Comparative Analysis of the Large Truck Crash Causation Study and Naturalistic Driving Data

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

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FOREWORD

Truck crashes represent a significant problem on our Nation's highways. Large trucks accounted for 4 percent of all registered vehicles in 2007and represented 8 percent of all vehicles involved in fatal crashes. Successful prevention of truck crashes is dependent on having a deep understanding of the crash genesis (i.e., the factors or sequence of events that led to the crash). To help achieve this level of understanding, this study performed a generalized comparative analysis of data from the Large Truck Crash Causation Study (LTCCS), the General Estimates System (GES), and two large-truck naturalistic datasets—the Naturalistic Truck Driving Study (NTDS) and the Drowsy Driver Warning System Field Operational Test (DDWS FOT)—which were combined into one Naturalistic Driving (ND) dataset. Then the study focused on five specific analyses using only the LTCCS and ND datasets.

The LTCCS represents one of the most comprehensive post-hoc, large-truck crash reconstruction studies to date. It is rich with information about all vehicles, drivers, and trucking companies involved in high-severity truck crashes, as well as weather and roadway conditions. On the opposite end of the spectrum is ND data collection, which, through video and kinematic sensors, captures continuous data as drivers make their normal revenue-producing deliveries. Given that crashes are rare events, many of the crashes/events collected during an ND study are of a low severity (i.e., non-crashes, such as near-crashes, etc.). The goal of this study was twofold: to identify the discrepancies and the reasons for these discrepancies between the LTCCS and ND datasets, and to evaluate the feasibility of cross-comparisons using these types of datasets, thereby minimizing the weaknesses and combining the strengths in each dataset (e.g., ND has the advantage of seeing the driver's response to the threat, but the disadvantage of not seeing vehicle mechanical conditions that might have contributed to the inadequate response).

Findings are directly relevant to crash prevention. The inherent, contrasting strengths and weaknesses of these two fundamental approaches provide an opportunity for synergistic comparisons to complement each other, which will lead to a more complete understanding of crash genesis and potential countermeasures.

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16. Abstract (200 word maximum)
The aim of this study was to compare the Large Truck Crash Causation Study (LTCCS) and Naturalistic Driving (ND) datasets to identify discrepancies and to determine the source(s) of these discrepancies. The project included a generalized comparative analysis of the LTCCS, General Estimates System (GES), and ND datasets and then focused on five specific analyses using only two datasets (LTCCS and ND). The analyses investigated one selected crash/event type, two selected contributing factors, one selected environmental condition of occurrence, and one complex event scenario involving multiple elements. The rationale for these analyses was twofold: to identify the discrepancies and the reasons for these discrepancies between the LTCCS and ND datasets, and to evaluate the feasibility of cross-comparisons using these types of datasets, thereby minimizing the weaknesses and combining the strengths in each dataset (e.g., ND has the advantage of seeing the driver's response to the threat, but the disadvantage of not seeing vehicle mechanical conditions that might have contributed to the inadequate response).

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SI* (MODERN METRIC) CONVERSION FACTORS

TABLE OF 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	1000 L shall be shown in m^3	
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
		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	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°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

TABLE OF 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		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	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	Temperature is in exact degrees	
°C	Celsius	1.8c + 32	Fahrenheit	°F
		ILLUMINATION		
Lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force & 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. (Revised March 2003, Section 508-accessible version September 2009.)

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

CDL	commercial driver's license
CE	critical event
CMV	commercial motor vehicle
COTR	Contracting Officer's Technical Representative
CR	critical reason
DAS	data acquisition system
DDWS FOT	Drowsy Driver Warning System Field Operational Test
FMCSA	Federal Motor Carrier Safety Administration
GES	General Estimates System
HOS	hours-of-service
IEA	inadequate evasive action
IRB	Institutional Review Board
KABCO	a police-reported severity scale
LCL	lower confidence limit
LOS	level of service
LTCCS	Large Truck Crash Causation Study
NASS	National Automotive Sampling System
ND	naturalistic driving
NHTSA	National Highway Traffic Safety Administration
NTDS	Naturalistic Truck Driving Study
OD	opposite direction
OR	odds ratio
PAR	police accident report
RE-LVM	rear-end, lead vehicle moving
RE-LVS	rear-end, lead vehicle stopping
SCE	safety-critical event
SD	same direction
UCL	upper confidence limit
USDOT	U.S. Department of Transportation
VTTI	Virginia Technical Transportation Institute

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EXECUTIVE SUMMARY

INTRODUCTION

Truck crashes represent a significant problem on our Nation's highways. In 2008, approximately 380,000 large trucks (gross weight greater than 10,000 pounds) were involved in vehicle crashes. Of these, 4,066 were fatal crashes in which 4,229 people died; an additional 90,000 were injury-only crashes. Large trucks accounted for 4 percent of all registered vehicles in 2007 and represented 8 percent of all vehicles involved in fatal crashes.(1) There is a great opportunity to learn about crash causation by analyzing and comparing the Large Truck Crash Causation Study (LTCCS) and Naturalistic Driving (ND) data. Both of these datasets provide in-depth information, but have contrasting strengths and weaknesses. The LTCCS contains information on high-severity incidents (fatality and injury crashes), but relies on data collected during crash investigations. ND datasets relate primarily to non-crashes that are detectable from dynamic vehicle events, such as hard braking, swerving, etc. ND data provide direct video observations of the driver and the surrounding driving scene and precise information on driver inputs (kinematics) and captured events. ND datasets provide an "instant replay," allowing for the identification of critical driver behaviors leading to traffic conflicts. ND data are collected continuously, thereby capturing both incidents and non-incidents (i.e., baseline data) which can be used to calculate exposure.

The goal of this study was twofold: to identify the discrepancies and the reasons for these discrepancies between the LTCCS and ND datasets, and to evaluate the feasibility of cross-comparisons using these types of datasets, thereby minimizing the weaknesses and combining the strengths in each dataset (e.g., ND has the advantage of seeing the driver's response to the threat, but the disadvantage of not seeing vehicle mechanical conditions that might have contributed to the inadequate response).

Findings are directly relevant to crash prevention. The inherent, contrasting strengths and weaknesses of these two fundamental approaches provide an opportunity for synergistic comparisons to complement each other, which will lead to a more complete understanding of crash genesis (the factors or sequence of events that led to the crash) and potential countermeasures.

BACKGROUND

The LTCCS was conducted jointly by the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA) and encompassed 33 months of data collection. Two-person teams consisting of researchers from NHTSA's National Automotive Sampling System (NASS) and State truck inspectors assessed more than 1,000 variables related to the contributing factors in these large-truck crashes. These research teams were located in 24 sites across 17 States. Each truck crash investigated in the LTCCS had at least one large truck (gross weight greater than 10,000 pounds) and one fatality and/or injury. The LTCCS was based on nationally representative crash counts involving 963 crashes and 1,123 different large trucks. These 963 truck crashes were assigned sample weights that allowed the LTCCS to estimate the total number of fatal or injury-causing truck crashes that occurred during the study (an estimated 120,000 truck crashes).

The large-truck ND dataset included two separate studies: the Drowsy Driver Warning System Field Operational Test (DDWS FOT) and the Naturalistic Truck Driving Study (NTDS). In total, approximately 3 million miles of driving data and 250,000 hours of actigraphy data were collected on 203 different drivers in these two ND studies. These studies used continuous data collection in 55 instrumented trucks which gathered kinematic and video data. Each driver in the study was asked to wear an actigraphy device in order to collect sleep quantity and quality data. The resulting database contained approximately 4,500 safety-critical events (SCEs) and more than 19,000 baselines.

PROJECT OVERVIEW

A sophisticated understanding of traffic crashes/events recognizes that each specific scenario has its own distinct blend of events and contributing factors. While there may be some generalized findings across all crashes/events, many other findings are scenario-specific. Both the LTCCS and ND data addressed a full array of crash/event scenarios, contributing factors, and conditions of occurrence. Some comparative findings may be applicable to traffic events in general, but the most important findings will likely be specific to particular driving scenarios. Accordingly, the current project focused primarily on several selected scenarios, although it also included generalized comparisons. More specifically, the project analyses included generalized comparative analysis, event type (rear-end truck striking), contributing factors (truck driver fatigue and truck driver excessive speed), condition of occurrence (high traffic density), and complex scenario “crash trifecta” (pre-event speeding, tailgating, or other unsafe behavior; transient driver inattention; and unexpected traffic event). Such comparisons between these datasets provided the potential for cross-validation, extrapolation, and interpolation of findings, and the generation of new hypotheses that may be addressed in future studies. Findings are directly relevant to crash prevention, whether through future research and development or through information conveyed directly to safety professionals and drivers.

METHODS

Many of the variables in the LTCCS and ND studies were similarly (or identically) defined. As a result, it was determined that there would be value in performing direct comparisons between these datasets. However, through the course of this study, there were several occasions where the LTCCS and ND datasets required additional data reduction in order to make the ND database consistent with the LTCCS and/or to perform certain analyses. The comparative analyses consisted of these types of direct or descriptive comparisons: the frequency and percentage of selected variables relating to event basic characteristics, conditions of occurrence, event precipitation, key causal variables, and associated factors. In all of the analyses using the LTCCS data, the weighted counts were used, while no additional weighting was used in the ND data.

FMCSA published “relative risk” statistics regarding the *Following Too Closely* associated factor in the LTCCS. These relative risk statistics were based on comparisons between crashes where the truck was assigned the critical reason (CR) to crashes where the truck was not assigned the CR.[2,3] It was found that heavy-truck drivers were 22.6 times more likely to be assigned the CR if they were following too closely than if they were not. In itself, this is extremely alarming; however, the methodology used to calculate this statistic had a serious limitation. The relative risk estimate in this case was not an estimate of the increase in risk of a heavy-truck driver following too closely, but rather the increase in risk of being assigned the CR if he/she were following too closely. The ND dataset provides an opportunity to reproduce this estimate using events which did not result in a crash. An estimate of risk was developed using the lowest severity multi-vehicle events in the ND dataset (i.e., a crash-relevant conflict), in order to quantify the risk when the following distance falls to under 2 seconds (no single-vehicle ND incidents were included in this analysis).

A small pilot study was also conducted to assess the crash trifecta concept. The crash trifecta concept does not consider crash genesis as a simple unitary element, but as a convergence of multiple elements. More specifically, the crash trifecta was defined as three separate—but converging—events, including:

- An unsafe pre-incident behavior or maneuver (e.g., speeding, tailgating, unsafe turn).
- Transient driver inattention (which could either be related to driving, such as mirror use, or unrelated to driving, such as reaching for an object).
- An unexpected traffic event, such as unexpected stopping by the vehicle ahead.

RESULTS

Comparative Analyses

The current report presents many comparative analyses, each involving a different disaggregation of the data. As many of the variables in the comparative analyses of the LTCCS and ND datasets highlighted the similarities in these two datasets, the research team chose to explore some of the consistent trends that ran throughout the comparative analyses rather than highlight voluminous amounts of descriptive data. The variables in which there were consistent discrepancies between the LTCCS and ND datasets were as follows:

- Accident Type.
  - ND crashes/events were more frequently coded as *Roadside Departures* and *Rear-end Lead Vehicle Moving* (RE-LVM).
  - Many of the ND crashes were animal strikes.
- Attempted Avoidance Maneuver.
  - The *Attempted Avoidance Maneuver* and *No Attempted Avoidance Maneuver* variables were coded in a higher percentage of LTCCS crashes than ND crashes/events.
  - *Unknown Attempted Avoidance Maneuver* was coded in the LTCCS, but was never coded in the ND dataset.
  - ND crashes/events were more frequently coded as *Steered to the Left*.

- Pre-event Movement.
  - *Negotiating a Curve* was coded more frequently in the LTCCS dataset.
  - *Decelerating in Traffic Lane* was coded more frequently in the ND dataset.
- Number of Vehicles Involved in the Crash/Event.
  - Most of the ND crashes/events involved only one vehicle, while most of the LTCCS crashes involved two vehicles.
  - Very few of the ND crashes/events involved three or more vehicles, while almost a quarter of the LTCCS crashes involved three or more vehicles.
- Critical Event (CE).
  - The CEs "*This Vehicle Not Involved in First Harmful Event*" and "*This Vehicle Lost Control*" were rarely coded in multi-vehicle crashes/events in the ND dataset.
  - A higher percentage of the multi-vehicle crashes/events coded with the CE "*This Vehicle Traveling*" were present in the ND dataset compared to the LTCCS dataset.
  - Almost all the single-vehicle crashes/events in the ND dataset were coded with the CE "*This Vehicle Traveling*."
- Critical Reason (CR).
  - The CR "*No Driver Error*" was coded in multi-vehicle crashes in the LTCCS dataset more frequently than in the ND dataset.
  - The CR "*Recognition Error*" was coded in multi-vehicle crashes/events in the ND dataset more frequently than in the LTCCS dataset.
  - Almost all the single-vehicle crashes/events in the ND dataset were coded with the CR "*Recognition Error*."

CONCLUSIONS

The results above highlight the consistent discrepancies found in the comparative analyses performed in the current report. These discrepancies were found when comparing the LTCCS and ND datasets regardless of how the data were disaggregated. There were three primary sources, or explanations, for the discrepancies found when comparing the LTCCS and ND datasets, including:

- Inclusion of the lowest severity event in the ND dataset (i.e., unintentional lane deviations).
- Higher-severity crashes in the LTCCS dataset compared to lower-severity crashes and non-crashes in the ND dataset.
- Accuracy of the ND data collection approach in identifying driver behaviors using video and kinematic data.

Cross-comparisons between these two datasets are possible, but the differences in variable coding must be addressed. As there are more than 1,000 variables in the LTCCS, it would be difficult and beyond the scope of the current research project to indicate which variables would need to be re-coded. As it is rarely possible to recode variables in the LTCCS, additional data reduction will need to be performed in the ND dataset to make these two datasets equal (as was conducted in the current study with the LTCCS variable, *Traffic Factor*). This illustrates the unique strength of the ND data collection approach to assess new research questions, as the video and kinematic data are available for re-review.

POSSIBLE LIMITATIONS

The primary limitation in the current study was also the primary method of comparison used to evaluate trends in the datasets (i.e., descriptive statistics); while this information was needed to identify discrepancies, inferences made by the research team regarding the sources of these discrepancies were subjective. In order to fully understand the limitations in the LTCCS and ND data collection approaches, a direct comparison of the same crashes/events needs to be conducted using each data collection method. There are a few isolated examples of these types of comparisons in the 100-Car Study[6] and ND truck studies.[7,8] When available, police accident reports (PARs) were compared with ND data to assess the validity of the PARs. Most of these comparisons revealed errors in the PAR; however, the methodology employed in the LTCCS was arguably more rigorous than the methodology used by State police.

FUTURE RESEARCH

With the enormous amounts of data contained in the LTCCS and ND datasets, it is important to continue to find methods to extract usable information to answer socially important questions. Each of the proposed studies below provides an opportunity for a more complete understanding of truck crash genesis and potential countermeasures. The following are potential future research topics that were developed during this study:

- Further investigation of the crash trifecta concept, with possible risk ratio estimates using the presence of crash trifecta elements in baseline epochs.
- Direct comparison of crashes/events using the ND and LTCCS data collection approaches. While possible, this type of study would be an expensive and time-consuming undertaking. However, future and ongoing ND studies, including the 250 truck and 2,500 car studies, could compare police-reported crashes using ND data and PARs.
- Additional synthetic odds ratio analyses using crash data from the LTCCS and exposure data from the ND datasets.
- Additional research on the consequences of meta-analytic methods to combine data collected using ND and post-hoc techniques.

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1. INTRODUCTION

1.1 BACKGROUND

Truck crashes represent a significant problem on our Nation's highways. In 2008, approximately 380,000 large trucks (gross weight greater than 10,000 pounds) were involved in vehicle crashes. Of these, 4,066 were fatal crashes (in which 4,229 people died); an additional 90,000 were injury-only crashes. Large trucks accounted for only 4 percent of all registered vehicles in 2007, yet represented 8 percent of all vehicles involved in fatal crashes.(1) Successful prevention of truck crashes is dependent on having a deep understanding of crash genesis. To help achieve this level of understanding, the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA) collaborated to conduct the Large Truck Crash Causation Study (LTCCS). The LTCCS was based on a nationally representative sample of nearly 1,000 injury-causing and fatal crashes involving large trucks that occurred between April 2001 and December 2003. The data collected provide a detailed description of the physical events in each truck crash, along with an unprecedented amount of information about all vehicles and drivers, weather and roadway conditions, and trucking companies involved in the crashes. The LTCCS data relate to serious truck crashes and represent post-hoc reconstructions based on physical reconstruction and interviews with drivers and witnesses. Crash investigation, no matter how thorough and in-depth, has the inherent limitation of being an "after-the-fact" reconstruction rather than a direct observation.

On the opposite end of the spectrum from crash reconstruction is a data collection approach termed naturalistic driving (ND) data collection. ND data collection is a proactive approach, which involves data collection while drivers carry out their "day-to-day" operations in vehicles instrumented with sensors and video cameras. In comparison to the traditional approach in generating crash statistics through police accident reports (PARs), ND data have the advantage of recording exactly what happened in the instrumented vehicle prior to, during, and after the crash or near-crash. Rather than only being able to collect information at the time of the event, ND data allow for estimations of exposure to various environmental conditions and control conditions (i.e., normal driving incidence of various driver actions and behaviors). These exposure data (also called baseline) can then be used for rate ratio calculations. Crash databases do not lend themselves as readily to such exposure-based risk analysis; thus, they are limited to frequency counts rather than estimates of risk. Given that crashes are rare events, many of the crashes/events collected during an ND study are of a low severity (i.e., non-crashes, such as near-crashes, etc.).

There is a great opportunity to learn about crash causation by analyzing and comparing the LTCCS and ND data. Both of these datasets provide in-depth information, but have contrasting strengths and weaknesses. The LTCCS contains information on high-severity incidents (crashes and fatal crashes), but the study relied on data collected during crash investigations. The study identified principal driver errors (e.g., the critical reason [CR]), but not detailed behaviors or scenario sequences. ND datasets relate primarily to non-crashes that are detectable from dynamic vehicle events, such as hard braking, swerving, etc. ND data provide direct video observations of the driver and the surrounding driving scene and precise information on driver inputs (kinematics) and captured events. ND datasets provide an "instant replay," allowing for the identification of critical driver behaviors leading to traffic conflicts. ND studies also provide certain types of exposure data that cannot easily be obtained using crash reconstruction data. More specifically, ND data are collected continuously, thereby capturing both crashes/events and normal driving (i.e., baseline).

For part of the analysis, data from NHTSA's General Estimates System (GES) was accessed to fill in gaps between the LTCCS and the ND data (i.e., low-severity police-reported crashes were not represented in the LTCCS or ND datasets). GES contains relatively little in-depth causation data; however, it is considered the "gold standard" as it is based on a large, nationally representative crash sample. Thus, the GES is an important part of the LTCCS-ND cross-validation process. The current project involved an analysis that tapped into the strengths of the LTCCS and ND datasets to provide a more comprehensive and complementary insight into large truck crash causation and the methods for studying it.

1.2 PROJECT DATABASE

1.2.1 Large Truck Crash Causation Study

The LTCCS, a study conducted jointly by FMCSA and NHTSA, was based on 33 months of data collection. Two-person teams consisting of researchers from NHTSA's National Automotive Sampling System (NASS) and State truck inspectors assessed more than 1,000 variables related to the contributing factors in these large-truck crashes. These research teams were located in 24 sites across 17 States. Each truck crash investigated in the LTCCS had at least one large truck (gross weight greater than 10,000 pounds) and one fatality and/or injury. The LTCCS was based on nationally representative crash counts involving 963 truck crashes from 1,123 different large trucks. These 963 truck crashes were assigned sample weights that allowed the LTCCS to estimate the total number of fatal or injury-causing large-truck crashes that occurred during the study (an estimated 120,000 truck crashes).

Data collection in the LTCCS began as soon as possible after the crash occurred and included:

- Interviews with drivers, passengers, and eyewitnesses.
- Inspections on the truck, drivers' log books, and other pertinent documents.
- Review of the police, hospital, and coroners' reports.

Since the goal of the LTCCS was to determine the contributing factors in large-truck crashes, the data collection focused on pre-crash events. The core of the LTCCS database was the variables relating to the crash event, crash characteristics, conditions of occurrence, and associated factors. The key variables of interest related to crash causation were the critical event (CE) and the CR. The CE and CR are thought of as causal variables and are defined[(9)] as follows:

- **CE:** Identifies the event, which made the crash imminent (i.e., something occurred which made the collision inevitable). A pre-crash event is coded for each vehicle in the crash and documents the circumstances leading to this vehicle's first impact in the crash sequence.

- **CR:** Establishes the CR for the occurrence of the CE. The CR is the immediate reason for this event and is often the last failure in the causal chain (i.e., closest in time to the critical pre-crash event). Although the CR is an important part of the description of crash events, it is not the cause of the crash nor does it imply the assignment of fault.

Other LTCCS variables included the characteristics of the truck crash, conditions of the occurrence, or associated factors. The characteristics of the crash included information about the number of vehicles involved in the crash, the severity of the crash, and other general information about the type of crash and driver. The conditions of occurrence included variables that described the conditions the driver experienced during the crash (such as road type, weather, etc.). Other variables were considered associated factors that were denoted by the presence or absence of said factors (e.g., traffic factor, construction zone, etc.).

The principal strength of the LTCCS is that it provided in-depth investigations on a nationally representative sample of serious large-truck crashes. The LTCCS collected information on a large number of variables (about 1,000 potential variables for each case); however, many of the variables were only relevant to a small percentage of the truck crashes. In multi-vehicle large-truck crashes, every vehicle and driver was equally investigated. As indicated above, the primary disadvantages of the LTCCS included its reliance on interviews and the fact that no exposure data were collected to generate true risk ratio estimates.

