By comparing 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 imposition of 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, revealing the manner is which crashes vary both with hours of the day and number of continuous hours at the wheel.

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 characteristics under study would be extremely expensive. For example to assess the effect that varying hours of service (HOS) have upon truck crashes would require would require gaining 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, generally available samples are employed, often drivers or vehicles from the same accident; drivers causing accidents are compared with their passengers or with the not-at-fault driver. To evaluate the effect that hours of service (HOS) might have, one proposal is to compare single vehicle crashes with multi-vehicle crashes the former 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, inference as to cause face threats to validity different in nature but equal in magnitude to those encountered in investigative analyses.

Requirements of Investigative Analysis

The NASS Crash Event Assessment Form lists a large number of pre-crash events that are deemed to have played a role in bringing a bout 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 played a role in leading to the crash. Neither the events or the factors are referred to as causes; they only become so when an inference is made that particular events contributed to crash causation. The factors listed vary considerable 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 wouldn't have been mentioned if it weren't thought to have played some role. Yet some 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 played a role in the crash. Such factors could be revealed as crash-related through statistical analysis.

While the LTCCS research provides a data base 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 data base itself or the FMCSA effort that 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 report will offer means of securing causative information through investigative methods, including the process of causal inference, casual sequences, limits of inference, and aggregating causes.

Inferring Causes Through Investigative Analysis

The investigation of individual accidents through the years has led to a number and variety of preventive measures. Analysis of events surrounding the Titanic disaster brought about changes in Trans-Atlantic navigation procedures which have prevented similar maritime accidents over the years that have followed. Similarly, analyses of the Air Florida and ValuJet crashes led to changes in de-icing 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, as for example the TWA Flight that crashed near Long Island.

LTCCS Causal Factors

The LTCCS field staff gathers 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 involved 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 description of crashes.

- Driver related factors
  - Physical factors
    - Alcohol
    - Drugs illegal
    - Drugs over the counter
    - Drugs prescription
    - Fatigue
      - Fatigue condition
      - Sleep condition
      - Sleep related to
      - Sleep pattern
      - Work Schedule
      - Other fatigue
    - Illness
    - Visual
    - Other physical
  - Recognition factors
    - Inattention
    - Distraction
      - Conversation
      - Interior factors
      - Outside Factors
    - Inadequate Surveillance
    - Other
- Decision factors
  - Too fast for conditions
  - Following too closely
  - Gap misjudgment
  - False assumptions
- Performance factors
  - Illegal Maneuver
  - Inadequate Evasion
  - Aggressive driving (
  - Other
- Emotional Factors
  - Upset
  - Under work pressure
  - In a Hurry
  - Other
- Experience Factors
  - Unfamiliar Vehicle
  - Unfamiliar Roadway
  - Other
- Carrier/Employer Relations
  - Pressure to accept loads
  - Pressure to operate fatigue
  - Other factors
- Traffic Flow Factors
- Vehicle Condition Factors
- Environmental Factors
  - Roadway
  - Weather
  - Other

As noted earlier, causal factors underlying critical crash events are divided into driver, vehicle and environmental factors, as shown in the following list. The numbers in paragraph refer to the number of levels or subcategories of each factor.

In truck crashes, the ability to identify causes varies greatly from one crash to another. In many there is insufficient information to draw any conclusions regarding causes, including 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 losing control and leaving the roadway after long work hours, Equipment — failure of brakes or disintegration of tires and Road conditions — tractor trailers braking on a slippery surface and jackknifing. The evidence of these causes can be gained from conditions that remain following the crash. Less easily inferred are the sources of that arise out of human shortcomings which, absent on-board recording equipment, are rarely evident after a crash. Insight into the human (primarily driver) contributors to accidents comes primarily form analysis of the accident scene and information supplied by witnesses, including the involved drivers.