1.2.2 Large-truck Naturalistic Driving Datasets

The large-truck ND datasets include two separate studies sponsored by FMCSA: the Drowsy Driver Warning System Field Operational Test (DDWS FOT)[(7)] and the Naturalistic Truck Driving Study (NTDS).[(8)] In total, approximately 3 million miles of driving data and 250,000 hours of actigraphy data were collected in these 2 ND studies. The DDWS FOT was the largest ND commercial vehicle study ever conducted by the U.S. Department of Transportation (USDOT) with more than 12 terabytes of kinematic and video data. The DDWS FOT involved 3-fleet companies across 8 locations and 103 drivers. The study used continuous data collection in 46 trucks, which were instrumented to gather kinematic and video data. Each driver in the study was asked to wear an actigraphy device in order to collect sleep quantity and quality data. The resulting database contains approximately 2.3 million miles traveled and more than 8,000 days' worth of actigraphy data.

The NTDS also used instrumented heavy trucks, ultimately collecting more than four terabytes of kinematic and video data. The NTDS involved 4-fleet companies across 7 locations and 100 drivers. As in the DDWS FOT, the NTDS collected continuous driving data from nine instrumented trucks (including kinematic and video data). However, unlike the DDWS FOT, an additional channel of video was collected that allowed a view over the driver's shoulder. Participants in the NTDS also wore actigraphy devices. The resulting NTDS database contained approximately 735,000 miles of driving data and 65,000 hours of actigraphy data.

ND data collection has several major advantages over crash reconstruction, including:[(10)]

- Capture of the real-world driving data. In truck studies, drivers are driving company trucks on regular, revenue-producing delivery routes.

- Crashes/events can be directly observed rather than reconstructed post-hoc (as in crash investigation). This includes specific driver behaviors and multiple, rapidly-sequenced events.
- Large amounts of data can be obtained from safety-critical events (SCEs), which are far more numerous than actual crashes. Thus, ND data have more statistical power than the crash reconstruction approaches (as used in the LTCCS).
- As videos and other raw data are archived, data mining can be conducted long after the original data collection has ended.
- Control (baseline epoch) and other exposure data (e.g., miles or hours of driving) are readily available, providing denominator-generating rates and risk estimates.

The caveats and limitations in using ND data include the following:[7,8]

- The overwhelming majority of crashes/events are near-crashes and other incidents. There are relatively few crashes in these studies. The validity of using such surrogates in place of actual crashes is uncertain.
- There are multiple types of ND event "triggers"; however, these triggers do not capture all crash/event types equally. Hard-braking crashes/events are easily captured, whereas crashes/events involving no dynamic perturbation in vehicle movement (e.g., running a red light) may not be captured.
- ND data provides sharply different perspectives when two or more vehicles are involved. The instrumented vehicle is viewed with great detail; however, less is known about the other vehicle(s).
- ND studies (to date) have not included driver interviews regarding specific crashes/events, nor have they included vehicle and/or crash-scene inspections. Similarly, information on driver condition is limited to what is observable in videos (e.g., driver is only suspected of alcohol use based on the driver's performance unless it can be clearly seen that the driver was drinking while driving).

1.2.3 General Estimates System

GES is a nationally representative sample of police-reported crashes that includes the entire KABCO police-reported severity scale, where "K" represents crashes with a fatality, "A" represents incapacitating injury crashes, "B" represents non-incapacitating injury crashes, "C" represents possible injury crashes, and "O" represents no injury crashes. NHTSA collects PARs from 60 U.S. areas selected to represent different geographic regions and population densities (i.e., urban, suburban, rural). Approximately 45,000 PARs are analyzed each year, and heavy trucks are oversampled to improve the accuracy of truck statistics. The GES has very limited causation data; however, it provides extensive and reliable statistics on many crash characteristics (e.g., severity, number of vehicles).

As with the LTCCS, the GES national crash estimates are generated by assigning a weight to each crash reflecting the number of national crashes it represents. GES crash estimates are reliable for large subsamples (e.g., major crash types or other categories), but less reliable for smaller subsamples (e.g., infrequent crash types or characteristics). One way to increase the reliability during these situations is to combine multiple years of GES data to generate statistics that are more reliable. If several years of GES statistics are aggregated, they provide more reliable crash statistics. The GES variables are similar to standardized PAR variables relating to crash characteristics and conditions of occurrence. The GES also includes information on the pre-crash sequence of events for each vehicle (i.e., pre-crash maneuvers and driver reactions to threat); however, these variables have a high proportion of unknowns.

In the current project, the GES is used primarily for comparing and cross-validating LTCCS and ND statistics. For example, variables relating to conditions of occurrence (e.g., light condition, relation to junction, route signage, etc.) provided little causal information, but did provide insight into whether the LTCCS and ND data were capturing representative information on the same qualitative driving mishaps.

1.3 PROJECT OVERVIEW

The current project evaluated large-truck crash data from the LTCCS, two large-truck ND datasets (the DDWS FOT and the NTDS), and the GES. The DDWS FOT was initially analyzed for an FMCSA-funded study entitled "Phase I Commercial Vehicle Data Collection and Countermeasure Assessment Project." As the Phase I deliverables were due prior to the completion of the DDWS FOT, only three-fourths of the dataset were reduced.(7) However, under the sponsorship of the National Surface Transportation Safety Center for Excellence, the researchers completed reduction on the entire DDWS FOT dataset.(11) Wiegand et al. also completed reduction on 2,053 randomly selected baseline epochs, while the entire NTDS dataset had already been reduced and included 456 baseline epochs.(8) Olson et al. assessed commercial driver distraction using both the DDWS FOT and the NTDS. This required a complete reduction on approximately 20,000 baseline epochs (which are used in the current study).(12) Because of these extensive, existing ND databases, data reduction in the current study was limited to a few specific analytic questions relating to particular driving scenario types.

A sophisticated understanding of traffic crashes/events recognizes that each specific scenario has its own distinct blend of events and contributing factors. While there may be some generalized findings across all crashes/events, many other findings are scenario-specific. Both the LTCCS and ND data address full arrays of crash/event scenarios, contributing factors, and conditions of occurrence. Some comparative findings may be applicable to traffic events (crashes and SCEs) in general, but the most important findings will likely be specific to particular driving scenarios. Accordingly, this project focuses primarily on several selected scenarios, although it also includes generalized comparisons.

This project included a generalized comparative analysis of the three datasets (LTCCS, GES, and ND), and then focused on five specific analyses using only two datasets (LTCCS and ND). The analyses investigated one selected crash/event type, two selected contributing factors, one selected environmental condition of occurrence, and one complex multi-element event scenario. Each analysis involved unique comparisons and each should serve as a prototype for other analyses of a similar nature within that dimension. More specifically, the project analyses included:

- Generalized comparative analysis.
- One event type:
  - Rear-end, truck striking.
- Two contributing factors:
  - Truck driver fatigue.
  - Truck driver excessive speed.
- One condition of occurrence:
  - High traffic density.
- One complex scenario “crash trifecta”:
  - Pre-event speeding, tailgating, or other unsafe behavior.
  - Transient driver inattention.
  - Unexpected traffic event.

The above constitute six distinct and separate analyses (although not entirely mutually exclusive). Analysis of the last topic—the crash trifecta—focused largely on rear-end events. Regardless, each topical analysis was a significant safety issue in its own right and, as mentioned, an exemplary category for others of its type. There were multiple reasons for addressing these particular issues, including their inherent safety importance (i.e., significant roles in crashes and injuries) and heuristic value in advancing our knowledge of truck crash causation. Such comparisons between these datasets provided the potential for cross-validation, extrapolation, and interpolation of findings, and the generation of new hypotheses that may be addressed in future studies. Findings are directly relevant to crash prevention, whether via future research and development or through information conveyed directly to safety professionals and drivers.

2. METHODOLOGY

2.1 DATASET FORMATTING

In these ND datasets, crashes/events were analyzed using many of the same, or similar, variables and data elements that were employed in the LTCCS and the GES. Note that crashes/events include crashes, near-crashes, crash-relevant conflicts, illegal maneuvers, and unintentional lane deviations. The DDWS FOT and the NTDS defined the crashes/events as follows:[(12)]

- Crash: Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off the roadway, pedestrians, pedalcyclists, or animals.
- Near-crash: Any circumstance requiring a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash, or any circumstance that results in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrian(s), pedalcyclist(s), or animal(s), there is no avoidance maneuver or response. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.
- Crash-relevant Conflict: Any circumstance that requires a crash avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive maneuver (as defined above), but greater in severity than a "normal maneuver" to avoid a crash or any circumstance that results in close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrian(s), pedalcyclist(s), or animal(s), there is no avoidance maneuver or response. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. A "normal maneuver" for this subject vehicle is defined as a control input that falls within the 99-percent confidence limit of control inputs for the initial study data sample. Examples of potential crash-relevant conflicts include hard braking by a driver because of a specific crash threat, or proximity to other vehicles.
- Illegal Maneuver: Any circumstance where either the subject vehicle or the other vehicle performs an illegal maneuver, such as passing another vehicle across the double yellow line or on a shoulder. For many of these cases, neither driver performs an evasive action.
- Unintentional Lane Deviation: Any circumstance where the subject vehicle crosses over a solid lane line (e.g., onto the shoulder) where there is not a hazard (guardrail, ditch, vehicle, etc.) present.

Baseline epochs were defined as follows:[(12)]

- Baseline Epoch: Brief time periods (e.g., 6 seconds) that are randomly selected from the recorded dataset. Baseline epochs are described using many of the same variables and data elements used to describe and classify crashes, near-crashes, and incidents. Examples of such variables included ambient weather, roadway type, and driver behaviors.

This approach was adopted to take advantage of the design effort and expertise already invested in both the LTCCS and the GES, and to permit direct comparisons between the datasets. In the current study, crash-relevant conflicts, illegal maneuvers, and unintentional lane deviations were grouped together under a new categorization termed “incident.” Other formatting changes included the aggregation of certain variables due to unknown or undeterminable characteristics (i.e., in the ND dataset it was often difficult to determine if there was a braking lockup or not). Any other discrepancies in formatting between the datasets were resolved during the data reduction.

Three distinct datasets were created for the study, one for the ND data (i.e., combining the DDWS FOT and NTDS datasets), one for the LTCCS data, and one for the GES data. The three most recent calendar years (at the time this study was completed—2005, 2006, and 2007) of the GES data were used in the calculations with the weighted counts from each year summed and percentages reported. Weighted counts were also used in the LTCCS dataset and percentages reported.

2.2 DATA REDUCTION

Additional data reduction on the ND dataset was performed in order to make the ND database consistent with the LTCCS and/or to perform certain analyses. Four additional data reductions were completed; three of these were necessary to format and merge data in the ND dataset with the LTCCS, while the fourth reduction was a pilot test of the crash trifecta concept (described in more detail below). Table 1 shows the total number of crashes/events that were reviewed during each of the four reduction questions, while a brief description of each data reduction is provided below.

Table 1. Total number of crashes/events in each reduction.

Reduction Question	Total Number of Crashes/Events Reviewed
Inadequate Evasive Action	100
Crash Trifecta	272
Traffic Density	600
Too Fast for Curve	11

2.2.1 Inadequate Evasive Action

The CR "*Inadequate Evasive Action*" (IEA), was defined as a situation where a driver perceives a threat, but makes an inadequate evasive action in response to that threat. This can include the driver braking insufficiently, or only braking when both braking and steering are called for. This was an infrequent CR in the LTCCS, but was commonly observed in the ND dataset. ND has the advantage of seeing the driver’s response to the threat, but the disadvantage of not seeing vehicle mechanical conditions (e.g., brakes) that might have contributed to the inadequate response.

Explorations of inadequate evasive action in rear-end crashes/events in the LTCCS and ND datasets might provide insight into driver responses to crash threats. Accordingly, data analysts reviewed 100 different rear-end crashes/events with IEA as the CR and observed and recorded the “secondary” contributing factor in the rear-end crash/event. These secondary contributing factors were compared to the CRs assigned to rear-end crashes in the LTCCS.

During the data reduction, each data analyst reviewed 10 seconds prior to the trigger in the selected rear-end crash/event and marked the secondary contributing factor that best described the factor that contributed to the rear-end crash/event sequence (excluding the CR, IEA). More specifically, after removing the CR, IEA from the crash/event sequence, the data analysts recorded the secondary contributing factor that likely contributed to the rear-end crash/event sequence. Data analysts selected the secondary contributing factor from a list of CRs included in the LTCCS user’s manual.(13) See Appendix A for the data reduction protocol used in review of the 100 rear-end crashes/events with the CR, IEA.

2.2.2 Crash Trifecta

The crash trifecta was defined as three separate, but converging events, including:

- Unsafe pre-incident behavior or maneuver (e.g., speeding, tailgating, unsafe turn).
- Transient driver inattention, which may be related to driving (e.g., mirror use), or unrelated (e.g., reaching for an object).
- An unexpected traffic event (e.g., unexpected stopping by the vehicle ahead).

Not every element in the crash trifecta occurred in every crash/event, but often two or all three were present. The crash trifecta concept provides a structure for understanding the complexities of crash genesis. Both the LTCCS and ND studies have emphasized the CR as a primary proximal cause. Other factors have been identified as associated factors, but neither approach has identified these contributing factors in a systematic way. That is, no factor other than the CR has been specified as directly contributing to event genesis.

Unsafe driving behaviors (i.e., following too closely, failure to signal) were recorded in previous data reductions; from this an indicator variable was created to allow for easy detection of such behaviors.(7,8) Olson et al. also calculated the total time the driver’s eyes were off the forward roadway.(12) The current study determined that if the driver’s eyes were focused off the forward roadway for a total of 1 or more seconds in a 6-second window, transient driver inattention was present. A threshold of more than 1 second for the determination of transient driver inattention was consistent with the threshold for a significant increase in the odds of involvement in a crash/event, as documented in Olson et al.(12) Thus, two of the three crash trifecta concepts had already been reduced in prior data reduction. However, new data reduction was required to determine if an unexpected traffic event was present during the crash/event. Data analysts examined the 10 seconds prior to the trigger in the 272 selected crashes/events to obtain all the information needed to determine if an unexpected traffic event occurred (with respect to the driver of the instrumented truck). An unexpected traffic event indicated that something unforeseen occurred during the crash/event. This could indicate movement by another vehicle, object, or animal that was unexpected and/or an unexpected event due to driver inattention. See Appendix A for the data reduction protocols used in the crash trifecta reduction.

2.2.3 Traffic Density

The principal traffic density variable used in ND studies was *Level of Service* (LOS), which is a subjective variable that classified the degree of restriction of vehicle movement due to the presence of other vehicles on the roadway. The six-level LOS classification scheme included: light or “A”—free-flow traffic, medium or “B”—flowing traffic with some restrictions, and heavy or “C” to “F”—various degrees of restricted traffic flow, with “F” being bumper-to-bumper traffic. However, the LTCCS did not employ the LOS variable. Investigators in the LTCCS could not directly estimate the level of traffic density, but they did record whether traffic was a “factor” in the crash. The *Traffic Factor* variable in the LTCCS indicated whether or not any traffic-related factors were coded in the truck crash.

To reconcile these differences, 600 crashes/events randomly selected from each LOS level in the ND dataset were reviewed to determine if a traffic factor was present. Data analysts coded the presence of a traffic factor if the traffic volume or the actions of other road users present during the crash/event contributed to the genesis of the crash/event (e.g., Vehicle 1 or Vehicle 2 maneuver in response to traffic or slower/stopped traffic). Data analysts were instructed to review 10 seconds prior to the trigger in the 600 randomly selected crashes/events to obtain the information needed to determine if traffic was a factor during the crash/event. See Appendix A for the data reduction protocols used in the review of the 600 LOS crashes/events.

2.2.4 Too Fast for Conditions

Existing ND data captured the CR "*Too Fast for Conditions*," but not the CR "*Too Fast for Curve/Turn*" (as was recorded in the LTCCS). Therefore, comparisons involving these two different types of excessive speed required the disaggregation of ND crashes/events coded with the CR "*Too Fast for Conditions*." As the roadway alignment during the crash/event was coded in the ND dataset, each crash/event in the ND dataset coded with the CR, "*Too Fast for Conditions*," and the roadway alignment, curve, were reviewed to confirm that the excessive speed was curve-related rather than other-road-user-related.

More specifically, all the crashes/events that were reviewed during this reduction had been assigned the CR, *Too Fast for Conditions*, and occurred while the driver was negotiating a curve. Data analysts reviewed 10 seconds prior to the trigger during the 11 crashes/events in the ND dataset that were coded with the CR, *Too Fast for Conditions*, and occurred while the driver was negotiating a curve, to obtain all the information necessary to determine if the excessive speed was curve-related (e.g., as a result of the geometry of the road) rather than other-road-user-related (e.g., excessive speed, distraction that results in late and/or inefficient braking). See Appendix A for the data reduction protocols used to review *Too Fast for Conditions* SCEs that occurred on a curve.

2.2.5 Quality Control and Reliability

During any new data reduction that involves subjective interpretations of video and quantitative data, reliability estimates of data analysts’ subjective judgments are crucial. These reliability analyses will verify that different data analysts followed the data reduction protocols (i.e., inter-rater reliability) and that each data analyst has consistently followed the data reduction protocol (i.e., intra-rater reliability). Approximately 30 percent of the crashes/events that underwent data reduction in the current project received both intra- and inter-rater reliability statistics. Whole agreement, percent agreement reliability estimates were used, as this is the most stringent assessment of reliability (i.e., 0 percent or 100 percent agreement). Due to the limited number of *Too Fast for Curve* SCEs (n = 11 crashes/events), all these crashes/events were reduced by the same data analyst. Moreover, each crash/event in this reduction was included in inter-rater reliability; however, the limited sample size precluded intra-rater reliability estimates.

Prior to performing data reduction, each data analyst received extensive training where a senior staff member reviewed the data reduction protocols. During training, the senior staff member reviewed several crashes/events that exemplified each data reduction question. The data analyst was free to ask any questions regarding data reduction. Once the training was completed, the analyst was given a test consisting of five crashes/events for each of the four reduction questions. A senior staff member reviewed these test events. If the data analyst missed more than one test event, he/she was given feedback regarding the incorrect reduction, retrained, and then asked to reduce an additional five test events. This process was continued until the data analyst answered four or more of the test events correctly. Note that the training and test events did not include any crashes/events that were included in the current analyses.

Once the data analysts were properly trained and passed the training test, each data analyst reduced 20 crashes/events in each of the 4 reduction questions noted above. Upon completing these 20 crashes/events, a senior staff member reviewed the data analyst's reduction on each of these 20 crashes/events to assess accuracy. If the data analyst correctly answered 90 percent of these 20 crashes/events, he/she was allowed to review the next 50 crashes/events in that specific data reduction question. However, data analysts who scored lower than 90 percent received feedback on their mistakes and additional training. Then, the data analyst was allowed to review the next 20 crashes/events in that specific data reduction question. This process was continued until each reduction question was completed.

As intra-rater reliability included review of the same crashes/events on two different occasions, the first response by the data analyst was considered the primary response and the second response was used as a comparison response. Table 2 shows the total number of crashes/events, number of correct responses, and intra- and inter-rater reliability statistics for each specific reduction question. As shown in Table 2, the overall mean inter- and intra-rater reliability was 95.2 percent and 93.7 percent, respectively (80 percent is considered acceptable, while 90 percent is considered good).

Table 2. Reliability statistics for each reduction question.

Reduction	Inter-Rater Correct	Inter-Rater Total	Percentage	Intra-Rater Agreed	Intra-Rater Total	Percentage
Inadequate Evasive Action	28	30	93%	24	30	80%
Crash Trifecta	88	92	96%	86	92	93%
Traffic Density	171	180	95%	173	180	96%
Too Fast for Curve	11	11	100%	–	–	–
Total	**298**	**313**	**95.2%**	**283**	**302**	**93.7%**

2.3 ANALYSIS APPROACH

Below is a description of the analyses performed during each research question.

2.3.1 Descriptive Comparisons

Since many of the LTCCS, ND, and GES variables were defined similarly or identically, there was value in direct comparisons between these datasets. The first research question, the general comparative analysis, consisted of these types of direct or descriptive comparisons. These included the frequency and percentage of selected variables relating to event basic characteristics, conditions of occurrence, event precipitation, key causal variables, and associated factors. The inclusion of the GES data in these analyses permitted comparisons and cross validations between all KABCONI event severities. The spectrum of event severities represented a modification and extension of the KABCO PAR crash severity classification system (with the "N" and the "I" from ND data being added). Table 3 summarizes each event severity in the KABCONI categories and their sources.

Table 3. KABCONI severity level and their sources.

Category and Definition	Source(s)
K: Fatal Crash	LTCCS, GES
A: Incapacitating Injury Crash	LTCCS, GES
B: Non-Incapacitating Injury Crash	LTCCS, GES
C: Possible Injury Crash	GES
O: No Injury Crash	GES, ND
N: Near-crashes	ND
I: Incidents (Crash-relevant Conflicts)	ND

In the severity-level comparative analyses shown below in Section 3, the GES functioned as a "bridge" between the LTCCS and ND datasets. Both the LTCCS and the GES collected information on KAB-level crashes; thus, these datasets were directly compared. Only the GES provided C-level data; it was also the prime source for O-level data as there were few of these crashes in the ND dataset. ND data was the only source of NI-level data. As indicated above, analyses in the general comparative analysis consisted of simple descriptive statistics (frequency and percentage) followed by commentary. For all of the descriptive research questions, the statistics do not center around statistical significance, but rather the practical significance or representativeness of these data in relation to crash/event genesis.

2.3.2 Odds Ratios

While the descriptive analyses described above illustrate the prevalence of certain variables, they were unable to evaluate which of those variables increase (or decrease) risk of involvement in a crash or SCE. This information is critical in identifying which contributing factors and/or associative factors increase risk. Thus, those conditions can be targeted by enforcement, safety management techniques, technologies, etc., to avoid the genesis of crashes and SCEs.

One exploratory synthetic odds ratio analysis was performed by combining the LTCCS data with ND exposure or baseline data. This comparison involved combining LTCCS crash data as the numerator with ND exposure data as the denominator. Obviously, a major caveat in this comparison was the different sampling frames in the two datasets (thus, the use of “synthetic,” because an odds ratio is estimated from a dataset with an identical sampling frame). The rationale for conducting this comparison was that the ND exposure data were defined in the same manner as the LTCCS data and both datasets draw from the same vehicle type and freight operations. Given this limitation, the synthetic odds ratio may be the best practical approach to estimate crash risk associated with certain environmental situations and driver behaviors in which no other reliable exposure data exist (as in the LTCCS dataset).

An odds ratio was calculated to approximate the risk ratio for the associated factor "*Following Too Closely*" (i.e., tailgating). Typically, this analysis involves the use of baseline or control events to illustrate the behavior (tailgating) under normal driving conditions. However, the use of baseline events was not possible in this analysis, as the sensor suite used to detect crashes/events in the ND dataset would, by definition, define an instrumented truck following too closely as a safety event. Many of the crashes/events in the ND dataset were not considered high-severity (i.e., crashes or near-crashes), but rather less severe incidents. To evaluate the risk ratio of following too closely, incidents (more specifically, crash-relevant conflicts) were used in place of baseline events as a way to estimate risk (i.e., by comparing the odds of a driver tailgating given a high-severity SCE, such as a crash or near-crash, compared to the odds of tailgating given a crash-relevant conflict). Given the impossibility of following too closely without an additional vehicle, this analysis was performed using only multi-vehicle truck crashes and crash-relevant conflicts.

An odds ratio is a measure of association commonly employed in the analysis of 2×2 contingency tables.[(14)] The data for this specific analysis can be displayed as a 2×2 contingency table, as shown in Table 4. This table shows driver behavior (columns) cross-classified by event occurrence (rows) with margin totals in the last row and column.

Table 4. 2×2 Contingency table used to calculate tailgating odds ratio.

Event	Tailgating	No Tailgating	Total
Crashes in the LTCCS	A	B	$n_{1.}$
Crash-relevant Conflicts in the ND	C	D	$n_{2.}$
Total	$n_{.1}$	$n_{.2}$	$n_{..}$

Odds of occurrence were defined as the probability of event occurrence (i.e., crash in the LTCCS) divided by the probability of nonoccurrence (i.e., crash-relevant conflict in the ND). These probability estimates were conditioned on the presence and/or absence of the associated factor, tailgating, and then compared via ratios. The following formula was used to perform the calculation to determine the odds ratio in order to assess the increase (or decrease) in the probability of having a crash, compared to a crash-relevant conflict, in the presence of tailgating versus no tailgating: *Odds Ratio = (a)(d)/(c)(b).*

Odds ratios of “1.0” indicate that the outcome is equally likely to occur given the condition. An odds ratio greater than “1.0” indicates that the outcome is more likely to occur given the condition. Odds ratios of less than “1.0” indicate that the outcome is less likely to occur.[(15)] The hypothetical data presented in Table 5 illustrate how odds ratios were calculated in the current study. For this hypothetical example, assume there were a total of 100 crashes and 100 crash-relevant conflicts. The driver was found to be tailgating in 45 of the crashes, and was tailgating in 23 of the crash-relevant conflicts.

Table 5. Odds ratio example.

Event	Tailgating	No Tailgating
Crashes	45 (A)	55 (B)
Crash-relevant Conflicts	23 (C)	77 (D)

The formula for this calculation is shown in Figure 1:

$$\mathrm{OR} = \frac{A \times D}{B \times C}$$

$$\mathrm{OR} = \frac{45 \times 77}{23 \times 55}$$

$$\mathrm{OR} = 2.74$$

Figure 1. Equation. Formula for calculating the odds ratio.

In order to determine if the odds ratio of 2.74 is significant, a 95 percent confidence interval is calculated, including the upper confidence limits (UCL) and lower confidence limits (LCL). The formulas to calculate the UCL and LCL are shown in Figure 2:

$$UCL = OR \times e^{1.96\sqrt{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}+\frac{1}{d}}}$$

$$UCL = 2.74 \times e^{1.96\sqrt{\frac{1}{45}+\frac{1}{55}+\frac{1}{23}+\frac{1}{77}}}$$

$$UCL = 5.04 \times e$$

$$LCL = OR \times e^{-1.96\sqrt{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}+\frac{1}{d}}}$$

$$LCL = 2.74 \times e^{-1.96\sqrt{\frac{1}{45}+\frac{1}{55}+\frac{1}{23}+\frac{1}{77}}}$$

$$LCL = 1.49$$

Figure 2. Equation. Formulas to calculate the upper and lower confidence limits.

Since 1.0 is *not* included between the LCL and the UCL, the odds ratio is significantly different than 1.0. Thus, the researchers are 95 percent certain that the true odds ratio lies somewhere between 1.49 and 5.04. Therefore, this example can be interpreted to say that drivers who follow another vehicle too closely had odds of being involved in a crash (compared to a crash-relevant conflict) that were 2.74 times greater than if they were not following another vehicle too closely.

As the ND studies employed a retrospective approach (rather than a prospective approach), the use of odds ratios (rather than relative risk) is appropriate. The quantities obtained from a retrospective and prospective approach are not equal. The retrospective relative risk is calculated with the probability of the risky behavior given a crash; however, the prospective relative risk is calculated with the conditionality in the other direction. Since the total number of baselines and crashes/events is known in the ND studies, exposure risk can be calculated (i.e., the risk of dialing a cell phone given the driving event is a baseline or a SCE). In such situations, odds ratios are not used to approximate the risk ratio. Instead, the odds ratio is used to approximate the rate ratio. The current analysis framework used the odds ratio to approximate the rate ratio, which does not require the rare event assumption.(16)

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3. RESULTS

3.1 ANALYSIS 1: GENERAL COMPARATIVE ANALYSIS

The general comparative analysis was a top-level comparison of the LTCCS, GES, and ND datasets involving major crash/event variables. The general comparative analysis examined 20 fundamental crash characteristics using the KABCONI severity hierarchy previously described. As indicated above, the GES statistics were included in the general comparative analysis for two reasons: these data provided information on the middle severity levels (i.e., C and O) in the KABCONI severity hierarchy, and these statistics were representative of the total U.S. truck crash population. This analysis was possible as most of the top-level variables in the three datasets had the same definitions and data elements. Note that several variables were not available in GES; thus, comparisons in those situations only included the LTCCS and ND datasets. LTCCS and GES analyses were limited to combination-unit truck statistics as the ND datasets only included combination-unit trucks.

Note that specific CE and CR categories were disaggregated by single-vehicle and multi-vehicle crashes/events. The LTCCS and ND datasets have shown significant differences in the causal profiles of single-vehicle and multi-vehicle crashes/events.[8,17] These differences could have concealed any results that existed if the LTCCS or ND datasets were not disaggregated by single-vehicle and multi-vehicle crashes/events. Disaggregation by the vehicles involved allowed a more valid comparison between the LTCCS and ND datasets.

3.1.1 Accident Type

Table 6, Table 7, and Table 8 show the percentage of crashes/events in each "Accident Type" category across the GES, LTCCS, and ND datasets. The accident type categorizes the scenario of the crash/event the driver was involved in (i.e., *Right Roadside Departure*, etc.). The crash/event was defined as the first harmful event or projected first harmful event in a crash, near-crash, or incident between a vehicle and some object.[7,8] The object may be another vehicle, a person, an animal, a fixed object, the road surface, or the ground. Most of the crashes/events in the ND dataset had no contact between the subject vehicle and another object. In these cases, the analyst was instructed to project the likely scenario roles for the crashes/events where outcomes were not defined; or, if the crash/event had resulted in a crash, what the crash scenario would have been.[7,8]

Table 6. Distribution of accident types by crash/event severity in the GES dataset.

Accident Type	K—Fatal Crash (n = 9,445)	A—Incapacitating Injury (n = 41,424)	B—Non-incapacitating Injury (n = 73,943)	C—Possible Injury (n = 95,304)	O—No Injury (n = 740,936)	Total (n = 961,051)
Sideswipe Same Direction (SD)	6.18%	11.34%	12.89%	16.15%	22.63%	20.59%
Miscellaneous	14.02%	17.92%	17.87%	15.05%	14.95%	15.30%
Turn Across Path	6.70%	7.21%	8.40%	9.80%	10.76%	10.29%
Turn Into Path	9.14%	6.40%	5.67%	6.99%	8.02%	7.68%
Right Roadside Departure	5.22%	6.07%	6.91%	3.37%	6.15%	5.92%
Rear-end Lead Vehicle Stopped	2.20%	5.33%	4.74%	12.84%	5.12%	5.84%
Forward Impact Single-Vehicle	7.13%	3.01%	2.16%	0.78%	6.46%	5.42%
Rear-end Lead Vehicle Moving	3.13%	6.90%	6.21%	9.58%	4.33%	5.09%
Rear-ended Moving	7.64%	8.08%	6.25%	5.08%	3.94%	4.44%
No Impact	0.26%	1.70%	1.60%	2.01%	4.94%	4.21%
Sideswipe Opposite Direction (OD)	15.44%	6.91%	9.29%	3.17%	3.29%	4.01%
Rear-ended Stopped	3.27%	3.39%	4.22%	3.64%	3.53%	3.59%
Intersection Paths-Straight	6.44%	6.32%	7.15%	6.37%	2.38%	3.35%
Left Roadside Departure	1.82%	3.55%	3.93%	1.94%	1.77%	2.03%
Rear-end Other/Unknown	1.57%	2.42%	1.42%	1.36%	1.10%	1.21%
Head-on	9.54%	3.36%	1.04%	1.81%	0.58%	0.95%
Forward Impact Struck SD	0.00%	0.03%	0.08%	0.02%	0.04%	0.04%
Forward Impact Striking SD	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%
Forward Impact Struck OD	0.26%	0.01%	0.13%	0.00%	0.00%	0.01%
Forward Impact Striking OD	0.00%	0.05%	0.04%	0.01%	0.00%	0.01%
Forward Impact Other/Unknown SD	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%
Forward Impact Other/Unknown OD	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%

SD—same direction; OD—opposite direction

Table 7. Distribution of accident types by crash/event severity in the LTCCS dataset.

Accident Type	K—Fatal Crash (n = 8,727)	A—Incapacitating Injury (n = 39,125)	B—Non-Incapacitating Injury (n = 56,964)	Total (n = 104,815)
Sideswipe Same Direction (SD)	7.20%	12.57%	11.59%	11.59%
Miscellaneous	33.99%	18.36%	28.69%	25.28%
Turn Across Path	5.37%	5.17%	3.18%	4.10%
Turn Into Path	2.77%	4.12%	1.52%	2.60%
Right Roadside Departure	3.50%	9.29%	12.07%	10.32%
Rear-end Lead Vehicle Stopped	5.78%	4.31%	2.99%	3.71%
Forward Impact Single-Vehicle	4.23%	2.74%	0.68%	1.74%
Rear-end Lead Vehicle Moving	4.68%	6.36%	10.87%	8.67%
Rear-ended Moving	1.63%	7.35%	7.06%	6.72%
No Impact	1.18%	0.34%	1.62%	1.11%
Sideswipe Opposite Direction (OD)	7.92%	6.51%	3.52%	5.00%
Rear-ended Stopped	3.08%	5.09%	1.26%	2.84%
Intersection Paths-Straight	4.24%	7.24%	2.78%	4.57%
Left Roadside Departure	3.80%	4.44%	11.35%	8.14%
Rear-end Other/Unknown	1.04%	0.54%	0.60%	0.61%
Head-on	8.90%	5.38%	0.00%	2.75%
Forward Impact Struck/Striking SD	0.00%	0.02%	0.21%	0.12%
Forward Impact Struck/Striking OD	0.70%	0.18%	0.00%	0.12%
Forward Impact Other/Unknown SD	0.00%	0.00%	0.00%	0.00%
Forward Impact Other/Unknown OD	0.00%	0.00%	0.00%	0.00%

SD—same direction; OD—opposite direction

Table 8. Distribution of accident types by crash/event severity in the ND dataset.

Accident Type	O—No Injury (n = 21)	N—Near-crash (n = 195)	I—Incident (n = 4,258)	Total (n = 4,474)
Sideswipe Same Direction (SD)	4.76%	33.85%	11.81%	12.74%
Miscellaneous	4.76%	0.00%	0.16%	0.18%
Turn Across Path	0.00%	1.54%	0.89%	0.92%
Turn Into Path	0.00%	5.13%	3.03%	3.11%
Right Roadside Departure	9.52%	12.82%	54.04%	52.03%
Rear-end Lead Vehicle Stopped	4.76%	5.13%	2.16%	2.30%
Forward Impact Single-Vehicle	61.90%	17.95%	2.56%	3.51%
Rear-end Lead Vehicle Moving	0.00%	12.82%	20.27%	19.85%
Rear-ended Moving	4.76%	0.00%	0.19%	0.20%
No Impact	0.00%	0.00%	0.00%	0.00%
Sideswipe Opposite Direction (OD)	0.00%	2.05%	2.09%	2.08%
Rear-ended Stopped	0.00%	0.00%	0.05%	0.04%
Intersection Paths-Straight	0.00%	0.51%	0.66%	0.65%
Left Roadside Departure	9.52%	6.67%	1.53%	1.79%
Rear-end Other/Unknown	0.00%	0.00%	0.02%	0.02%
Head-on	0.00%	1.54%	0.28%	0.34%
Forward Impact SD	0.00%	0.00%	0.09%	0.09%
Forward Impact OD	0.00%	0.00%	0.16%	0.16%
Forward Impact Other/Unknown SD	0.00%	0.00%	0.00%	0.00%
Forward Impact Other/Unknown OD	0.00%	0.00%	0.00%	0.00%

SD—same direction; OD—opposite direction

In the ND dataset, the most commonly observed accident type was *Right Roadside Departure*, as shown in Table 8 (52 percent). However, the most prevalent accident types among no injury crashes and near-crashes in the ND dataset were *Forward Impact Single Driver* (61.9 percent) and *Sideswipe Same Direction* (33.9 percent). The accident types "*Right Roadside Departure*" and "*Left Roadside Departure*" were also frequently coded during no-injury crashes in the ND dataset (9.5 percent each).

Right and left roadside departures were less frequent among GES non-incapacitating injury crashes (6.9 percent and 3.9 percent, respectively) compared to the LTCCS dataset (12.1 percent and 11.3 percent, respectively). In the ND dataset, *Forward Impact Single Driver* was the most commonly observed accident type in no-injury crashes (61.9 percent); however, this accident type was only recorded in 6.5 percent of the no-injury crashes in the GES dataset. The distribution of the higher-severity crashes/events in the ND dataset (i.e., no-injury crashes and near-crashes) follows a similar distribution of the accident type categories found in the LTCCS and GES datasets.

3.1.2 Attempted Avoidance Maneuver

Table 9, Table 10, and Table 11 show the percentage of crashes/events in each *Attempted Avoidance Maneuver* category across the GES, LTCCS, and ND datasets. The attempted avoidance maneuver documents the driver's actions initiated in response to the realization of impending danger.[7,8] The primary difference between the LTCCS and ND datasets involved the coding of the attempted avoidance maneuver "*No Avoidance Maneuver*." The attempted avoidance maneuver "*No Avoidance Maneuver*" was frequently coded in the LTCCS dataset (43.8 percent), but rarely coded in the ND dataset (1.2 percent). This large discrepancy was likely a combination of three factors:

- ND data collection can detect minor driving performance measures during an avoidance maneuver (e.g., steering, braking, etc.) compared to the LTCCS.
- The high frequency of crashes in the LTCCS where another vehicle collided with a truck making no avoidance maneuver (e.g., rear-end, other vehicle striking).
- The difference between higher-severity events in the LTCCS (fatal and injury crashes) and lower-severity events in the ND dataset (e.g., SCEs).

As there were a large number of crashes in the GES dataset that were characterized as having an unknown attempted avoidance maneuver (67.2 percent), making comparisons between the GES and LTCCS and ND datasets was difficult. However, the lack of data in the GES illustrates the advantages of using an in-depth, post-hoc crash reconstruction (as in the LTCCS) and continuous data collection (as in the ND).

Table 9. Distribution of attempted avoidance maneuvers by crash/event severity in the GES dataset.

Attempted Avoidance Maneuver	K—Fatal Crash (n = 9,445)	A—Incapacitating Injury (n = 41,424)	B—Non-incapacitating Injury (n = 73,943)	C—Possible Injury (n = 95,304)	O—No Injury (n = 740,936)	Total (n = 961,051)
Accelerated	0.37%	0.04%	0.17%	0.40%	0.12%	0.15%
Accelerated and Steered to Left	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accelerated and Steered to Right	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Braked and Reversed (No Lockup or Lockup Unknown)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Braked and Steered to Left (Lockup)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Braked and Steered to Left (Unknown/No Lockup)	5.34%	1.93%	1.02%	0.51%	0.43%	0.59%
Braked and Steered to Right (Lockup)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Braked and Steered to Right (Unknown/No Lockup)	4.43%	1.28%	1.27%	0.69%	0.56%	0.70%
Braked (Lockup)	4.44%	4.57%	3.14%	3.57%	1.00%	1.61%
Braked (Unknown/No Lockup)	4.02%	3.15%	3.84%	4.38%	2.32%	2.70%
No Avoidance Maneuver	12.20%	16.08%	16.07%	20.88%	21.74%	20.89%
No Driver Present	0.86%	1.32%	0.95%	0.61%	0.38%	0.49%
Other	0.25%	0.55%	0.49%	0.50%	0.29%	0.33%
Released Gas Pedal Without Braking	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Released Gas Pedal Without Braking and Steered to Left	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Released Gas Pedal Without Braking and Steered to Right	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Released Brakes	0.00%	0.01%	0.08%	0.00%	0.00%	0.01%
Steered to Left	8.03%	4.35%	3.49%	2.37%	1.79%	2.15%
Steered to Right	9.04%	3.96%	5.25%	2.75%	2.98%	3.24%
Unknown	51.02%	62.74%	64.24%	63.35%	68.38%	67.15%

Table 10. Distribution of attempted avoidance maneuvers by crash/event severity in the LTCCS dataset.

Attempted Avoidance Maneuver	K—Fatal Crash (n = 8,727)	A—Incapacitating Injury (n = 39,125)	B—Non-incapacitating Injury (n = 56,964)	Total* (n = 104,815)
Accelerated	0.00%	2.12%	0.00%	0.79%
Accelerated and Steered to Left	0.00%	0.41%	0.60%	0.48%
Accelerated and Steered to Right	0.00%	0.00%	0.23%	0.13%
Braked and Reversed (No Lockup or Lockup Unknown)	0.00%	0.00%	0.00%	0.00%
Braked and Steered to Left (Lockup)	0.00%	0.00%	0.00%	0.00%
Braked and Steered to Left (Unknown/No Lockup)	2.78%	4.57%	7.52%	6.02%
Braked and Steered to Right (Lockup)	0.00%	0.00%	0.00%	0.00%
Braked and Steered to Right (Unknown/No Lockup)	11.70%	11.42%	8.93%	10.09%
Braked (Lockup)	16.97%	7.30%	7.58%	8.26%
Braked (Unknown/No Lockup)	10.22%	8.16%	13.96%	11.49%
No Avoidance Maneuver	40.60%	47.47%	41.78%	43.81%
No Driver Present	0.23%	1.93%	0.25%	0.87%
Other	6.26%	5.22%	7.91%	6.77%
Released Gas Pedal Without Braking	0.00%	0.00%	0.00%	0.00%
Released Gas Pedal Without Braking and Steered to Left	0.00%	0.00%	0.00%	0.00%
Released Gas Pedal Without Braking and Steered to Right	0.00%	0.00%	0.00%	0.00%
Released Brakes	0.00%	0.00%	0.00%	0.00%
Steered to Left	3.67%	1.59%	6.00%	4.16%
Steered to Right	3.84%	5.78%	3.63%	4.45%
Unknown	3.72%	4.02%	1.61%	2.68%

*LTCCS numbers only reflect combination-unit trucks.

Table 11. Distribution of attempted avoidance maneuvers by crash/event severity in the ND database.