Recognizing that human inadequacy underlies an accident does not imply "fault," is 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 than led to the crash and taken defensive measures. While failure to do so cannot be considered an "error" the investigative analysis could benefit by broadening the identification of contributing factors to include lack of "defensive" precautions where conditions indicate an accident potential. In a case just described, an experienced truck driver might have anticipated that the car on a side street could possibly pull out as soon as other intersecting vehicles had passed and therefore might have slowed down, being ready to brake and sound the horn at the first sign of motion. Determining whether this would have reduced the chances of a collision would required further study of the data base.

Bases of Causal Inference

In most of the LTCCS crashes causes must be inferred from some 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 isn't clear. It appears that causal inferences within LTCCS are, by design, rather closely tied to the information furnished by the field staff. Lacking the technical expertise of accident reconstuctionists, the field data collectors are not encouraged to offer causal inferences. Moreover, while the field staff can seek to question witnesses, it lacks 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," based upon the driver's statements. However, given available sight distances and the speed of the truck, it appears unlikely the truck would not have been visible at the position it occupied when the driver pulled out. Further testimony discloses that the driver looked left, saw nothing coming, looked right and 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 the chance that conditions have changed and the 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 then pulls out without re-checking for oncoming traffic again. One of the FMCSA cases involves a car making a left turn, pausing and then pulling into the path of an oncoming truck where photographs of the scene indicate the truck would have been visible to the car driver.

These two examples illustrate the extent to which familiarity with common driver errors can benefit the process of causal inference. In a similar vein, when a tractor trailer was struck at by a train at crossing where there was no signal, the fact that the driver used the crossing five times a week, and the train was not operating on its usual schedule would strike a familiar chord to those familiar with the role of expectation by frequent users of unsignalized crossings.

Specialists in accident prevention, given the opportunity to review the LTCSS data base, and freed from the inferential constraints under which the FMCSA operates may be capable of furnishing insight into causes that is more revealing of causes than what currently emerges from the Crash Event Assessment. While concern may be raised as to the seemingly 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. But conclusions as to cause reached by independent analysts, with professional competence in truck design, motor carrier operations, human factors and other related disciplines, coupled with backgrounds in motor vehicle crash investigation and research are likely to offer the greatest possible validity.

Instruction and practice in the analytic process, the identification of causes, and the terminology used in describing shortcomings can enhance the accuracy of judgments, as can follow-up discussions among the parties to the assessment process. Nevertheless, inference as to cause remains a judgmental process. Lacking independent measures of whatever is being judged, a common method of assessment is to measure the agreement among different people independently making the same judgments — inter-judge reliability. While high levels of agreement do not assure accuracy, its absence certainly undermines confidence — it is a necessary yet not sufficient condition. The authors of the Indiana TRI-Level study of traffic accidents (Treat et al. 1979) went a step further in having those ascribing cause to each accident rate their confidence in their judgments and using the result to assign credibility levels to .\casual inferences.

Sequence of cause.

Rarely are accidents the result of a single cause. Most are characterized by a sequence of events in which interruption of any point would have prevented the accident from occurring. Take for example a truck driver who is advised that his brakes are defective, but decides to continue with a delivery anyway. At the top of a long grade, he could have downshifted to avoid accelerating beyond the ability of the brakes to slow and stop the vehicle but didn’t do it, possibly in order to make the green light at the bottom. When the light changes the driver could take to the berm to avoid crashing into vehicles queued up at the bottom but didn’t. A different choice at any one of these points in the sequence might have prevented the crash.

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 sub-categories: personal, characteristics of the people contributing to an incident, including both the physical and 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 and is currently being applied to several analytic efforts ongoing in aviation and maritime, and rail transportation.

As noted earlier the FMCSA process employs a method developed by Perchonok, a late associate of the Veridian staff, which identifies for each crash a "Critical Event" and "Critical Reasons" for that event. However, in many the accident results from a chain of events. The Reason model does not make a distinction among events contributing to an accident. Any one, the absence of which would have prevented the accident, is considered as critical as any other. In the example, driving off with defective brakes, descending a hill without downshifting and failing to take evasive action would be considered equally critical. With access to the LTCCS data base, researchers and crash investigators could extend the search for events and reasons well back from the crash itself.