Attempted Avoidance Maneuver	O—No Injury (n = 21)	N—Near-crash (n = 195)	I—Incident (n = 4,258)	ND Total (n = 4,474)
Accelerated	0.00%	0.00%	0.16%	0.16%
Accelerated and Steered to Left	0.00%	1.03%	2.04%	1.99%
Accelerated and steered to Right	0.00%	0.00%	0.82%	0.78%
Braked and Reversed (No Lockup or Lockup Unknown)	0.00%	0.51%	0.16%	0.18%
Braked and Steered to Left (Lockup)	0.00%	0.00%	0.07%	0.07%
Braked and Steered to Left (Unknown/No Lockup)	14.29%	13.85%	4.58%	5.03%
Braked and Steered to Right (Lockup)	0.00%	0.51%	0.00%	0.02%
Braked and Steered to Right (Unknown/No Lockup)	4.76%	23.59%	4.96%	5.77%
Braking (Lockup)	0.00%	0.51%	0.16%	0.18%
Braking (Unknown/No Lockup)	28.57%	26.15%	22.95%	23.11%
No Avoidance Maneuver	33.33%	1.54%	1.01%	1.18%
No Driver Present	0.00%	0.00%	0.00%	0.00%

Attempted Avoidance Maneuver	O—No Injury (n = 21)	N—Near-crash (n = 195)	I—Incident (n = 4,258)	ND Total (n = 4,474)
Other	0.00%	0.00%	0.05%	0.04%
Released Gas Pedal Without Braking	0.00%	0.51%	0.73%	0.72%
Released Gas Pedal Without Braking and Steered to Left	4.76%	3.59%	1.03%	1.16%
Released Gas Pedal Without Braking and Steered to Right	0.00%	3.08%	0.70%	0.80%
Released Brakes	4.76%	0.00%	0.05%	0.07%
Steered to Left	0.00%	12.82%	56.43%	54.27%
Steered to Right	9.52%	12.31%	4.09%	4.47%
Unknown	0.00%	0.00%	0.00%	0.00%

3.1.3 Pre-event Movement

Table 12, Table 13, and Table 14 show the percentage of crashes/events in each of the *Pre-event Movement* categories across the GES, LTCCS, and ND datasets. The pre-event movement documents the vehicle's movement pattern prior to the CE.[7,8] As shown in the tables, the pre-event movement "*Going Straight*" was the most frequently coded pre-event movement in the ND, LTCCS, and GES datasets (69.4 percent, 54.9 percent, and 47.8 percent, respectively). The pre-event movements "*Accelerating in Traffic Lane* and *Decelerating in Traffic Lane*" were much more prevalent in the ND dataset (5.5 percent and 11.3 percent, respectively) than in the LTCCS (1.8 percent and 4 percent, respectively) or GES (0.3 percent and 3.7 percent, respectively) datasets. A much higher percentage of crashes in the LTCCS occurred while negotiating a curve (21.6 percent) compared to the ND and GES datasets (6 percent and 6.7 percent, respectively). The pre-event movement "*Stopped in Traffic Lane*" occurred more frequently in the LTCCS (5.6 percent) and GES (6.7 percent) datasets than in the ND dataset (0.4 percent).

Table 12. Distribution of pre-event movements by crash/event severity in the GES dataset.

Pre-event Movement	K—Fatal Crash (n = 9,445)	A—Incapacitating Injury (n = 41,424)	B—Non-incapacitating Injury (n = 73,943)	C—Possible Injury (n = 95,304)	O—No Injury (n = 740,936)	Total (n = 961,051)
Accelerating in Traffic Lane	0.00%	0.95%	0.09%	0.62%	0.20%	0.26%
Backing Up (Other than for Parking Position)	0.15%	0.66%	1.31%	3.68%	6.59%	5.57%
Changing Lanes	2.00%	4.15%	4.55%	6.63%	7.22%	6.77%
Decelerating in Traffic Lane	1.67%	5.18%	3.40%	3.92%	3.60%	3.67%
Disabled or Parked in Travel Lane	0.36%	0.14%	0.06%	0.13%	0.03%	0.05%
Entering a Parking Position, Backing	0.00%	0.02%	0.00%	0.02%	0.33%	0.26%
Entering a Parking Position, Moving Forward	0.00%	0.02%	0.00%	0.02%	0.33%	0.26%
Going Straight	69.83%	56.14%	55.99%	53.55%	45.50%	47.80%
Leaving a Parking Position, Moving Forward	0.00%	0.05%	0.09%	0.00%	0.31%	0.25%
Making a U-turn	0.82%	0.63%	0.81%	0.74%	0.70%	0.71%
Merging	0.23%	0.68%	0.57%	0.32%	0.79%	0.71%
Negotiating a Curve	13.77%	10.00%	11.64%	6.68%	5.87%	6.65%
No driver Present	0.86%	1.32%	0.95%	0.61%	0.38%	0.49%
Other (Specify)	0.51%	0.27%	0.10%	0.40%	0.46%	0.42%
Passing or Overtaking Another Vehicle	0.27%	0.51%	1.06%	0.73%	0.77%	0.77%
Starting in Traffic Lane	1.08%	1.08%	1.28%	2.37%	1.62%	1.64%
Stopped in Traffic Lane	3.51%	7.85%	8.00%	6.89%	6.48%	6.67%
Successful Avoidance Maneuver	0.00%	0.04%	0.26%	0.03%	0.09%	0.09%
Turning Left	3.84%	6.30%	5.17%	7.52%	8.15%	7.74%
Turning Right	0.83%	2.82%	4.11%	4.56%	9.77%	8.43%
Unknown	0.27%	1.20%	0.56%	0.59%	1.14%	1.04%

Table 13. Distribution of pre-event movements by crash/event severity in the LTCCS dataset.

Pre-event Movement	K—Fatal Crash (n = 8,727)	A—Incapacitating Injury (n = 39,125)	B—Non-incapacitating Injury (n = 56,94)	Total (n = 104,815)
Accelerating in Traffic Lane	2.10%	2.43%	1.34%	1.81%
Backing up (Other Than for Parking Position)	0.25%	0.35%	0.00%	0.15%
Changing Lanes	3.26%	3.80%	2.27%	2.92%
Decelerating in Traffic lane	4.16%	3.19%	4.53%	4.00%
Disabled or Parked in Travel Lane	0.00%	0.00%	0.00%	0.00%
Entering a Parking Position, Backing	0.00%	0.00%	0.00%	0.00%
Entering a Parking Position, Moving Forward	0.00%	0.00%	0.00%	0.00%
Going Straight	61.21%	60.46%	50.05%	54.87%
Leaving a Parking Position, Moving Forward	0.00%	0.00%	0.00%	0.00%
Making a U-turn	0.00%	0.08%	0.00%	0.03%
Merging	0.00%	0.00%	0.28%	0.15%
Negotiating a Curve	13.10%	17.54%	25.68%	21.59%
No Driver Present	0.23%	1.93%	0.25%	0.87%
Other (specify)	0.00%	0.10%	0.82%	0.48%
Passing or Overtaking Another Vehicle	0.00%	0.35%	2.81%	1.66%
Starting in Traffic Lane	0.11%	0.54%	0.22%	0.33%
Stopped in Traffic Lane	15.33%	5.16%	4.45%	5.62%
Successful Avoidance Maneuver	0.24%	0.94%	3.05%	2.03%
Turning Left	0.00%	2.34%	3.38%	2.71%
Turning Right	0.00%	0.76%	0.89%	0.77%
Unknown	0.00%	0.02%	0.00%	0.01%

Table 14. Distribution of pre-event movements by crash/event severity in the ND dataset.

Pre-event Movement	O—No Injury (n = 21)	N—Near-crash (n = 195)	I—Incident (n = 4,258)	Total (n = 4,474)
Accelerating in Traffic Lane	0.00%	10.26%	5.31%	5.50%
Backing up (Other Than for Parking Position)	0.00%	0.00%	0.05%	0.04%
Changing Lanes	9.52%	3.08%	2.40%	2.46%
Decelerating in Traffic Lane	14.29%	14.36%	11.16%	11.31%
Disabled or Parked in Travel Lane	0.00%	0.00%	0.00%	0.00%
Entering a Parking Position, Backing	4.76%	0.00%	0.00%	0.02%
Entering a Parking Position, Moving Forward	0.00%	0.00%	0.02%	0.02%
Going Straight	42.86%	47.18%	70.55%	69.40%
Leaving a Parking Position, Moving Forward	0.00%	1.54%	0.07%	0.13%
Making a U-turn	0.00%	0.00%	0.02%	0.04%
Merging	0.00%	3.59%	0.96%	1.07%
Negotiating a Curve	0.00%	8.21%	5.97%	6.03%
No Driver Present	0.00%	0.00%	0.00%	0.00%
Other (specify)	0.00%	0.00%	0.09%	0.09%
Passing or Overtaking Another Vehicle	4.76%	1.03%	0.47%	0.51%
Starting in Traffic Lane	0.00%	1.54%	0.16%	0.22%

Pre-event Movement	O—No Injury (n = 21)	N—Near-crash (n = 195)	I—Incident (n = 4,258)	Total (n = 4,474)
Stopped in Traffic Lane	0.00%	1.03%	0.33%	0.36%
Successful Avoidance Maneuver	4.76%	0.51%	0.12%	0.16%
Turning Left	9.52%	2.05%	0.87%	0.96%
Turning Right	4.76%	5.64%	1.46%	1.65%
Unknown	0.00%	0.00%	0.00%	0.00%

3.1.4 Number of Vehicles Involved

Table 15 shows the percentage of crashes/events in each *Number of Vehicles Involved* category across the LTCCS, ND, and GES datasets. The most notable difference in Table 17 was the high proportion of single-vehicle crashes/events in the ND dataset (57.2 percent) compared to the LTCCS and GES datasets (29.1 percent and 19 percent, respectively). While almost all the no-injury crashes in the ND dataset were single-vehicle (85.7 percent), there were only 21 no-injury crashes in this dataset. However, there was also a significant number of unintentional lane deviations in the ND dataset (27.1 percent of the total crashes/events in the ND dataset); thus, this skews the distribution of single-vehicle crashes/events in the ND dataset. Another notable difference in Table 17 was the high proportion of two-vehicle crashes in the GES dataset (74.2 percent) compared to the LTCCS and ND datasets (46.6 percent and 39.8 percent, respectively). While the distribution of two-vehicle crashes/events in the ND and LTCCS datasets was relatively similar, the large proportion of two-vehicle crashes found in the GES data might reflect coding discrepancies and/or the lack of detailed information regarding the crash (as was not present in the LTCCS and ND datasets).

Table 15. Distribution of number of vehicles involved by crash/event severity in the GES, LTCCS, and ND datasets.

Crash/Event Severity	1 Vehicle	2 Vehicles	3 Vehicles	4 or More Vehicles
GES K—Fatal Crash (n = 8,827)	17.86%	67.94%	9.94%	4.26%
GES A—Incapacitating Injury (n = 38,546)	19.10%	66.20%	10.41%	4.29%
GES B—Non-incapacitating Injury (n = 69,717)	18.14%	65.85%	12.66%	3.36%
GES C—Possible Injury (n = 91,550)	8.56%	76.66%	11.09%	3.69%
GES O—No Injury (n = 703,818)	20.46%	75.23%	3.79%	0.52%
GES Total (n = 912,457)	19.00%	74.21%	5.54%	1.25%
LTCCS K—Fatal Crash (n = 8,727)	10.91%	44.88%	16.86%	27.35%
LTCCS A—Incapacitating Injury (n = 39,125)	21.97%	56.83%	12.19%	9.01%
LTCCS B—Non-incapacitating Injury (n = 56,964)	36.77%	39.86%	14.76%	8.61%

Crash/Event Severity	1 Vehicle	2 Vehicles	3 Vehicles	4 or More Vehicles
LTCCS Total (n = 104,815)	29.09%	46.61%	13.97%	10.32%
ND O—No Injury (n = 21)	85.71%	9.52%	4.76%	0.00%
ND N—Near-crash (n = 195)	37.44%	58.46%	4.10%	0.00%
ND I—Incident (n = 4,258)	58.01%	39.06%	2.65%	0.28%
ND Total (n = 4,474)	57.24%	39.76%	2.73%	0.27%

3.1.5 Driver Age

Table 16 shows the percentage of crashes/events in each *Driver Age* category across the GES, LTCCS, and ND datasets. Driver age indicates the age of the truck driver (in years) involved in the crash/event. As shown in Table 18, the age distribution of the crashes/events in the ND dataset closely resembles the overall age distribution of the truck drivers in the GES and LTCCS datasets. This suggests that the LTCCS and ND datasets are nationally representative across age groups.

Table 16. Distribution of driver age by crash/event severity in the LTCCS, ND, and GES datasets.

Crash/Event Severity	30 or Younger	31–40	41–50	51–60	61 or Older	No Occupant
GES K—Fatal Crash (n = 9,262)	14.11%	22.23%	29.07%	22.74%	11.86%	0.00%
GES A—Incapacitating Injury (n = 39,766)	16.08%	26.38%	28.39%	21.28%	7.87%	0.00%
GES B—Non-incapacitating Injury (n = 71,474)	18.34%	26.92%	29.70%	17.49%	7.55%	0.00%
GES C—Possible Injury (n = 91,727)	20.71%	26.96%	30.15%	15.73%	6.45%	0.00%
GES O—No Injury (n = 698,189)	18.26%	27.16%	29.84%	18.10%	6.63%	0.00%
GES Total (n = 910,418)	18.37%	27.04%	29.79%	18.00%	6.79%	0.00%
LTCCS K—Fatal Crash (n = 8,727)	14.72%	23.42%	33.00%	19.11%	9.53%	0.23%
LTCCS A—Incapacitating Injury (n = 39,125)	6.43%	24.79%	37.35%	20.99%	8.51%	1.93%
LTCCS B—Non-incapacitating Injury (n = 56,964)	17.93%	26.82%	33.35%	19.27%	2.38%	0.25%
LTCCS Total (n = 104,815)	13.37%	25.78%	34.82%	19.90%	5.26%	0.87%
ND O—No Injury (n = 21)	14.29%	28.57%	47.62%	9.52%	0.00%	0.00%
ND N—Near-crash (n = 195)	16.92%	32.31%	36.41%	13.85%	0.51%	0.00%

Crash/Event Severity	30 or Younger	31–40	41–50	51–60	61 or Older	No Occupant
ND I—Incident (n = 4,258)	14.33%	31.94%	35.37%	15.29%	3.08%	0.00%
ND Total (n = 4,474)	14.44%	31.94%	35.47%	15.20%	2.95%	0.00%

3.1.6 Critical Event

Table 17 shows the overall distribution of CE categories by crash/event severity in the LTCCS and ND datasets. The CE was only recorded in the LTCCS and ND datasets; therefore, the following section makes no comparisons with the GES dataset. The CE is defined as the event that immediately led to the crash/event or the action or event which put the vehicle or vehicles on a course that made the crash/event unavoidable, given reasonable driving skills and vehicle handling (note that in the ND dataset the events were reviewed as if a collision had occurred).[7,8]

Table 17. Overall distribution of CEs by crash/event severity in the LTCCS and ND datasets.

Crash/Event Severity	Other Motor Vehicle in Lane	Other Motor Vehicle Encroaching into Lane	This Vehicle Not Involved in First Harmful Event	This Vehicle Traveling	This Vehicle Loss of Control	Other (specify)	Object or Animal	Pedestrian, Pedalcyclist, or Other Non-motorist
LTCCS K—Fatal Crash (n = 8,727)	23.79%	20.98%	30.18%	12.63%	6.88%	1.18%	0.57%	3.80%
LTCCS A—Incapacitating Injury (n = 39,125)	27.72%	21.89%	11.26%	23.33%	10.93%	2.23%	0.18%	2.38%
LTCCS B—Non-incapacitating Injury (n = 56,964)	22.70%	14.46%	10.51%	25.15%	24.84%	1.12%	1.19%	0.00%
LTCCS Total (n = 104,815)	24.66%	17.81%	12.43%	23.43%	18.71%	1.54%	0.76%	1.20%
ND O—No Injury (n = 21)	4.76%	0.00%	0.00%	33.33%	0.00%	0.00%	61.90%	0.00%
ND N—Near-crash (n = 195)	16.41%	21.03%	0.00%	46.67%	1.03%	1.03%	12.31%	1.54%
ND I—Incident (n = 4,258)	17.12%	11.25%	0.00%	69.99%	0.05%	0.12%	1.24%	0.23%
ND Total (n = 4,474)	17.03%	11.62%	0.00%	68.80%	0.09%	0.16%	2.01%	0.29%

As shown in Table 17, the most obvious differences in the overall distribution of CE categories between the LTCCS and ND datasets involved the CE categories "*This Vehicle Not Involved in First Harmful Event*" (12.4 percent and 0 percent of the LTCCS crashes and ND crashes/events, respectively), "*This Vehicle Traveling*" (23.4 percent and 68.8 percent of the LTCCS crashes and ND crashes/events, respectively), and "*This Vehicle Loss of Control*" (18.7 percent and 0.1 percent of the LTCCS crashes and ND crashes/events, respectively). The lack of the CE category "*This Vehicle Loss of Control*," and the abundance of the CE category "*This Vehicle Traveling*" in the ND dataset likely reflects the preponderance of non-crashes in this dataset (compared to crashes in the LTCCS dataset).

Table 18 shows the percentage of multi-vehicle crashes/events in each CE category across the LTCCS and ND datasets. The distribution of CEs in LTCCS multi-vehicle crashes and ND multi-vehicle crashes/events was fairly similar. The largest differences between these two datasets during multi-vehicle crashes/events occurred in the CE categories "*This Vehicle Not Involved in First Harmful Event*" (17.5 percent and 0 percent, respectively), "*This Vehicle Traveling*" (16.3 percent and 32.7 percent, respectively), and "*This Vehicle Loss of Control*" (5 percent and 0 percent, respectively). Similar to Table 17, the ND multi-vehicle crashes/events in Table 18 for the CE categories "*This Vehicle Loss of Control*" and "*This Vehicle Traveling*" likely reflect the preponderance of non-crashes in the ND dataset.

Table 18. Distribution of CEs by multi-vehicle crash/event severity in the LTCCS and ND datasets.

Crash/Event Severity	Crash/Event Severity	Other Motor Vehicle in Lane	Other Motor Vehicle Encroaching into Lane	This Vehicle Not Involved in First Harmful Event	This Vehicle Traveling	This Vehicle Loss of Control	Other (specify)	Object or Animal	Pedestrian, Pedalcyclist, or Other Non-motorist
LTCCS	LTCCS K—Fatal Crash (n = 7,775)	26.71%	23.54%	33.87%	10.30%	5.05%	0.53%	0.00%	0.00%
LTCCS	LTCCS A—Incapacitating Injury (n = 30,531)	35.52%	27.49%	14.43%	17.01%	3.18%	2.38%	0.00%	0.00%
LTCCS	LTCCS B—Non-Incapacitating Injury (n = 36,016)	35.90%	22.37%	16.63%	17.02%	6.50%	1.42%	0.16%	0.00%
LTCCS	LTCCS Total (n = 74,322)	34.78%	24.59%	17.53%	16.31%	4.99%	1.72%	0.08%	0.00%
ND	ND O—No Injury (n = 3)	33.33%	0.00%	0.00%	66.67%	0.00%	0.00%	0.00%	0.00%
ND	ND N—Near-crash (n = 122)	26.23%	32.79%	0.00%	40.16%	0.00%	0.82%	0.00%	0.00%
ND	ND I—Incident (n = 1,788)	40.66%	26.79%	0.00%	32.10%	0.00%	0.28%	0.11%	0.06%
ND	ND Total (n = 1,913)	39.73%	27.13%	0.00%	32.67%	0.00%	0.31%	0.10%	0.05%

Table 19 shows the percentage of single-vehicle crashes/events in each CE category across the LTCCS and ND datasets. There were discrepancies in single-vehicle crashes/events between the LTCCS and ND datasets in the CE categories "*This Vehicle Loss of Control*" (50.3 percent of the LTCCS crashes and 0.16 percent of the ND crashes/events) and "*This Vehicle Traveling*" (40.8 percent of the LTCCS crashes and 95.8 percent of the ND crashes/events). As in Table 18, the few ND single-vehicle crashes/events in the CE categories "*This Vehicle Loss of Control*" and "*This Vehicle Traveling*" likely reflects the preponderance of non-crashes in the ND dataset.

Table 19. Distribution of CEs by single-vehicle crash/event severity in the LTCCS and ND datasets.

Crash/Event Severity	Other Motor Vehicle in Lane	Other Motor Vehicle Encroaching into Lane	This Vehicle Not Involved in First Harmful Event	This Vehicle Traveling	This Vehicle Loss of Control	Other (specify)	Object or Animal	Pedestrian, Pedalcyclist, or Other Non-motorist
LTCCS K—Fatal Crash (n = 952)	0.00%	0.00%	0.00%	31.69%	21.79%	6.51%	5.22%	34.79%
LTCCS A—Incapacitating Injury (n = 8,594)	0.00%	2.39%	0.00%	45.81%	38.48%	1.69%	0.80%	10.83%
LTCCS B—Non-incapacitating Injury (n = 20,948)	0.00%	0.88%	0.00%	39.13%	56.44%	0.61%	2.94%	0.00%
LTCCS Total (n= 30,494)	0.00%	1.28%	0.00%	40.78%	50.30%	1.10%	2.41%	4.14%
ND O—No Injury (n = 18)	0.00%	0.00%	0.00%	27.78%	0.00%	0.00%	72.22%	0.00%
ND N—Near-crash (n = 73)	0.00%	1.37%	0.00%	57.53%	2.74%	1.37%	32.88%	4.11%
ND I—Incident (n = 2,470)	0.08%	0.00%	0.00%	97.41%	0.08%	0.00%	2.06%	0.36%
ND Total (n = 2,561)	0.08%	0.04%	0.00%	95.78%	0.16%	0.04%	3.44%	0.47%

3.1.7 Critical Reason

Table 20 shows the distribution of CRs by crash/event severity in the LTCCS and ND datasets. Similar to the CE, this information was only collected in the ND and LTCCS datasets; thus, no comparisons were made with the GES dataset. The CR is the immediate reason or failure leading to the CE. Note that only one CR was coded in each crash/event.[7,8] As shown in Table 20, the most apparent difference between the LTCCS and ND datasets involved the CR categories "*Recognition Error*" (15.3 percent and 53.5 percent, respectively) and "*No Driver Error*" (44.6 percent and 14.3 percent, respectively). While it is likely that some of this variability reflects the difference between crashes and non-crashes, much of this variability likely reflects the ability of ND to collect detailed information on what the driver was doing prior to the crash/event. The LTCCS relied on witnesses and driver interviews; thus, a witness must have observed a distracted truck driver and/or the truck driver must have divulged that he/she was distracted. It is difficult to observe the truck driver’s in-cab behavior (especially from within a passenger car), and truck drivers might be motivated not to self-disclose this information for fear of prosecution.

Table 20. Distribution of CRs by crash/event severity in the LTCCS and ND datasets.

Crash/Event Severity	No Driver Error	Decision Error	Recognition Error	Performance Error	Physical Driver Error	Vehicle Related	Environment: Highway	Environment: Weather	Environment: Other	Unknown
LTCCS K—Fatal Crash (n = 8,727)	72.88%	8.79%	7.54%	3.41%	3.03%	3.57%	0.03%	0.00%	0.00%	0.75%
LTCCS A—Incapacitating Injury (n = 39,125)	53.41%	15.42%	16.66%	6.99%	4.18%	2.96%	0.37%	0.02%	0.00%	0.00%
LTCCS B—Non-incapacitating Injury (n = 56,964)	34.28%	29.40%	15.46%	5.08%	8.64%	6.10%	0.82%	0.22%	0.00%	0.00%
LTCCS Total (n = 104,815)	44.64%	22.46%	15.25%	5.65%	6.50%	4.72%	0.59%	0.13%	0.00%	0.06%
ND O—No Injury (n = 21)	4.76%	9.52%	14.29%	14.29%	0.00%	0.00%	0.00%	0.00%	57.14%	0.00%
ND N—Near-crash (n = 195)	25.26%	12.89%	36.08%	7.22%	2.58%	0.00%	5.67%	0.00%	9.79%	0.52%
ND I—Incident (n = 4,258)	13.83%	19.02%	54.46%	1.88%	6.58%	0.00%	2.25%	0.05%	1.53%	0.40%
ND Total (n = 4,474)	14.28%	18.71%	53.46%	2.17%	6.37%	0.00%	2.39%	0.04%	2.17%	0.40%

Table 21 shows the distribution of CRs by multi-vehicle crash/event severity in the LTCCS and ND datasets. The data in Table 21 suggest that truck drivers in a multi-vehicle crash in the LTCCS dataset were far less likely to be coded with the CR "*No Driver Error*," compared to truck drivers in the ND dataset (61.5 percent versus 33.3 percent, respectively). Note that the vehicle-based sensor suite employed in ND is better suited for detecting instrumented truck-initiated actions than non-instrumented truck-initiated actions; thus, there was a predominance of instrumented truck driver CRs in this dataset. This is also the likely reason for the large discrepancy in “decision errors” during multi-vehicle crashes/events between the LTCCS and ND datasets (17 percent versus 42.3 percent, respectively). While the overall total of recognition errors in LTCCS multi-vehicle crashes and ND multi-vehicle crashes/events was relatively similar (15.5 percent and 16.1 percent, respectively), recognition errors during ND multi-vehicle no-injury crashes and near-crashes (66.7 percent and 37.7 percent, respectively) were far higher than during LTCCS multi-vehicle crashes (range = 7.3 percent to 17.8 percent).

Table 21. Distribution of CRs by multi-vehicle crash/event severity in the LTCCS and ND datasets.

Crash/Event Severity	No Driver Error	Decision Error	Recognition Error	Performance Error	Physical Driver Error	Vehicle Related	Environment: Highway	Environment: Weather	Environment: Other	Unknown
LTCCS K—Fatal Crash (n = 7,775)	78.21%	7.07%	7.29%	3.27%	0.26%	3.37%	0.00%	0.00%	0.00%	0.54%
LTCCS A—Incapacitating Injury (n = 30,531)	65.96%	12.59%	14.83%	3.05%	0.15%	2.92%	0.48%	0.02%	0.00%	0.00%
LTCCS B—Non-incapacitating Injury (n = 36,016)	54.22%	22.84%	17.75%	2.77%	1.13%	1.30%	0.00%	0.00%	0.00%	0.00%
LTCCS Total (n = 74,322)	61.56%	16.98%	15.46%	2.93%	0.64%	2.18%	0.20%	0.01%	0.00%	0.06%
ND O—No Injury (n = 3)	33.33%	0.00%	66.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
ND N—Near-crash (n = 122)	40.16%	14.75%	37.70%	3.28%	0.00%	0.00%	3.28%	0.00%	0.00%	0.82%
ND I—Incident (n = 1,788)	32.94%	44.30%	14.54%	2.13%	0.22%	0.00%	4.70%	0.11%	0.34%	0.73%
ND Total (n = 1,913)	33.40%	42.34%	16.10%	2.20%	0.21%	0.00%	4.60%	0.10%	0.31%	0.73%

Table 22 shows the distribution of CRs by single-vehicle crash/event severity in the LTCCS and ND datasets. As shown in this table, almost all of the single-vehicle crashes/events in the ND dataset were coded with the CRs "*Recognition Error*" (81.4 percent) and "*Physical Driver Error*" (11 percent). Many of the ND single-vehicle crashes/events were characterized with the accident types "*Right Roadside Departure*" and "*Left Roadside Departure*" (94 percent of the single-vehicle crashes/events in the ND dataset). This particular accident type would lend itself to the CR "*Recognition Error*," which was most likely the reason for the large CR discrepancy between the LTCCS and ND datasets during single-vehicle crashes/events.

Table 22. Distribution of CRs by single-vehicle crash/event severity in the LTCCS and ND datasets.

Crashes/Events	No Driver Error	Decision Error	Recognition Error	Performance Error	Physical Driver Error	Vehicle Related	Environment: Highway	Environment: Weather	Environment: Other	Unknown
LTCCS K—Fatal Crash (n = 952)	29.37%	22.83%	9.60%	4.60%	25.70%	5.22%	0.25%	0.00%	0.00%	2.43%
LTCCS A—Incapacitating Injury (n = 8,594)	8.82%	25.46%	23.15%	21.00%	18.48%	3.10%	0.00%	0.00%	0.00%	0.00%
LTCCS B—Non-Incapacitating Injury (n = 20,948)	0.00%	40.68%	11.53%	9.05%	21.54%	14.36%	2.24%	0.61%	0.00%	0.00%
LTCCS Total (n= 30,494)	3.40%	35.83%	14.74%	12.28%	20.81%	10.90%	1.45%	0.42%	0.00%	0.08%
ND O—No Injury (n = 18)	0.00%	11.11%	5.56%	16.67%	0.00%	0.00%	0.00%	0.00%	66.67%	0.00%
ND N—Near-Crash (n = 73)	0.00%	9.59%	32.88%	13.70%	6.85%	0.00%	9.59%	0.00%	27.40%	0.00%
ND I—Incident (n = 2,470)	0.00%	0.73%	83.36%	1.70%	11.17%	0.00%	0.49%	0.00%	2.39%	0.16%
ND Total (n = 2,561)	0.00%	1.05%	81.37%	2.15%	10.97%	0.00%	0.74%	0.00%	3.55%	0.16%

3.2 ANALYSIS 2: EVENT TYPE: REAR-END, TRUCK STRIKING

Rear-end crashes/events consist of two primary event configurations: rear-end, lead vehicle stopped (RE-LVS) and rear-end, lead vehicle moving (RE-LVM). These two rear-end crash/event types have different, but overlapping, characteristics and causal profiles. These differences were explored using key variables, such as the CR and CE coded during the RE-LVS and RE-LVM crash/event. These key variables were compared across the LTCCS and ND datasets with the major differences highlighted. The rear-end crashes/events that were considered in the analysis included only the LTCCS crashes where a heavy truck struck another vehicle and ND crashes/events where the instrumented vehicle struck another vehicle (or would have struck another vehicle had there not been a successful avoidance maneuver). The data collection methods used in the naturalistic studies made it difficult to determine the various key causal variables when the striking vehicle was not instrumented; therefore, these crashes/events in the LTCCS and ND datasets were not considered in the current study.

3.2.1 Rear-end Event Comparative Analysis

Table 23 shows the percentage of attempted avoidance maneuvers during LTCCS and ND rear-end crashes/events. As shown in this table, *Braking (No Lockup or Lockup Unknown)* was the most frequently observed attempted avoidance maneuver during ND rear-end crashes/events (55.4 percent) and the second most prevalent attempted avoidance maneuver during LTCCS rear-end crashes (20.2 percent). The most frequently recorded attempted avoidance maneuver during LTCCS rear-end crashes was *Braking (Lockup)*, coded in 25.3 percent of the rear-end crashes. Given the higher-severity crashes in the LTCCS dataset, compared to the ND dataset, it would be expected that when the brakes were applied, a lockup would be more likely (given the severity of the situation). In 16.1 percent of the LTCCS rear-end crashes, *No Avoidance Maneuver* was attempted by the driver; however, this attempted avoidance maneuver was observed in only 1.5 percent of the ND rear-end crashes/events. It is likely that some of this variability could be due to the higher-severity crashes in the LTCCS; however, it is more likely that the attempted avoidance maneuver made by the drivers during these LTCCS rear-end crashes was so minor that the crash investigator was unable to detect it (compared to ND where these minor maneuvers could be observed through the video or kinematic data).

Table 23. LTCCS and ND rear-end crashes/events by attempted avoidance maneuver.

Attempted Avoidance Maneuver	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
No Avoidance Maneuver	20.68%	5.43%	16.11%	1.69%	0.00%	1.51%
Braking (No Lockup or Lockup Unknown)	21.69%	16.83%	20.23%	55.41%	55.34%	55.40%
Braking (Lockup)	30.57%	12.87%	25.26%	0.23%	0.97%	0.30%
Steering Left	3.79%	1.94%	3.23%	8.78%	4.85%	8.38%
Steering Right	0.55%	0.00%	0.38%	2.03%	2.91%	2.12%
Braking and Steering Left	9.29%	1.88%	7.07%	11.71%	8.74%	11.40%

Attempted Avoidance Maneuver	LTCCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
Braking and Steering Right	6.26%	21.04%	10.69%	6.42%	19.42%	7.77%
Other Action	6.42%	9.88%	7.46%	0.00%	0.00%	0.00%
Unknown	0.76%	30.14%	9.57%	0.00%	0.00%	0.00%
Released Gas Pedal and Steered to Left	0.00%	0.00%	0.00%	1.58%	0.00%	1.41%
Released Gas Pedal and Steered to Right	0.00%	0.00%	0.00%	0.56%	2.91%	0.81%
Released Gas Pedal Without Braking	0.00%	0.00%	0.00%	3.04%	0.00%	2.72%
Accelerated	0.00%	0.00%	0.00%	0.23%	0.00%	0.20%
Accelerated and Steered to Left	0.00%	0.00%	0.00%	6.76%	1.94%	6.26%
Accelerated and Steered to Right	0.00%	0.00%	0.00%	1.58%	2.91%	1.72%

Table 24 shows the percentage of pre-event movement during LTCCS and ND rear-end crashes/ events. As shown in this table, the pre-event movement "*Going Straight*" accounted for 89.1 percent of the LTCCS rear-end crashes and 51.6 percent of the ND rear-end crashes/events. The only other pre-event movement types that represented more than 2 percent of the LTCCS rear-end crashes were: *Passing or Overtaking Another Vehicle* (3.3 percent), *Negotiating a Curve* (2.6 percent), and *Changing Lanes* (3.9 percent). The pre-event movements during the ND rear-end crashes/events were more dispersed than those indicated in the LTCCS. For example, more than a third of the ND rear-end crashes/events were coded with the pre-event movements "*Decelerating in Traffic Lane*" (26.8 percent) and "*Accelerating in Traffic Lane*" (11.3 percent).

Table 24. LTCCS and ND rear-end crashes/events by pre-event movement.

Pre-event Movement	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
Going Straight	86.80%	94.39%	89.07%	53.72%	33.01%	51.56%
Decelerating in Traffic Lane	0.33%	2.44%	0.96%	25.00%	42.72%	26.84%
Accelerating in Traffic Lane	0.38%	0.00%	0.26%	12.05%	4.85%	11.30%
Passing or Overtaking Another Vehicle	4.70%	0.00%	3.29%	0.45%	0.97%	0.50%
Negotiating a Curve	2.95%	1.61%	2.55%	1.69%	7.77%	2.32%
Changing Lanes	4.85%	1.56%	3.86%	5.18%	2.91%	4.94%
Merging	0.00%	0.00%	0.00%	0.90%	2.91%	1.11%
Starting in Traffic Lane	0.00%	0.00%	0.00%	0.23%	0.00%	0.20%
Stopped in Traffic Lane	0.00%	0.00%	0.00%	0.23%	1.94%	0.40%

Pre-event Movement	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
Successful Avoidance of Previous CE	0.00%	0.00%	0.00%	0.00%	0.97%	0.10%
Turning Left	0.00%	0.00%	0.00%	0.45%	1.94%	0.61%
Turning Right	0.00%	0.00%	0.00%	0.11%	0.00%	0.10%

Table 25 shows the percentage of number of vehicles involved during LTCCS and ND rear-end crashes/events. As shown in this table, most of the ND rear-end crashes/events involved two vehicles (95.2 percent). Two-vehicle crashes were also prevalent during LTCCS rear-end crashes (48.6 percent). However, LTCCS rear-end crashes involving three vehicles and four or more vehicles represented 33.3 percent and 18.1 percent of the LTCCS rear-end crashes, respectively, while only 4.6 percent and 0.2 percent of the ND rear-end crashes/events involved three vehicles and four or more vehicles, respectively. The lack of crashes in the ND dataset involving more than two vehicles is likely the product of the lower-severity crashes/events in the ND dataset. For example, when a truck made contact with another vehicle, it is likely that the energy involved in the collision caused one or more of the vehicles to make contact with a third vehicle (or more). Most of the events in the ND dataset were non-crashes, which did not involve any physical contact between vehicles.

Table 25. LTCCS and ND rear-end crashes/events by number of vehicles involved.

Number of Vehicles Involved	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
2 Vehicles	47.02%	52.43%	48.64%	95.27%	94.17%	95.16%
3 Vehicles	37.02%	24.58%	33.29%	4.50%	5.83%	4.64%
4 or More Vehicles	15.96%	22.98%	18.06%	0.23%	0.00%	0.20%

Table 26 shows the percentage of driver age during LTCCS and ND rear-end crashes/events. There was a slightly higher proportion of drivers 31–40 years old during ND rear-end crashes/events (38 percent) compared to drivers in LTCCS rear-end crashes (31.0 percent). However, the LTCCS had a higher proportion of drivers 41–50 years old than did the ND dataset (39.9 percent versus 34.9 percent, respectively).

Table 26. LTCCS and ND rear-end crashes/events by driver age.

Driver Age	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
30 or Younger	16.46%	12.40%	15.24%	18.24%	17.48%	18.16%
31–40	35.72%	20.12%	31.04%	38.29%	35.92%	38.04%
41–50	33.56%	54.68%	39.89%	34.35%	39.81%	34.91%
51–60	14.26%	11.65%	13.48%	8.67%	6.80%	8.48%
61 or Older	0.00%	1.14%	0.34%	0.45%	0.00%	0.40%

Table 27 shows the percentage of CEs during LTCCS and ND rear-end crashes/events. As shown in this table, the most frequently observed CE category in the LTCCS and ND datasets was *Other Motor Vehicle in Lane* (87.1 percent and 69 percent of the crashes/events, respectively). The CE category "*This Vehicle Traveling*" was coded in 25 percent of the ND rear-end crashes/events; however, this CE category was only coded in 0.5 percent of the LTCCS rear-end crashes. The CE "*This Vehicle Loss of Control*" was coded in 5.6 percent of LTCCS rear-end crashes, but 0 percent of the ND rear-end crashes/events. Relatively few of the LTCCS rear-end crashes were coded with the CE category "*This Vehicle Traveling*" (0 percent of the RE-LVM crashes and 1.6 percent of the RE-LVS crashes); however, this CE was coded in 25 percent and 11.7 percent of the ND RE-LVM and RE-LVS crashes/events, respectively.

Table 27. LTCCS and ND rear-end crashes/events by critical event category.

CE Category	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
This Vehicle Loss of Control	7.35%	1.51%	5.60%	0.00%	0.00%	0.00%
This Vehicle Traveling	0.00%	1.55%	0.47%	25.00%	11.65%	25.00%
Other Motor Vehicle in Lane	82.82%	96.94%	87.06%	69.03%	73.79%	69.03%
Other Motor Vehicle Encroaching into Lane	9.82%	0.00%	6.88%	5.97%	14.56%	5.97%

Table 28 shows the percentage of CRs during LTCCS and ND rear-end crashes/events. As shown in Table 28this table, most of the LTCCS and ND rear-end crashes/events were assigned a CR in the *Driver Decision Factor* category (41.2 percent and 67.2 percent, respectively). *Driver Decision Error* was the most frequently coded CR in ND RE-LVM and RE-LVS crashes/events (69.5 percent and 47.6 percent, respectively), and it was the most frequently coded CR during LTCCS RE-LVM crashes (48.2 percent) and the second most frequently coded CR during LTCCS RE-LVS crashes (24.6 percent). This discrepancy was in large part due to the prevalence of the specific CR, IEA (a CR in the *Driver Decision Error* category), in the ND dataset (coded in 39.5 percent of the ND rear-end crashes/events compared to 0.5 percent of the LTCCS rear-end crashes). The CR "*Driver Recognition Error*" was the second most prevalent CR category in both datasets (30.6 percent in the LTCCS versus 17.1 percent in the ND dataset). Both datasets had approximately the same proportion of rear-end crashes/events coded with the CR "*No Driver Error*" (11.8 percent in the LTCCS versus 13.7 percent in the ND dataset).

Table 28. LTCCS and ND rear-end crashes/events by CR category.

CR Category	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
No Driver Error	16.87%	0.00%	11.81%	12.05%	28.16%	13.72%
Physical Driver Error	4.42%	0.00%	3.10%	0.23%	0.00%	0.20%
Driver Recognition Error	25.41%	42.71%	30.60%	16.78%	19.42%	17.05%
Driver Decision Error	48.24%	24.65%	41.17%	69.48%	47.57%	67.20%
Driver Performance Error	4.41%	12.52%	6.84%	1.01%	4.85%	1.41%

CR Category	LTCCS RE-LVM (n = 9,089)	LTCCS RE-LVS (n = 3,892)	LTCCS RE Total (n = 12,981)	ND RE-LVM (n = 888)	ND RE-LVS (n = 103)	ND RE Total (n = 991)
Vehicle-Related Error	0.65%	19.30%	6.24%	0.00%	0.00%	0.00%
Unknown Reason	0.00%	0.82%	0.25%	0.23%	0.00%	0.20%
Environmental:-Weather	0.00%	0.00%	0.00%	0.23%	0.00%	0.20%

One of the most significant discrepancies between the LTCCS and the ND datasets was that 28.2 percent of the ND RE-LVS crashes/events were coded with the CR "*No Driver Error*," compared to 0 percent of the LTCCS RE-LVS crashes. While there were some differences between the CR categories coded in RE-LVS and RE-LVM profiles in the ND and LTCCS datasets (noted above), their overall profiles were very similar.

3.2.2 Analysis of Associated Factor: Following Too Closely

FMCSA published "relative risk" statistics[2,3] regarding the associated factor "*Following Too Closely*" in the LTCCS. These were based on comparisons between crashes where the truck was assigned the CR to crashes where the truck was not assigned the CR. It was found that the associated factor "*Following Too Closely*" had a relative risk of 22.6 (i.e., heavy-truck drivers were 22.6 times more likely to be assigned the CR if they were following too closely than if they were not). In itself, this is extremely alarming; however, the methodology used to calculate this statistic had a serious limitation. The relative risk estimate in this case was not an estimate of the increase in risk of a heavy-truck driver following too closely, but rather the increase in risk of being assigned the CR if the truck driver were following too closely. An accurate risk ratio estimate needs to have a reliable estimate for exposure to a risk factor. The estimate for exposure in this calculation was the crashes in which the truck was not assigned the CR; however, this may not be a typical driving scenario. The ND dataset provides an opportunity to reproduce this estimate using events which did not result in crashes. An estimate of risk was developed using the lowest severity multi-vehicle events in the ND dataset (i.e., an incident), in order to quantify the risk when the following distance falls to under 2 seconds (no single-vehicle ND incidents were included in this analysis; thus, unintentional lane deviations were excluded).

Table 29 shows the 2 x 2 contingency table of following too closely (i.e., tailgating behavior) in ND incidents and LTCCS crashes. This table shows that 66,537 of the LTCCS crashes (89.5 percent of the total multi-vehicle LTCCS crashes) and 1,644 ND incidents (92 percent of the total multi-vehicle ND incidents) were not coded with *Following Too Closely*, while 7,785 LTCCS crashes (10.5 percent of the total multi-vehicle LTCCS crashes) and 144 ND incidents (8 percent of the total multi-vehicle ND incidents) were coded with that associated factor.

Table 29. Contingency table of following too closely by LTCCS crashes and ND incidents.

Crashes/Events	No Tailgating	Tailgating	Total Tailgating
ND Incidents	1,644	144	1,788
LTCCS Crashes	66,537	7,785	74,322
Total	**68,182**	**7,929**	**76,111**

The odds ratio for the factor "*Following Too Closely*" was 1.34 with a LCL of 1.12 and a UCL of 1.59. Thus, drivers were 1.34 times more likely to be involved in a crash than an ND incident if they were tailgating. Since incidents were used to calculate the odds ratio, they do not represent normal (or baseline) driving. Therefore, the point estimate and confidence interval should be considered more of a lower limit estimate, since one would expect fewer instances of following too closely under normal or baseline driving conditions.

3.2.3 Rear-end Event Critical Reason: Inadequate Evasive Action

The CR "IEA" is defined as a situation where a driver perceives a threat but makes an inadequate evasive action. The driver may brake insufficiently, or may brake only, when both braking and steering are called for. This was an infrequent CR in the LTCCS (0.5 percent of rear-end crashes), but was commonly observed in the ND dataset (39.5 percent of rear-end crashes/events). ND has the advantage of being able to view the driver's pre- and post-response to the threat; however, one disadvantage is the inability to assess the mechanical condition (i.e., brakes) that might have contributed to the inadequate response. The rear-end crashes/events in the ND dataset with this CR were re-reviewed by trained data analysts to determine salient characteristics. In particular, data analysts re-reviewed these crashes/events and noted the secondary contributing factor. These secondary CRs may reveal how the CR "IEA" interacts with other contributing factors. However, they may also demonstrate that the CR "IEA" plays a much bigger role in crashes than indicated in the LTCCS dataset (e.g., this behavior may not be discernible to crash investigators who cannot reconstruct driver response in sufficient detail). A detailed analysis of 100 ND rear-end crashes/events coded with the CR "IEA" may provide insight into why this particular CR varied markedly between the LTCCS and ND datasets.