The further back one seeks causes in the chain of events leading up to an accident, the more tenuous becomes causal inference. As a cause "Looking for a street address" can be readily traced to a crash, so long as it can be verified by testimony of the driver or witnesses. But, the fact that the driver "Drivers 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 System-Hardware-Environment-Liveware (SHEL) matrix addresses background accident contributors (Edwards, 1985; Hawkins, 1987). It is highly detailed and has been applied to 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 environment.

Presently, efforts to identify the strings of causes leading to accidents are taking place in the aviation, maritime and rail applications mentioned previously. The cost of the intensive investigation required to reveal the more remote causes has confined its applications to modes of transportation in which accidents are fewer in number and more serious in consequence than the thousand large truck accidents under study in the LTCCS. It nevertheless includes the range of causes that underlie accidents in any mode. Within the LTCCS, it would be more useful in statistical than investigative analyses.

In summary, additional analysis of the LTCCS would benefit by extending the analysis of critical events, and critical reasons somewhat further back in the causal chain, where information concerning earlier events is available within the data base, and inferences as to their role in contributing to crashes can be reliably drawn from the data. This should not become an invitation to speculate as to changes in individual behavior, group interaction, procedures or policy that might have prevented a crash but rather to take advantage of what can be reasonably concluded from available information.

Aggregation of Causes

While investigation of catastrophic accidents such as those mentioned have led directly to preventive measures, accidents involving user-operated vehicles such as trucks, cars, and motorcycles, are far too numerous, and their causes for too diverse, to base preventive measures on individual events. The fact that a part failure results in one accident doesn't necessarily make it he object of concern, or even attention. For example, transmission failures that once caused automobiles of one model year to shift itself 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. While 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, a qualitative factor analysis. A term frequently applied to the classification on 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. Grouping similar causes together it allows them to be more effectively and efficiently addressed than trying to consider each separately. In the case of truck crashes it would seem most useful to group causes together in terms of the steps needed to prevent them. For example the fact that 10 crashes were attributed to inadequate surveillance on the part of truck drivers , while 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.. On the other hand, the fact that only two of the first 126 crashes investigated involved brake failure suggests that this is not a big item.

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 the Indiana TRI-Level study has been mentioned. A human factors analysis of motorcycle crashes (McKnight, McPherson and Knipper 1980) using data collected on 900 incidents (Hurt, Ouelett and Thom 1981) by showed a quarter of them being attributed to lack of front wheel braking and locking the rear wheel in an emergency, supporting the need to use the front brake at all times to make it a reflex response. A classification of human factors in recreational boating accidents (McKnight, Becker, Pettit 2001), based upon analysis of over 3,000 accidents, revealed great differences across boat type, pointing to the for more boat-specific instruction. In some instances it is appropriate to consider the seriousness of an accident in the classification, although a "minor" truck crash may be self-contradiction and wouldn't apply to the LTCCS.

The starting point in a taxonomy of accident causes is typically some a-priori classification, much like the list of over 400 causal items in the LTCCS of critical events and reasons presented earlier. The list will be ultimately have to be pared down by dropping individual factors that arise too infrequently to warrant attention or combining them with others that are similar enough in their preventive requirements to be addressed as a single category. As an example, the taxonomy of recreational boating errors just mentioned started out as a list of over 500 possible boating accident contributors and was ultimately reduced to 68 errors occurring in more than 1% of accidents to any boat. This enabled errors to become part of the U. S. Coast Guard accident reporting system and national data base.

Degree of detail

Devising a classification system requires choice as to the level of detail in which causes are to be specified. It must be specific enough to allow targeting of preventive steps yet broad enough to allow aggregation of those requiring similar steps. Arriving at a useful taxonomy becomes a process of successive approximations. It cannot effectively commence until enough accidents have been analyzed to provide a 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 the entire sample of crashes has been completed. As noted most classification efforts begin with a highly differentiated system, with very specific causes. As a set of accidents is analyzed and coded the, categories with too few accidents may be combined, new ones are added to accommodate unanticipated causes and some are dropped entirely.

The ability to support a highly differentiated taxonomy in the LTCCS will be limited by sample size. While a thousand crashes looks like a large sample, the numbers diminish rapidly when the sample is stratified by factors that are likely to lead to different patterns of causes. For one, in the multi-vehicle crashes which make up the majority of cases, the causes are split between trucks and other road users, primarily automobiles. Moreover, even within the truck population crash patterns may vary across type, such as straight truck versus tractor trailer, to the extent that they need to be analyzed separately to furnish meaningful results. The result may well be a decision to continue data collection, across the board, or for certain categories of trucks or crashes.

The need for development of a useful taxonomy of truck crash causes has yet to 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 would seem useful to involve specialists from various aspects of truck crash prevention.

Investigative Analyses Needs

The LTCCS will generate a data base 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. These take two forms (1) more extensive ***investigative analysis*** of crash data extend the range and depth of causal inferences possible and (2) *statistical analyses* revealing the association of various driver, vehicle, and environmental characteristics with crashes. Plans for statistical analyses by the University of Michigan Transportation Research Institute have been documented. The forgoing discussion has identified needs for continuation of investigative analyses beyond the present LTCCS. These needs include the following:

<u>Depth of Analyses</u> — 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 calls for study by professionals and technicians in various aspects of prevention whose knowledge and experience, and whose freedom from the constraints imposed by the LTCCS, enables them to identify causative factors beyond those emerging from the study itself. Achieving this means making the data base fully available to qualified specialists, with access to all collected information, with appropriate steps to safeguard confidentiality and, where appropriate, anonymity. It would include those capable of spotting design flaws and maintenance deficiencies leading to equipment problems, of recognizing deficiencies in rules and procedures that permit unsafe operation, of detecting human shortcomings that lead drivers to dangerous acts, or expose them to the dangerous acts of others. While the inability to apply these capabilities to the data collection itself compromises the investigate analysis to a great extent, the objective at this point is to make the most of what will be the best available source of preventive information.

<u>Chain of Causality</u> — Many truck crashes are the result of more than one cause. Where a part fails, its failure might not have caused a crash had it been earlier detected and corrected, or had the driver reacted more appropriately when a crash was imminent. The part failure, the failure to detect and correct it, and the failure to respond appropriately are all causes in that avoiding any one of the failures would have prevented a crash. The method employed 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 accepts multiple causes. The ability to search upstream in events leading to a truck crash is limited by the data collected in the field. However, it is evident that many of the causative factors in the Crash Event Assessment relate to events that occur well before the critical event. For example “Driver was in a hurry” implies a delay and a poor decision in dealing with it. Some of the narratives describe earlier events. Here again, specialists with knowledge and experience, having access to the data base may be able to infer causes that have not been recorded in the data base itself. The further back one goes in the causal chain, the more tenuous can become the connection with the crash and the more speculative can become inferences as to cause. The search for causes must be constrained by available evidence and means of checking on the reliability of judgments employed.

<u>Aggregation of Causes</u> — Where causes of major disasters can and do become the basis of preventive measures, those leading to individual truck crashes are typically too numerous to become appropriate targets. Rather preventive measures are more effectively directed at those that are the more frequent causes. Doing so requires some means of aggregating causes in a way that groups together those having

similar preventive requirements. Developing an appropriate means of classifying causes best takes place after the full range of causes has been identified. The process typically employed, as exemplified by the LTCCS, is to start with a preliminary classification based upon what is known about causes in advance of the investigatory process. The initial categories are sufficiently detailed to help assure that needed distinctions are made, the result being large numbers of categories. The LTCCS Crash Assessment Form differentiates over 400 causal factors. Eventually, the list will be reduced when those having similar origins and preventive measures are combined, and rarely occurring causes dropped or grouped with others. The eventual classification structure, or "taxonomy" will not only present the outcome in a way that helps guide preventive efforts, but may also become a part of the process by which data in future truck crashes are gathered, processed, and reported. Responsibility for this activity has yet to be assigned. .

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