Table 30 shows secondary contributing factors in the re-review of 100 ND rear-end crashes/events coded with the CR, IEA. As shown in this table, 99 percent of these ND rear-end crashes/events were recorded with the CR category "*Driver Decision Error*," as the secondary contributing factor, while the remaining 1 percent were coded with the CR category "*Driver Recognition Error*" as the secondary contributing factor. The most frequently recoded secondary contributing factor during the 100 ND rear-end crash/events was *Misjudgment of Gap or Others' Speed* (51 percent), followed by *Aggressive Driving Behavior* (44 percent), *False Assumption of Other Road Users' Actions* (4 percent), and *Internal Distraction* (1 percent).

Table 30. Secondary contributing factor in 100 ND rear-end IEA crashes/events.

Secondary Contributing Factor	Percent of 100 ND Rear-End Crashes/Events with the CR, IEA
Driver Decision Error—Aggressive Driving Behavior	44.00%
Driver Decision Error—False Assumption of Other Road Users' Actions	4.00%
Driver Decision Error—Misjudgment of Gap or Others' Speed	51.00%
Driver Recognition Error—Internal Distraction	1.00%

3.3 ANALYSIS 3: CONTRIBUTING FACTOR: DRIVER FATIGUE

In the LTCCS and ND datasets, *Fatigue* was either a CR or an associated factor. In the LTCCS, the only fatigue-related CR required the driver to be asleep at the wheel (3.8 percent of the total LTCCS crashes), while the ND dataset included both asleep at the wheel (0.6 percent of the total

ND crashes/events) and high-fatigue-related CRs (10.4 percent of the total ND crashes/events). Due to the limited number of ND crashes/events in which the CR "*Asleep*" was coded, it is expected that many of the results between these two datasets will vary. The following comparative analysis explored key variables, such as CR, CE, etc.; however, differences were also explored by disaggregating lane departure event types.

3.3.1 Driver Fatigue Comparative Analysis

Table 31 shows accident type by driver fatigue in the LTCCS and ND datasets. The most commonly recorded accident type in fatigue-related crashes/events in the LTCCS and ND datasets was *Right Roadside Departure* (56.5 present and 94.4 percent, respectively). The LTCCS had a higher proportion of fatigue-related crashes with the accident type "*Left Roadside Departure*" (32.2 percent), compared to crashes/events in the ND dataset (3.9 percent). The accident type, RE-LVM, was also recorded in 12.1 percent of the LTCCS crashes in which the CR was *Fatigue*, while only 0.7 percent of the ND crashes/events in which the CR was *Fatigue*.

Table 31. Driver fatigue by accident type in the LTCCS and ND datasets.

Accident Type	LTCCS Fatigue is the CR (n = 4,011)	LTCCS Fatigue Present But Not CR (n = 11,319)	ND Fatigue is the CR (n = 285)	ND Fatigue Present But Not CR (n = 369)
Miscellaneous	0.00%	23.88%	0.00%	0.00%
Forward Impact (Opposite Direction)	0.00%	0.00%	0.00%	0.00%
Forward Impact (Same Direction)	0.00%	0.00%	0.00%	0.00%
Forward Impact Single-Vehicle	0.00%	1.28%	0.35%	7.05%
Head-On	0.00%	6.08%	0.00%	0.27%
Intersection Paths-Straight	0.00%	11.24%	0.00%	0.27%
Left Roadside Departure	32.20%	14.90%	3.86%	3.52%
No Impact	1.24%	0.18%	0.00%	0.00%
Rear-end Lead Vehicle Moving	10.02%	12.07%	0.70%	15.45%
Rear-end Lead Vehicle Stopped	0.00%	2.28%	0.00%	2.17%
Rear-end Other/Unknown	0.00%	1.87%	0.00%	0.00%
Rear-ended Moving	0.00%	2.03%	0.00%	0.00%
Rear-ended Stopped	0.00%	0.98%	0.00%	0.00%
Right Roadside Departure	56.54%	20.31%	94.39%	59.89%
Sideswipe Opposite Direction	0.00%	0.00%	0.35%	0.81%
Sideswipe Same Direction	0.00%	1.75%	0.35%	10.03%
Turn Across Path	0.00%	1.16%	0.00%	0.00%
Turn Into Path	0.00%	0.00%	0.00%	0.54%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Among the ND crashes/events in which *Fatigue* was an associated factor, the most commonly recorded accident type was *Right Roadside Departure* (59.9 percent); however, the most commonly recorded accident type in LTCCS crashes where fatigue was an associated factor was *Miscellaneous* (23.9 percent) followed by *Right Roadside Departure* (20.3 percent). The accident type "*Left Roadside Departure*" was coded more often in LTCCS crashes where *Fatigue* was an associated factor (14.9 percent) compared to ND crashes/events where *Fatigue* was an associated factor (3.5 percent). Table 32 shows the attempted avoidance maneuver by driver fatigue in the LTCCS and ND datasets. In 99.3 percent of the LTCCS crashes where the CR was fatigue, *No Avoidance Maneuver* was attempted; however, the most common attempted avoidance maneuver in ND crashes/events with the CR "*Fatigue*" was *Steering Left* (92.3 percent). The primary reason for this difference was the coding of the CR "*Fatigue*" in both datasets. As indicated above, fatigue was only coded as a CR in LTCCS crashes if the driver was asleep (thus, unlikely to make an avoidance response), whereas the CR, *Fatigue*, in the ND dataset could reflect the driver being asleep or high-fatigue (although the former was rarely coded in the ND dataset). As indicated in Table 31, 94.4 percent of the ND crashes/events with the CR, *Fatigue*, were coded with the accident type "*Right Roadside Departure*;" thus, it is intuitive that the majority of attempted avoidance maneuvers during these ND crashes/events would be *Steering Left* (92.3 percent).

Table 32. Driver fatigue by attempted avoidance maneuver in the LTCCS and ND datasets.

Attempted Avoidance Maneuver	LTCCS Fatigue is the CR (n = 4,011)	LTCCS Fatigue Present But Not CR (n = 11,319)	ND Fatigue is the CR (n = 285)	ND Fatigue Present But Not CR (n = 369)
No Driver Present	0.00%	0.00%	0.00%	0.00%
No Avoidance Maneuver	99.25%	27.81%	0.00%	0.81%
Braking (No Lockup or Lockup Unknown)	0.00%	15.00%	0.70%	20.60%
Braking (Lockup)	0.00%	5.90%	0.00%	0.27%
Braked and Reversed (No or Unknown Lockup)	0.00%	0.00%	0.00%	0.00%
Steering Left	0.75%	9.61%	92.28%	61.79%
Steering Right	0.00%	7.19%	2.81%	4.61%
Braking and Steering Left	0.00%	8.77%	0.70%	4.07%
Braking and Steering Right	0.00%	10.52%	0.35%	4.88%
Accelerating	0.00%	6.08%	0.00%	0.00%
Accelerating and Steering Left	0.00%	0.00%	0.70%	1.08%
Accelerating and Steering Right	0.00%	0.00%	0.35%	0.00%
Other Action (Specify)	0.00%	9.12%	0.00%	0.00%
Released Gas Pedal Without Braking	0.00%	0.00%	0.00%	0.00%
Released Gas Pedal Without Braking and Steered to Left	0.00%	0.00%	1.75%	1.36%
Released Gas Pedal Without Braking and Steered to Right	0.00%	0.00%	0.35%	0.54%
Releasing Brakes	0.00%	0.00%	0.00%	0.00%
Unknown	0.00%	0.00%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

The profile of the attempted avoidance maneuvers for the crashes/events in which *Fatigue* was an associated factor was similar in both datasets. The two most frequently observed attempted avoidance maneuvers in ND crashes/events where *Fatigue* was an associated factor were *Steering Left* and *Braking (No or Unknown Lockup)* (61.8 percent and 20.6 percent, respectively). While *Braking (No or Unknown Lockup)* was the second most frequently coded attempted avoidance maneuver (15.0 percent) in LTCCS crashes where *Fatigue* was an associated factor "*No Avoidance Maneuver*" was coded in 27.8 percent of these LTCCS crashes.

Table 33 shows the pre-event movement by driver fatigue in the LTCCS and ND datasets. In both the LTCCS and ND datasets where *Fatigue* was the CR, the most frequently coded pre-event movement was *Going Straight* (65.1 percent and 89.8 percent, respectively), while the second most frequently coded pre-event movement in these LTCCS and ND crashes/events was *Negotiating a Curve* (27.6 percent and 7.7 percent, respectively). A similar distribution was found in the pre-event movements during LTCCS and ND crashes/events where *Fatigue* was an associated factor.

Table 33. Driver fatigue by pre-event movement in the LTCCS and ND datasets.

Pre-event Movement	LTCCS Fatigue is the CR (n = 4,011)	LTCCS Fatigue Present But Not CR (n = 11,319)	ND Fatigue is the CR (n = 285)	ND Fatigue Present But Not CR (n = 369)
No Driver Present	0.00%	0.00%	0.00%	0.00%
Going Straight	65.14%	41.12%	89.82%	76.15%
Decelerating in Traffic Lane	0.00%	1.16%	0.35%	8.40%
Accelerating in Traffic Lane	0.00%	6.27%	1.40%	3.79%
Starting in Traffic Lane	0.00%	0.00%	0.00%	0.00%
Stopped in Traffic Lane	0.00%	5.26%	0.00%	0.00%
Passing or Overtaking Another Vehicle	3.44%	6.07%	0.00%	0.00%
Turning Right	0.00%	1.12%	0.00%	0.27%
Turning Left	0.00%	0.30%	0.35%	0.00%
Making a U-turn	0.00%	0.00%	0.00%	0.00%
Backing up (Other Than for Parking Position)	0.00%	0.60%	0.00%	0.00%
Negotiating a Curve	27.55%	35.42%	7.72%	8.13%
Changing Lanes	3.12%	1.81%	0.00%	2.71%
Merging	0.75%	0.00%	0.35%	0.27%
Successful Avoidance to a Previous CE	0.00%	0.00%	0.00%	0.00%
Other	0.00%	0.86%	0.00%	0.27%
Entering a Parking Position, Backing	0.00%	0.00%	0.00%	0.00%
Entering a Parking Position, Moving Forward	0.00%	0.00%	0.00%	0.00%
Leaving a Parking Position, Moving Forward	0.00%	0.00%	0.00%	0.00%
Unknown	0.00%	0.00%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 34 shows the number of vehicles involved by driver fatigue in the LTCCS and ND datasets. The overwhelming majority of LTCCS and ND crashes/events with the CR "*Fatigue*" involved only one vehicle (90 percent and 98.6 percent). However, the distribution was vastly different when *Fatigue* was coded as an associated factor. While the majority of LTCCS and ND crashes/events where *Fatigue* was an associated factor involved two or fewer vehicles (81.2 percent and 98.9 percent, respectively), a significant portion of the LTCCS crashes where *Fatigue* was an associated factor involved three vehicles or four or more vehicles (11.3 percent and 7.5 percent, respectively). The differences in the number of vehicles involved when *Fatigue* was an associated factor closely resembles those observed in the general comparative analysis. This illustrates one of the inherent differences between the LTCCS and ND datasets: severity level of the crashes/events. As indicated above, the LTCCS focused on the highest severity crashes while non-crashes mostly populated the ND dataset.

Table 34. Driver fatigue by number of vehicles involved in the LTCCS and ND datasets.

Number of Vehicles Involved	LTCCS is the CR (n = 4,011)	LTCCS Fatigue Present But Not CR (n = 11,319)	ND Fatigue is the CR (n = 285)	ND Fatigue Present But Not CR (n = 369)
1 Vehicle	89.97%	49.13%	98.60%	70.46%
2 Vehicles	9.86%	32.07%	1.40%	28.46%
3 Vehicles	0.00%	11.28%	0.00%	1.08%
4 or More Vehicles	0.17%	7.52%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 35 shows driver fatigue by driver age in the LTCCS and ND datasets. As shown in this table, the age distributions in the LTCCS and ND datasets were relatively similar. However, LTCCS crashes with the CR "*Fatigue*" were more likely to be truck drivers 51–60 years old (21.8 percent), while only 13.3 percent of the ND crashes/events with the CR "*Fatigue*" involved a truck driver 51–60 years old.

Table 35. Driver fatigue by driver age in the LTCCS and ND datasets.

Driver Age	LTCCS Fatigue is the CR (n = 4,011)	LTCCS Fatigue Present But Not CR (n = 11,319)	ND Fatigue is the CR (n = 285)	ND Fatigue Present But Not CR (n = 369)
30 or Younger	1.99%	14.53%	3.51%	14.36%
31–40	26.90%	26.64%	34.74%	34.96%
41–50	49.26%	32.18%	45.96%	21.68%
51–60	21.84%	25.11%	13.33%	26.83%
61 or Older	0.00%	1.54%	2.46%	2.17%
No Occupant	0.00%	0.00%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 36 shows driver fatigue by CE category in the LTCCS and ND datasets. As shown in this table, the CE category profiles of LTCCS and ND crashes/events with the CR "*Fatigue*" were very similar (the CE "*This Vehicle Traveling*" was coded in 90 percent of the LTCCS crashes and

99.3 percent of the ND crashes/events with the CR "*Fatigue*"). However, the CE "*Other Motor Vehicle in Lane*" was coded in 10.0 percent of the LTCCS crashes with the CR "*Fatigue*," while only 0.7 percent of the ND crashes/events with the CR "*Fatigue*" were coded with the same CE.

Table 36. Driver fatigue by CE category in the LTCCS and ND datasets.

CE Category	LTCCS Fatigue is the CR (n = 4,011)	LTCCS Fatigue Present But Not CR (n = 11,319)	ND Fatigue is the CR (n = 285)	ND Fatigue Present But Not CR (n = 369)
This Vehicle Loss of Control	0.00%	31.96%	0.00%	0.27%
This Vehicle Traveling	89.97%	43.67%	99.30%	70.73%
Other Motor Vehicle in Lane	10.02%	15.95%	0.70%	14.36%
Other Motor Vehicle Encroaching into Lane	0.00%	5.33%	0.00%	8.67%
Pedestrian, Pedalcyclist, or Other Non-motorist	0.00%	0.18%	0.00%	0.54%
Object or Animal	0.00%	0.00%	0.00%	5.42%
Other	0.00%	0.77%	0.00%	0.00%
This Vehicle Not Involved in First Harmful Event	0.00%	2.14%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

The most prevalent CE category in LTCCS and ND crashes/events where *Fatigue* was an associated factor was *This Vehicle Traveling* (43.7 percent and 70.7 percent, respectively). The primary discrepancy between the LTCCS and ND crashes/events where *Fatigue* was an associated factor was the CE "*This Vehicle Loss of Control*" (32 percent and 0.27 percent, respectively), while the CE '"*Object or Animal*" was coded far more often in the ND dataset (5.4 percent) compared to the LTCCS dataset (0.43 percent).

3.3.2 Lane Departures

A lane deviation in the ND dataset was defined as any circumstance where the instrumented vehicle crossed over a solid lane line and no hazard was present (e.g., metal barrier, parked car, Jersey barrier, etc.). Lane departures were therefore among the lowest severity events in the ND dataset. In the ND dataset, 98.2 percent of the crashes/events with the CR "*Fatigue*" and 63.4 percent of the crashes/events where *Fatigue* was an associated factor were lane departures. In the LTCCS dataset, 88.7 percent of crashes with the CR "*Fatigue*" and 35.2 percent of the crashes where *Fatigue* was an associated factor were lane departures. A more detailed comparison of the CRs and CEs during lane departures where *Fatigue* was as associated factor was conducted in order to determine the impact of these low-severity ND events.

Table 37 shows the CE category in lane departure crashes/events in the LTCCS and ND datasets where *Fatigue* was an associated factor. Almost all of these lane departures in the ND dataset were coded with the CE "*This Vehicle Traveling*" (99.6 percent), whereas only 45.9 percent of the LTCCS lane departure crashes were coded with this same CE.

Table 37. CE category in lane departure crashes/events where fatigue was an associated factor in the LTCCS and ND datasets.

CE Category	LTCCS Fatigue Absent (n = 9,486)	LTCCS Fatigue Present But Not CR (n = 3,986)	ND Fatigue Absent (n = 1,894)	ND Fatigue Present But Not CR (n = 234)
This Vehicle Loss of Control	46.78%	54.13%	0.16%	0.43%
This Vehicle Traveling	49.67%	45.87%	99.63%	99.57%
Other Motor Vehicle in Lane	1.38%	0.00%	0.05%	0.00%
Object or Animal	0.00%	0.00%	0.05%	0.00%
Other	0.00%	0.00%	0.05%	0.00%
Other Motor Vehicle Encroaching into Lane	2.17%	0.00%	0.05%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

In the LTCCS, the two fatigue levels of interest were mainly split between the two CE categories "*This Vehicle Loss of Control*" and "*This Vehicle Traveling*." In lane-departure crashes in the LTCCS in which *Fatigue* was absent, 46.8 percent were assigned to the CE category "*This Vehicle Loss of Control*," and 49.7 percent were assigned to the CE category "*This Vehicle Traveling*." In lane departure crashes in which *Fatigue* was an associated factor, *This Vehicle Loss of Control* was the assigned CE category 54.1 percent of the time, and the remaining 45.9 percent of the crashes were assigned the CE category *This Vehicle Traveling*. This would indicate that in lane departures, the level of fatigue has little impact on the CE category assigned for the event.

Table 38 below shows the CR category in lane departure events in both the LTCCS and ND datasets by whether or not *Fatigue* was present as an associated factor. As in the previous analysis, the case where the crash's CR was fatigue-related is not examined because for either dataset, all of these events would belong to the *Physical Driver Error* CR category.

Table 38. Driver fatigue lane departure crashes/events by CR category in the LTCCS and ND datasets.

CR Category	LTCCS Fatigue Absent (n = 9,486)	LTCCS Fatigue Present But Not CR (n = 3,986)	ND Fatigue Absent (n = 1,894)	ND Fatigue Present But Not CR (n = 234)
No Driver Error	2.17%	0.00%	0.00%	0.00%
Physical Driver Error	4.06%	38.01%	0.00%	0.00%
Driver Recognition Error	21.34%	3.20%	96.94%	93.59%
Driver Decision Error	34.37%	40.58%	0.37%	2.14%
Driver Performance Error	6.65%	18.21%	2.22%	3.42%
Vehicle-Related Factor	25.65%	0.00%	0.00%	0.00%
Environment—Highway	4.42%	0.00%	0.26%	0.00%
Environment—Weather	1.34%	0.00%	0.00%	0.00%
Environment—Other	0.00%	0.00%	0.11%	0.00%
Unknown Reason	0.00%	0.00%	0.11%	0.85%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Among crashes in the LTCCS in which *Fatigue* was present as an associated factor, only five CR categories were assigned. In 40.6 percent of these crashes, *Driver Decision Error* was the assigned CR category, which was a larger proportion than for the lane departure crashes in which *Fatigue* was absent. *Physical Driver Error* was the assigned CR category in 38 percent of the lane departures in which *Fatigue* was an associated factor, but was only assigned to 4.1 percent of the crashes in which *Fatigue* was absent. *Driver Performance Error* also was more prevalent in crashes in which *Fatigue* was an associated factor (18.2 percent) than in crashes in which *Fatigue* was absent (6.7 percent). The CR category "*Driver Decision Error*" was only assigned to 3.2 percent of the lane departure crashes where *Fatigue* was an associated factor.

The sample size of lane departures in which *Fatigue* was an associated factor was small enough to make it difficult to generalize. However, the differences in the LTCCS CR category profiles among crashes in which *Fatigue* was absent and when *Fatigue* was an associated factor would indicate that these lane departures have key differences. In both types of lane departures, the CR category "*Driver Decision Error*" was the most frequently assigned; however, approximately one quarter of the crashes in which *Fatigue* was absent were assigned the CR category of *Vehicle Related Factor* and this CR category was never assigned to crashes in which *Fatigue* was an associated factor. Similar differences exist for the categories of *Physical Driver Error* and *Driver Recognition Error*.

3.4 ANALYSIS 4: CONTRIBUTING FACTOR: EXCESSIVE SPEED

Excessive Speed was a frequently recorded CR in the LTCCS dataset (13.5 percent of the total crashes); however, this CR was rarely coded in the ND dataset (0.9 percent of the total crashes/events). There were two specific CRs related to excessive speed in the LTCCS: *Too Fast for Conditions to be Able to Respond to Unexpected Actions of Other Road Users* and *Too Fast for Curve/Turn.* However, only *Too Fast for Conditions* was coded in the ND dataset (not *Too Fast for Curve/Turn*). To resolve this discrepancy, crashes/events in the ND dataset with the CR "*Too Fast for Conditions*" that occurred on a curve were re-reviewed to confirm that the excessive speed was “curve-related” or “other-road-user-related” (as was the original code). During the data reduction process, it was discovered that the ND dataset had very few crashes/events in which the CR "*Too Fast for Conditions*" also occurred on a curve or turn. However, of the 11 total crashes/events that were re-reviewed by data analysts, only 9 were determined to have excessive speed that was curve-related, while the remaining 2 were other-road-user-related. Thus, no conclusions or interpretations have been made between the LTCCS and ND datasets with respect to the CR "*Too Fast for Curve/Turn*."

As indicated above, the CR "*Too Fast for Conditions*" was coded less frequently in the ND dataset than in the LTCCS dataset. This discrepancy could be due to crash/event severity (i.e., misbehaviors like speeding were more common in severe crashes/events) or the video and kinematic data that were available to ND data analysts, affording them the opportunity to accurately view non-speed behaviors (as accurate speed information was easily obtainable from the kinematic data). Conversely, the CR "*Too Fast for Conditions*" may be a default CR during crash investigations with limited information on a driver’s pre-crash behavior. The comparative analysis of speed-related events in the LTCCS and ND datasets included comparisons between key characteristics and associated factors. During this analysis, an excessive-speed crash/event was defined as a crash/event in the LTCCS and ND datasets that has been assigned the specific CR, *Too Fast for Conditions to be Able to Respond to Unexpected Actions of Other Road Users.*

3.4.1 Too Fast For Conditions Comparative Analysis

Table 39 shows the percentage of accident types for LTCCS and ND crashes/events with the CR, *Too Fast for Conditions*. As shown in this table and the other tables in this section, there were only 31 ND crashes/events with the CR "*Too Fast for Conditions*." Thus, given the limited sample size in the ND dataset, the tables are presented, but the research team refrained from making any direct comparison between the LTCCS and ND datasets.

Table 39. LTCCS and ND crashes/events with the CR "too fast for conditions," by accident type.

Accident Types	LTCCS Crashes with the CR "Too Fast for Conditions" (n = 5,918)	ND Crashes/Events with the CR "Too Fast for Conditions" (n = 31)
Miscellaneous	12.30%	0.00%
Forward Impact Single Vehicle	3.31%	6.45%
Left Roadside Departure	17.26%	3.23%
No Impact	7.43%	0.00%
Rear-end Lead Vehicle Moving	18.40%	61.29%
Rear-end Lead Vehicle Stopped	8.12%	12.90%
Rear-end Other/Unknown	3.79%	0.00%
Right Roadside Departure	5.76%	3.23%
Sideswipe Opposite Direction	5.44%	3.23%
Sideswipe Same Direction	18.22%	3.23%
Turn Across Path	0.00%	3.23%
Turn Into Path	0.00%	3.23%
Total	**100.00%**	**100.00%**

Table 40 shows the percentage of attempted avoidance maneuvers for LTCCS and ND crashes/events with the CR "Too Fast for Conditions."

Table 40. LTCCS and ND crashes/events with the CR "too fast for conditions," by attempted avoidance maneuver.

Attempted Avoidance Maneuver	LTCCS Crashes with the CR "Too Fast for Conditions" (n = 5,918)	ND Crashes/Events with the CR "Too Fast for Conditions" (n = 31)
No Avoidance Maneuver	9.67%	0.00%
Braking (No or Unknown Lockup)	24.21%	64.52%
Braking (Lockup)	10.28%	0.00%
Steering Left	2.11%	6.45%
Steering Right	0.00%	3.23%
Braking and Steering Left	28.80%	6.45%
Braking and Steering Right	13.97%	12.90%
Accelerating and Steering Left	0.00%	6.45%
Other Action (Specify)	10.96%	0.00%
Unknown	0.00%	0.00%
Total	**100.00%**	**100.00%**

Table 41 shows the percentage of pre-event movements during LTCCS and ND crashes/events with the CR "*Too Fast for Conditions*."

Table 41. LTCCS and ND crashes/events with the CR "too fast for conditions" by pre-event movement.

Pre-event Movement	LTCCS Crashes with the CR "Too Fast for Conditions" (n = 5,918)	ND Crashes/Events with the CR "Too Fast for Conditions" (n = 31)
Going Straight	48.39%	48.39%
Decelerating in Traffic Lane	8.47%	25.81%
Turning Right	2.15%	3.23%
Turning Left	0.00%	0.00%
Negotiating a Curve	25.40%	6.45%
Changing Lanes	8.38%	12.90%
Passing or Overtaking Another Vehicle	0.00%	3.23%
Successful Avoidance Maneuver to a Previous CE	7.21%	0.00%
Total	**100.00%**	**100.00%**

Table 42 shows the percentage of number of vehicles involved in the LTCCS and ND crashes/events with the CR "*Too Fast for Conditions*."

Table 42. LTCCS and ND crashes/events with the CR "too fast for conditions," by the number of vehicles involved.

Number of Vehicles Involved	LTCCS Crashes with the CR "Too Fast for Conditions" (n = 5,918)	ND Crashes/Events with the CR "Too Fast for Conditions" (n = 31)
1 Vehicle	33.78%	12.90%
2 Vehicles	30.29%	80.65%
3 Vehicles	13.74%	6.45%

Number of Vehicles Involved	LTCCS Crashes with the CR "Too Fast for Conditions" (n = 5,918)	ND Crashes/Events with the CR "Too Fast for Conditions" (n = 31)
4 or More Vehicles	22.19%	0.00%
Total	**100.00%**	**100.00%**

Table 43 shows the percentage of driver age in the LTCCS and ND crashes/events with the CR "*Too Fast for Conditions*."

Table 43. LTCCS and ND crashes/events with the CR "too fast for conditions," by driver age.

Driver Age	LTCCS Crashes with the CR "Too Fast for Conditions" (n = 5,918)	ND Crashes/Events with the CR "Too Fast for Conditions" (n = 31)
30 or Younger	26.60%	12.90%
31–40	27.51%	61.29%
41–50	29.08%	25.81%
51–60	16.60%	0.00%
61 or Older	0.21%	0.00%

Table 44 shows the percentage of CEs during LTCCS and ND crashes/events with the CR "*Too Fast for Conditions*."

Table 44. LTCCS and ND crashes/events with the CR "too fast for conditions," by critical event.

CE Category	LTCCS Crashes with the CR "Too Fast for Conditions" (n = 5,918)	ND Crashes/Events with the CR "Too Fast for Conditions" (n = 31)
Object or Animal	0.00%	3.23%
This Vehicle Loss of Control	37.28%	0.00%
This Vehicle Traveling	30.06%	22.58%
Other Motor Vehicle in Lane	29.35%	70.97%
Other Motor Vehicle Encroaching into Lane	0.00%	3.23%
Pedestrian, Pedalcyclist, or Other Non-motorist	3.31%	0.00%
Total	**100.00%**	**100.00%**

3.4.2 High-speed Comparative Analysis

As there were few ND crashes/events with the CR "*Too Fast for Conditions*," the research team used another speed-related variable, the vehicle's pre-crash speed, to assess the influence of high travel speeds during LTCCS and ND crashes/events. This variable permitted the identification of high-speed crashes/events; that is, those occurring at some designated speed, such as greater than or equal to 60 mi/h (irrespective of the CR assigned in the crash/event). During this analysis, a high-speed crash/event was defined as a crash/event where the truck's pre-event speed was greater than or equal to 60 mi/h (i.e., hereafter referred to as a "top speed crash/event"). This speed was selected as the criterion for high travel speeds as all of the trucking companies in the ND dataset had trucks with active speed limiters (set at speeds greater than 60 mi/h). These top-speed crashes/events were compared using key characteristics and associated factors.

Table 45 shows the percentage of accident types for LTCCS and ND top-speed crashes/events. The largest discrepancy between the LTCCS and ND datasets was the large percentage of right roadside departures during ND top-speed crashes/events (78.3 percent; while only 21.8 percent of the LTCCS crashes were coded with this accident type). This large discrepancy was the result of a large percentage (43.1 percent of the total sample) of unintentional lane deviations in the ND top-speed crashes/events. Another interesting discrepancy involved the accident type "*Miscellaneous*." While 15.4 percent of the LTCCS top-speed crashes were coded with this accident type, zero were coded with this accident type in ND top-speed crashes/events.

Table 45. LTCCS and ND top-speed crashes/events by accident type.

Accident Type	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
Turn into Path	0.43%	0.26%
Forward Impact Same Direction	0.59%	0.00%
Forward Impact Single Vehicle	2.23%	1.48%
Left Roadside Departure	10.97%	2.40%
Miscellaneous	15.40%	0.00%
No Impact	0.43%	0.00%
Rear-end, Lead Vehicle Moving	11.32%	8.12%
Rear-end, Lead Vehicle Stopped	6.42%	0.26%
Rear-end, Other/Unknown	1.09%	0.00%
Head-on	0.21%	0.10%
Right Roadside Departure	21.77%	78.28%
Rear-ended Moving	0.00%	0.05%
Sideswipe Opposite Direction	3.66%	0.10%
Sideswipe Same Direction	25.49%	8.89%
Total	**100.00%**	**100.00%**

Table 46 shows the percentage of attempted avoidance maneuvers during LTCCS and ND top-speed crashes/events. There were two large discrepancies between the LTCCS and ND datasets. First, the most frequently coded attempted avoidance maneuver in ND top-speed crashes/events was *Steering Right* (79.9 percent); however, this accident type was only coded in 4.4 percent of the LTCCS top-speed crashes. As indicated in Table 45, the large percentage of unintentional lane deviations in ND top-speed crashes/events is the likely reason for this discrepancy. Second, 52.2 percent of the LTCCS top-speed crashes were coded with the attempted avoidance maneuver "*No Avoidance Maneuver*;" however, only 1 percent of the ND top-speed crashes/ events were coded with the same attempted avoidance maneuver. Some of this variability in the LTCCS and ND datasets may be explained by the method employed in the ND data collection to identify crashes/events (i.e., through spikes in the kinematic data). However, the kinematic data also allowed the ND data analyst to identify minor vehicle maneuvers made by the driver.

Table 46. LTCCS and ND top-speed crashes/events by attempted avoidance maneuver.

Attempted Avoidance Maneuver	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
No Avoidance Maneuver	52.17%	0.77%
Braking (No or Unknown Lockup)	4.92%	8.33%
Braking (Lockup)	7.29%	0.05%
Steering Left	4.43%	79.87%
Braking and Steering Right	14.06%	2.40%
Steering Right	2.65%	3.63%
Accelerated and Steered to Left	0.00%	0.92%
Released Gas Pedal Without Braking and Steered to Left	0.00%	0.92%
Other Action (Specify)	7.03%	0.00%
Released Gas Pedal Without Braking and Steered to Right	0.00%	0.36%
Released Gas Pedal Without Braking	0.00%	0.05%
Braking and Steering Left	4.61%	2.45%
Accelerated and Steered to Right	0.00%	0.15%
Released Brakes	0.00%	0.10%
Unknown	2.84%	0.00%
Total	**100.00%**	**100.00%**

Table 47 shows the percentage of pre-event movement in LTCCS and ND top-speed crashes/events. As shown in this table, the distributions of the LTCCS and ND datasets were relatively the same. The most frequently coded pre-event movement during LTCCS and ND top-speed crashes/events was *Going Straight* (79.5 percent and 87.9 percent, respectively), while the second most frequently coded pre-event movement was *Negotiating a Curve* (13.2 percent and 5.9 percent, respectively).

Table 47. LTCCS and ND top-speed crashes/events by pre-event movement.

Pre-event Movement	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
Going Straight	79.50%	87.94%
Passing or Overtaking Another Vehicle	5.64%	0.51%
Negotiating a Curve	13.24%	5.88%
Accelerating in Traffic Lane	0.00%	1.94%
Decelerating in Traffic Lane	1.09%	1.74%
Merging	0.00%	0.31%
Changing Lanes	0.52%	1.69%
Total	**100.00%**	**100.00%**

Table 48 shows the percentage of number of vehicles involved in LTCCS and ND top-speed crashes/events. Most of the ND top-speed crashes/events involved only one vehicle (81.3 percent), while most of the LTCCS top-speed crashes involved one or two vehicles (35.2 percent and 47.5 percent, respectively).

Table 48. LTCCS and ND top-speed crashes/events by number of vehicles involved.

Number of Vehicles Involved	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
1 Vehicle	35.16%	82.17%
2 Vehicles	47.45%	16.71%
3 Vehicles	7.03%	1.12%
4 or More Vehicles	10.36%	0.00%
Total	**100.00%**	**100.00%**

Table 49 shows the percentage of driver age groups in LTCCS and ND top-speed crashes/events. As shown in this table, the age distribution in LTCCS and ND top-speed crashes/events was similar and conforms to the distribution that was observed in the overall general comparative analysis.

Table 49. LTCCS and ND top-speed crashes/events by driver age.

Driver Age	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
30 or younger	15.56%	12.83%
31–40	18.14%	31.89%
41–50	43.31%	31.73%
51–60	20.71%	18.40%
61 or older	2.29%	5.16%

Table 50 shows the percentage of each CE category in LTCCS and ND top-speed crashes/events. While the most frequently coded CE category in LTCCS and ND top-speed crashes/events was *This Vehicle Traveling*, there was a large discrepancy between these two datasets (41.2 percent versus 85.6 percent, respectively). The CE categories "*Other Motor Vehicle in Lane*" and "*Other Motor Vehicle Encroaching into Lane*," were each coded in 6.5 percent of the ND top-speed crashes/events; however, these same two CE categories, *Other Motor Vehicle in Lane* and *Other Motor Vehicle Encroaching into Lane*, were coded in 16.2 percent and 23.7 percent, respectively, of the LTCCS top-speed crashes. As above, it appears the large percentage of unintentional lane deviations in the ND top-speed crashes/events skews the results.

Table 50. LTCCS and ND top-speed crashes/events by CE category.

CE Category	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
This Vehicle Not Involved in First Harmful Event	8.71%	0.00%
This Vehicle Loss of Control	7.98%	0.05%
This Vehicle Traveling	41.15%	85.59%
Other Motor Vehicle in Lane	16.19%	6.49%
Other Motor Vehicle Encroaching into Lane	23.74%	6.49%
Other	0.00%	0.05%

CE Category	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
Object or Animal	2.23%	1.33%
Total	**100.00%**	**100.00%**

Table 51 shows the percentage of each CR category in LTCCS and ND top-speed crashes/events. As shown in this table, the most frequently coded CR category in ND top-speed crashes was *Driver Recognition Error* (72.4 percent), while the three most frequently coded CR categories in LTCCS top-speed crashes were: *No Driver Error* (33 percent), *Physical Driver Error* (25.8 percent), and *Driver Recognition Error* (23.26 percent).

Table 51. LTCCS and ND top-speed crashes/events by CR category.

CR Category	LTCCS Top-speed Crashes (n = 11,676)	ND Top-speed Crashes/Events (n = 1,957)
No Driver Error	32.95%	7.46%
Physical Driver Error	25.83%	10.32%
Driver Recognition Error	23.16%	72.41%
Driver Decision Error	7.25%	6.59%
Driver Performance Error	2.63%	1.64%
Environment—Highway Related	0.00%	0.05%
Environment—Other	0.00%	1.23%
Vehicle Related Factor	2.63%	0.00%
Driver Related	0.00%	0.31%
Total	**100.00%**	**100.00%**

3.5 ANALYSIS 5: CONDITION OF OCCURRENCE: HIGH TRAFFIC DENSITY

The principal traffic density variable used in ND studies was LOS. LOS was a subjective variable that classified the degree of restriction of vehicle movement due to the presence of other vehicles on the roadway. The six-level LOS classification scheme was: light (A)—free-flowing traffic, medium (B)—flowing with some restrictions (due to the presence of other vehicles), and heavy (C-F)—various degrees of restricted traffic flow. High traffic density (C-F) elevates traffic conflict rate by about sixfold compared to low density.(7,18)

The LTCCS did not employ the LOS variable. While LTCCS investigators could not directly estimate the level of traffic density, they did record whether traffic was a factor in the crash. Traffic-related factors were determined in the LTCCS by the case reviewer using all available information inputs, with the primary sources being the driver interview, the PAR, and the researchers' on-scene investigation. In order to reconcile these data collection discrepancies between the LTCCS and ND datasets, 600 randomly selected crashes/events from each of the six LOS levels were reviewed to determine if any traffic factors were present during each crash/event. Although 600 ND crashes/events were reviewed, one crash/event had an unknown traffic factor and therefore was eliminated from consideration.

3.5.1 High Traffic Density Comparative Analysis

Table 52 shows the percentage of accident type by traffic factor in the LTCCS and ND datasets. Most of the ND crashes/events where a traffic factor was present were coded with the accident types RE-LVM (40.8 percent) and *Sideswipe Same Direction* (40.6 percent). The accident types in LTCCS crashes where a traffic factor was present were more evenly distributed; however, the two most frequently coded accident types in these LTCCS crashes were *Miscellaneous* (25.5 percent) and RE-LVM (22.4 percent).

Table 52. Accident type by traffic factor in the LTCCS and ND datasets.

Accident Type	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
Miscellaneous	25.20%	25.47%	0.53%	0.24%
Forward Impact Opposite Direction	0.17%	0.00%	0.00%	0.49%
Forward Impact Same Direction	0.09%	0.20%	0.00%	0.00%
Forward Impact Single Vehicle	1.55%	2.26%	11.05%	2.44%
Head-on	3.62%	0.39%	0.53%	0.73%
Intersection Paths-Straight	6.26%	0.00%	0.00%	0.49%
Left Roadside Departure	9.63%	4.13%	5.26%	0.73%
No Impact	1.47%	0.13%	0.00%	0.00%
Rear-end Lead Vehicle Moving	3.60%	22.36%	4.21%	40.83%
Rear-end Lead Vehicle Stopped	1.25%	10.35%	0.53%	6.85%
Rear-end Other/Unknown	0.38%	1.25%	0.00%	0.00%
Rear-ended Moving	5.47%	10.09%	0.00%	0.73%
Rear-ended Stopped	2.50%	3.76%	0.00%	0.00%
Right Roadside Departure	13.00%	3.09%	72.11%	0.98%
Sideswipe Opposite Direction	5.46%	3.78%	1.05%	0.49%
Sideswipe Same Direction	11.58%	11.63%	3.16%	40.59%
Turn Across Path	5.50%	0.35%	0.00%	1.22%
Turn Into Path	3.28%	0.75%	1.58%	3.18%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 53 shows the percentage of attempted avoidance maneuvers by traffic factor in the LTCCS and ND datasets. Most of the ND crashes/events where a traffic factor was present were coded with the attempted avoidance maneuver "*Braking (No or Unknown Lockup)*" (59.7 percent), followed by *Braking and Steering to the Right* (11.7 percent) and *Braking and Steering to the Left* (9.3 percent). As in the general comparative analysis above, the most frequently coded attempted avoidance maneuver in LTCCS crashes where a traffic factor was present was *No Avoidance Maneuver* (39.5 percent), followed by *Braking (No or Unknown Lockup)* and *Braking (Lockup)* (13.6 percent and 12.2 percent, respectively).

Table 53. Attempted avoidance maneuver by traffic factor in the LTCCS and ND datasets.

Attempted Avoidance Maneuver	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
No Driver Present	1.18%	0.04%	0.00%	0.00%
No Avoidance Maneuver	45.39%	39.54%	3.68%	1.22%
Braking (No or Unknown Lockup)	10.70%	13.60%	8.42%	59.66%
Braking (Lockup)	6.81%	12.18%	0.00%	0.24%
Steering Left	3.69%	5.43%	71.58%	5.13%
Steering Right	4.95%	3.11%	7.37%	5.13%
Braking and Steering Left	5.58%	7.21%	1.58%	9.29%
Braking and Steering Right	11.21%	7.09%	3.16%	11.74%
Braked and Reversed	0.00%	0.00%	0.00%	0.24%
Accelerating	1.08%	0.00%	0.00%	0.49%
Accelerating and Steering Left	0.44%	0.57%	1.58%	1.71%
Accelerating and Steering Right	0.17%	0.00%	0.00%	0.73%
Released Gas Pedal Without Braking	0.00%	0.00%	0.53%	1.22%
Released Gas Pedal Without Braking and Steered to Left	0.00%	0.00%	1.05%	1.47%
Released Gas Pedal Without Braking and Steered to Right	0.00%	0.00%	0.53%	1.71%
Releasing Brakes	0.00%	0.00%	0.53%	0.00%
Other Action (Specify)	6.91%	6.39%	0.00%	0.00%
Unknown	1.88%	4.86%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 54 shows the percentage of pre-event movement by traffic factor in the LTCCS and ND datasets. The most frequently coded pre-event movement in ND crashes/events where a traffic factor was present was *Going Straight* (49.4 percent), followed by *Decelerating in Traffic Lane* (19.3 percent) and *Accelerating in Traffic Lane* (15.2 percent). Most of the LTCCS crashes where a traffic factor was present were also coded with the pre-event movement "*Going Straight*" (65.7 percent).

Table 54. Pre-event movement by traffic factor in the LTCCS and ND datasets.

Pre-event Movement	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
No Driver Present	1.18%	0.04%	0.00%	0.00%
Going Straight	50.84%	65.72%	73.16%	49.39%
Decelerating in Traffic Lane	2.96%	6.81%	5.79%	19.32%
Accelerating in Traffic Lane	1.79%	1.86%	2.63%	15.16%
Starting in Traffic Lane	0.22%	0.63%	0.53%	0.49%
Stopped in Traffic Lane	4.38%	8.96%	0.53%	0.98%
Passing or Overtaking Another Vehicle	2.27%	0.00%	0.53%	1.71%
Turning Right	0.78%	0.75%	2.63%	1.22%
Turning Left	3.67%	0.12%	1.58%	0.98%

Pre-event Movement	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
Making a U-turn	0.00%	0.11%	0.53%	0.00%
Backing up (Other Than for Parking Position)	0.09%	0.32%	0.00%	0.00%
Negotiating a Curve	27.83%	4.79%	8.42%	1.96%
Changing Lanes	2.80%	3.25%	1.58%	4.89%
Merging	0.21%	0.00%	0.00%	3.18%
Successful Avoidance Maneuver to a Previous CE	0.79%	5.35%	0.53%	0.49%
Other (specify)	0.19%	1.26%	0.00%	0.24%
Unknown	0.00%	0.02%	0.00%	0.00%
Entering a Parking Position, Backing	0.00%	0.00%	0.53%	0.00%
Entering a Parking Position, Moving Forward	0.00%	0.00%	0.00%	0.00%
Leaving a Parking Position, Moving Forward	0.00%	0.00%	1.05%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 55 shows the percentage of number of vehicles involved by traffic factor in the LTCCS and ND datasets. As was expected, most of the ND crashes/events where a traffic factor was present involved two or more vehicles (95.9 percent). This was also found in the LTCCS crashes where a traffic factor was present (91.7 percent); however, the LTCCS crashes were more evenly distributed, while the ND crashes/events were mostly two-vehicle crashes/events.

Table 55. Number of vehicles involved by traffic factor in the LTCCS and ND datasets.

Number of Vehicles Involved	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
One	36.81%	8.29%	88.95%	4.16%
Two	50.48%	36.18%	9.47%	86.80%
Three	9.45%	26.18%	1.05%	8.07%
Four or More	3.27%	29.35%	0.53%	0.98%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 56 shows the percentage of driver age by traffic factor in the LTCCS and ND datasets. Overall, the age profiles in LTCCS and ND crashes/events where a traffic factor was present were relatively the same.

Table 56. Driver age by traffic factor in the LTCCS and ND datasets.

Driver Age	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
30 or younger	13.63%	12.65%	19.47%	19.56%
31–40	24.95%	28.01%	20.00%	31.05%
41–50	34.18%	36.52%	36.32%	37.16%
51–60	20.88%	17.26%	22.11%	11.74%
61 or older	5.17%	5.51%	2.11%	0.49%
No Occupant	1.18%	0.04%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 57 shows the percentage of CE category by traffic factor in the LTCCS and ND datasets. Most of the ND crashes/events where a traffic factor was present were coded with one of three CEs, including *Other Motor Vehicle in Lane* (39.4 percent), *Other Motor Vehicle Encroaching into Lane* (32.3 percent), and *This Vehicle Traveling* (27.6 percent). While the most frequently coded CE in LTCCS crashes where a traffic factor was present was also the CE "*Other Vehicle in Lane"* (47.7 percent), 22.2 percent of the LTCCS crashes were assigned the CE "*This Vehicle Not Involved in First Harmful Event*" (0 percent of the ND crashes/events were assigned to the CE category "*This Vehicle Not Involved in First Harmful Event*").

Table 57. CE category by traffic factor in the LTCCS and ND datasets.

CE Category	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
This Vehicle Loss of Control	22.30%	7.02%	0.53%	0.00%
This Vehicle Traveling	26.82%	14.30%	83.16%	27.63%
Other Motor Vehicle in Lane	16.11%	47.73%	3.68%	38.39%
Other Motor Vehicle Encroaching into Lane	22.21%	5.96%	2.63%	32.27%
Pedestrian, Pedalcyclist, or Other Non-motorist	0.80%	2.31%	0.53%	0.00%
Object or Animal	1.04%	0.00%	9.47%	1.47%
Other (Specify)	1.93%	0.49%	0.00%	0.24%
This Vehicle Not Involved in First Harmful Event	8.80%	22.21%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 58 shows the percentage of CR categories by traffic factor in the LTCCS and ND datasets. The CR profiles between the LTCCS and ND datasets where a traffic factor was present were very similar. Most of the CRs in the LTCCS and ND datasets where a traffic factor was present were distributed across three different CRs, including *No Driver Error* (48 percent and 37.9 percent, respectively), *Driver Decision Error* (24.1 percent and 36.7 percent, respectively), and *Driver Recognition Error* (19.7 percent and 20.1 percent, respectively).

Table 58. CR category by traffic factor in the LTCCS and ND datasets.

CR Category	LTCCS Absent (n = 76,463)	LTCCS Present (n = 28,353)	ND Absent (n = 190)	ND Present (n = 409)
No Driver Error	43.38%	48.03%	3.16%	37.90%
Physical Driver Error	8.91%	0.02%	6.84%	0.24%
Driver Recognition Error	13.59%	19.72%	68.95%	20.05%
Driver Decision Error	21.86%	24.10%	6.32%	36.67%
Driver Performance Error	5.34%	6.50%	4.21%	2.44%
Vehicle-Related Error	6.01%	1.23%	0.00%	0.00%
Environment—Highway	0.72%	0.22%	1.58%	1.71%
Environment—Weather	0.17%	0.02%	0.00%	0.00%
Environment—Other	0.00%	0.00%	8.95%	0.24%
Unknown Reason	0.03%	0.15%	0.00%	0.73%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

3.6 ANALYSIS 6: COMPLEX SCENARIO: CRASH TRIFECTA

Review of video and other ND data has revealed a frequently occurring sequence which has been termed by researchers as the crash trifecta.[4,10] The crash trifecta consists of three separate, but converging elements:

- Unsafe pre-incident behavior or maneuver (e.g., speeding, tailgating, unsafe turn).
- Transient driver inattention (which may be related to driving, such as mirror use, or unrelated, such as reaching for an object).
- An unexpected traffic event, such as unexpected stopping by the vehicle ahead.

Not every element of the crash trifecta occurred in every crash/event, but often two were present. The ND data allowed researchers to directly observe crashes/events to see convergences of multiple elements, such as the common pattern outlined above in the crash trifecta. This analysis reviewed a sample of ND crashes/events to assess and explicate the crash trifecta concept and perhaps other concepts of event convergence as a contributing factor in crashes/events.

The value of the crash trifecta concept, and convergence concepts in crash causation, is that it provides a structure for understanding the complexities of crash genesis. Both the LTCCS and ND studies to date have emphasized the CR as a primary proximal cause in the crash/event. However, other factors have been identified as associated factors and neither data collection approach has identified contributing factors in a systematic way. That is, no factor other than the CR has been specified as directly contributing to event genesis. In some ways, this appears to be a matter of convenience as it is easy to report and understand that speeding was the primary proximal cause in the truck crash. Yet, the CR variable consists of some CR choices that could be ongoing pre-event behaviors (e.g., tailgating) and others that are more likely to be transient, precipitating errors (e.g., inattention). Both could exist in the same crash/event. Coding rules in the LTCCS require that the same vehicle be assigned the CE and CR; thus, there is no variable that captures unexpected triggering events outside the vehicle with the CR. Plus, analysis of the crash trifecta requires joint consideration of all three elements in relation to crashes/events, not the compilation of three independent variables.

The crash trifecta could apply to any type of crash/event, but given the variety of crash types and scenarios, the initial crash trifecta analysis focused on only a few crash/event scenarios. Rear-end crashes/events represent the richest subset for crash trifecta assessment. To provide some generalization of findings, another crash type was also examined. Road departures are an important crash type where the convergence of multiple factors often causes the crash. As noted above, the crash trifecta concept may have heuristic value even if all three elements were not present in analyzed events.

To analyze and demonstrate the crash trifecta concept, 272 ND crashes/events were re-reviewed to determine the frequency and type of each of the crash trifecta elements. Then, these crashes/events were classified in terms of the joint presence or absence of the three trifecta elements. Table 59 shows the severity level of the ND crashes/events used in the crash trifecta analysis. Since only a combined 54 crashes and/or near-crashes were characterized as RE-LVS, RE-LVM, or roadside departures, all of these crashes/events were included in the analysis. However, the remaining crashes/events were randomly selected.

Table 59. Crash trifecta event classification.

Severity Level	Number of Crash Trifecta Crashes/Events (n = 272)
Crash	4
Crash-relevant Conflict	180
Near-crash	50
Unintentional Lane Deviation	38

The presence of the crash trifecta components was identified using a combination of existing data and the creation of a new variable, *Unexpected Traffic Event*. The driver was deemed to have experienced transient inattention if the time his/her eyes were off the forward roadway exceeded 1.0 seconds (s). A list of driver behaviors performed during the crash/event was created in prior data reduction. (See references 9, 10, 13, and 14.) This list of driver behaviors was used to indicate the presence of an unsafe pre-incident behavior or maneuver. An additional data reduction was performed in order to ascertain the presence of the unexpected traffic event (see Appendix A for a detailed data reduction protocol). Once all these three data elements were compiled, the combination of crash trifecta elements (or lack thereof) was calculated on the 272 ND crashes/events.

Table 60 shows the presence of crash trifecta elements by crash/event severity. Though limited in sample size, there appears to be a trend in the percent of all crash trifecta elements being present as the severity level of the crash/event increases (0 percent in unintentional lane deviations, 9.4 percent in crash-relevant conflicts, 20 percent in near-crashes, and 25 percent in crashes). While only 2.6 percent of the ND crashes/events had none of the crash trifecta components present, 47.5 percent of the ND crashes/events had two of the crash trifecta elements present.

Table 60. Crash trifecta components by event classification.

Crash Trifecta Elements	Crash Number (Percent)	Near-crash Number (Percent)	Crash-relevant Conflict Number (Percent)	Unintentional Lane Deviation Number (Percent)	Total Safety Events Number (Percent)
None	0 (0%)	3 (6%)	4 (2%)	0 (0%)	7 (3%)
Unexpected Traffic Event	0 (0%)	0 (0%)	1 (1%)	0 (0%)	1 (0%)
Transient Inattention	0 (0%)	1 (2%)	4 (2%)	0 (0%)	5 (2%)
Unsafe Behavior	0 (0%)	15 (30%)	477 (3%)	10 (26%)	102 (38%)
Unexpected Traffic Event + Transient Inattention	0 (0%)	0 (0%)	1 (1%)	0 (0%)	1 (0%)
Unexpected Traffic Event + Unsafe Behavior	0 (0%)	4 (8%)	18 (10%)	0 (0%)	22 (8%)
Unsafe Behavior + Transient Inattention	3 (75%)	17 (34%)	58 (32%)	28 (74%)	106 (39%)
Crash Trifecta	1 (25%)	10 (20%)	17 (9%)	0 (0%)	28 (10%)
Total	**4 (100%)**	**50 (100%)**	**180 (100%)**	**38 (100%)**	**272 (100%)**

4. DISCUSSION

4.1 CONCLUSIONS

The discussion below highlights the consistent discrepancies found in the comparative analyses performed in the current report. These discrepancies were found when comparing the LTCCS and ND datasets regardless of how the data were disaggregated, including across all crashes/events (i.e., general comparative analysis), rear-end crashes/events, driver fatigue crashes/events, excessive speed crashes/events, high-traffic density crashes/events, and lane departure crashes/events.

4.1.1 Comparative Analyses

4.1.1.1 Accident Type

One of the consistent discrepancies observed in LTCCS and ND comparisons involved the variable, accident type. As indicated above, the accident type categorized the scenario of the crash/event the driver was involved in (i.e., right roadside departure, etc.). The crash/event was defined as the first harmful event or projected first harmful event in a crash, near-crash, or incident between a vehicle and some object.[7,8] The object may be another vehicle, a person, an animal, a fixed object, the road surface, or the ground. Most of the crashes/events in the ND dataset had no contact between the subject vehicle and another object. In these cases, the analyst was instructed to project the likely scenario roles for the crashes/events where outcomes were not defined; or, if the event had resulted in a crash, what the crash scenario would have been.[7,8]

The accident types "*Right Roadside Departure*" and RE-LVM, were coded far more often in the ND dataset than the LTCCS dataset, while the accident types "*Miscellaneous*" and "*Head-on*" were coded far more frequently in the LTCCS dataset than the ND dataset. In addition, a larger percentage of the crashes in the ND dataset were coded with the accident type "*Forward Impact Single Vehicle*," compared to the LTCCS dataset. These discrepancies were the primary reason for the skewed comparisons between the LTCCS and ND datasets. The large percentage of ND crashes/events with the accident type "*Right Roadside Departure*" was greatly influenced by the inclusion of unintentional lane deviations (the lowest severity event in the ND dataset). Unintentional lane deviations were characterized as any circumstance where the subject vehicle crossed over a solid lane line where there was not a hazard present (guardrail, ditch, vehicle, etc.). These events in the ND dataset were almost exclusively distraction and fatigue-related events. This should come as no surprise as many prior studies have found a strong relationship between lane deviations and driver fatigue and distraction.[19,20] By definition, unintentional lane deviations involved the accident types "*Right Roadside Departure*" and "*Left Roadside Departure*" (although most of these were right roadside departures). The large proportion of unintentional lane deviations (approximately 27 percent of all ND crashes/events) greatly increased the proportion of roadside departures in the ND dataset.

The discrepancies found between the LTCCS and ND datasets in regard to the accident types RE-LVM and "*Miscellaneous*," illustrate the strength of the ND data collection methodology in collecting very detailed information via video and kinematic sensors. The accident type "*Miscellaneous*" was used as a catch-all in the LTCCS when very detailed information on the crash was unavailable. This rarely occurred in the ND dataset as data analysts had access to "instant replays" of the crash/event. Similarly, the large percentage of the accident type, RE-LVM, in the ND dataset (compared to the LTCCS dataset) likely reflects the ability of ND data collection to detect minor movements in other vehicles and the instrumented truck (whereas they might be coded as RE-LVS in the LTCCS without detailed kinematic data).

The accident type "*Head-on*" was coded far more often in the LTCCS than in the ND dataset. This illustrates the difference between high-severity crashes (as in the LTCCS) and non-crashes in the ND dataset. This accident type is likely to result in a crash given the closing velocities involved in this crash scenario. Lastly, more than 60 percent of the crashes in the ND dataset were animal strikes coded with the accident type "*Forward Impact Single Vehicle*." This accident type was coded far less often in the LTCCS dataset. While animal strikes in large trucks are undoubtedly a safety hazard, these types of crashes are lower-severity than those in the LTCCS and will rarely result in a fatality and/or injury. This discrepancy between the LTCCS and ND datasets highlights the differences in comparing lower-severity crashes and non-crashes (as found in the ND dataset) with higher-severity crashes (as found in the LTCCS dataset).

4.1.2 Attempted Avoidance Maneuver

The attempted avoidance maneuver documented the driver's actions initiated in response to the realization of impending danger.(7,8) There were four consistent discrepancies when comparing the LTCCS and ND datasets regarding the attempted avoidance maneuvers "*No Avoidance Maneuver*," "*Steered to the Left, Braking (Lockup)*," and "*Unknown*." The attempted avoidance maneuver "*No Avoidance Maneuver*" was coded far more often in the LTCCS dataset compared to the ND dataset. One likely explanation for this discrepancy involves the capture of crashes/events in the ND data collection methodology. Given the voluminous amount of video data, ND uses "spikes" in the kinematic data (such as a hard brake, swerve, etc.) to identify possible crashes/events. Thus, most of the crashes/events in the ND dataset were identified by the instrumented truck driver's avoidance response. As such, there were very few ND crashes/events with the attempted avoidance maneuver "*No Avoidance Maneuver*." However, some of the variability in the attempted avoidance maneuver "*No Avoidance Maneuver*" was likely explained by the ability of the ND data collection methodology to detect minor movements in the instrumented vehicle. The kinematic data allowed data analysts to detect very minor avoidance responses, such as minor steering and/or braking responses made by the instrumented truck driver, which would be difficult to assess using the LTCCS data collection methodology. Note that 33 percent of the crashes in the ND dataset were coded with this attempted avoidance maneuver; however, many of these crashes were animal strikes (truck drivers are trained to make no avoidance response during an animal strike). The video and kinematic data in the ND dataset also explains why the attempted avoidance maneuver "*Unknown*" was coded in the LTCCS but never in the ND dataset (as data analysts would always be able to observe the truck drivers' response(s) unless there was a malfunction in the data collection equipment).

The attempted avoidance maneuver "*Braking (Lockup)*," was coded more often in the LTCCS dataset than in the ND dataset. This illustrates the difference between high-severity crashes (as in the LTCCS) and non-crashes in the ND dataset. An avoidance response that required the driver to apply force to the brakes that created a lockup was likely to be a significant safety event (thereby more likely to involve a crash).

Not surprisingly, the attempted avoidance maneuver "*Steered to the Left*" was coded more often in the ND dataset than the LTCCS dataset. This is directly related to the large percentage of ND crashes/events coded with the accident type "*Right Roadside Departure*" which would require a steering movement to the left to avoid a crash. As indicated above, the inclusion of unintentional lane deviations in the ND dataset skewed the comparison with the LTCCS dataset.

4.1.3 Pre-event Movement

The pre-event movement documented the vehicle's movement pattern prior to the CE.(7,8) Far more LTCCS crashes were coded with the pre-event movement "*Negotiating a Curve*" than during ND crashes/events, while more ND crashes/events were coded with the pre-event movement "*Decelerating in Traffic Lane*," than during LTCCS crashes. While it was difficult to determine the exact source of the discrepancy in the pre-event movement, the GES data seem to indicate that as the severity of the truck crash increased, there would be a larger proportion of crashes with the pre-event movement "*Negotiating a Curve*." Thus, it appears this discrepancy might be the result of differences between high-severity crashes in the LTCCS dataset and lower-severity crashes and non-crashes in the ND dataset.

The reason for the discrepancy in the percentage of crashes/events in the LTCCS and ND datasets with the pre-event movement "*Decelerating in Traffic Lane*" was likely the difference in severity levels in the LTCCS and ND datasets and the ND data collection approach. The ND data collection approach allows subtle distinctions in the instrumented vehicle's pre-event movement; thus, subtle braking responses and the instrumented driver taking his/her foot off the accelerator can be observed in ND. However, the identification of crashes/events in the ND data collection approach primarily involved "spikes" in the kinematic data. Instrumented drivers in the ND dataset were often observed to have subtle braking responses prior to the kinematic trigger (as if they were anticipating the traffic safety situation), whereas these types of anticipatory responses by drivers in the LTCCS dataset may have been less likely during higher-severity crashes (and/or not able to be detected using the LTCCS data collection approach).

The pre-event movement "*Stopped in Traffic Lane*" was coded more often in the LTCCS than the ND dataset. This illustrates a weakness in the ND data collection methodology to detect safety events directly behind the instrumented truck (as there was no rear-facing camera on the trailer). As 33 percent of the LTCCS crashes with this pre-event maneuver involved the truck being struck from behind, the lack of a rear-facing camera explains the discrepancy.

4.1.4 Number of Vehicles Involved

One of the most notable differences between the LTCCS and ND datasets reflects the number of vehicles involved. The ND dataset included more single-vehicle crashes/events than the LTCCS dataset. As more than a quarter of the ND crashes/events were unintentional lane deviations (involving a single vehicle), it was not surprising the ND dataset included more single-vehicle crashes/events than the LTCCS dataset. The LTCCS dataset included far more crashes involving three or more vehicles than the ND dataset. This discrepancy was likely a reflection of high-severity crashes in the LTCCS and lower-severity crashes and non-crashes in the ND dataset. There was no physical contact between vehicles in the majority of ND crashes/events; thus, ND crashes/events were unlikely to involve more than two vehicles, whereas the energy in a high-severity truck crash (as in the LTCCS dataset) was likely to result in the truck and/or other vehicle being “pushed” into other vehicles.

4.1.5 Critical Event

The CE was defined as the event that immediately led to the crash/event or the action or event which put the vehicle or vehicles on a course that made the crash/event unavoidable, given reasonable driving skills and vehicle handling.[7,8] This was the first variable that was disaggregated by single-vehicle and multi-vehicle crashes/events. In multi-vehicle crashes/events, the LTCCS dataset was coded with more of the CEs "*This Vehicle Not Involved in First Harmful Event*" and "*This Vehicle Lost Control*" than in the ND dataset. Conversely, the CE "*This Vehicle Traveling*" was coded far more often in the ND dataset compared to the LTCCS dataset in multi-vehicle crashes/events. These discrepancies clearly illustrate the lack of higher-severity multi-vehicle crashes in the ND dataset (or conversely, the abundance of high-severity multi-vehicle crashes in the LTCCS dataset). The CE "*This Vehicle Not Involved in First Harmful Event*" refers to a traffic safety scenario where another vehicle(s) crashes, and the impact of that vehicle(s) resulted in an interaction with the truck. As indicated above, there were very few ND crashes/events that involved more than two vehicles; thus, if there was no physical contact between vehicles, it is unlikely there was a second harmful event. Similarly, the likelihood of an actual crash, rather than a SCE, is greatly increased given that the vehicle loses control. Thus, it is not surprising that multi-vehicle crashes/events in the ND dataset were coded with the CE "*This Vehicle Traveling*" far more often than multi-vehicle crashes in the LTCCS dataset.

The discrepancies in single-vehicle crashes/events in the LTCCS and ND datasets were more pronounced than they were for multi-vehicle crashes/events. Almost all the single-vehicle crashes/events in the ND dataset were coded with the CE "*This Vehicle Traveling*." Most of the single-vehicle crashes/events in the ND dataset were unintentional lane deviations; thus, these lower-severity events in the ND dataset skewed the data.

4.1.6 Critical Reason

The CR was the immediate reason or failure leading to the CE (only one CR was coded in each crash/event).[7,8] The CR was disaggregated by multi-vehicle and single-vehicle crashes/events. As with the CE, the CRs in multi-vehicle crashes/events in the LTCCS and ND datasets were more similar than the CRs in single-vehicle crashes/events in the LTCCS and ND datasets. A larger percentage of multi-vehicle crashes/events in the LTCCS dataset were coded with the CR "*No Driver Error*," compared to the ND dataset. The vehicle-based sensor suite employed in ND data collection best explains this discrepancy. The sensor suite employed in the ND studies included in the current study were better suited for detecting instrumented truck-initiated actions than non-instrumented truck-initiated actions; thus, there was a predominance of CRs assigned to the instrumented trucks in these ND datasets.

There was also a large discrepancy in multi-vehicle crashes/events with the CR "*Decision Error*." A decision error was coded more often in the ND dataset during multi-vehicle crashes/events than in the LTCCS dataset. One reason for this discrepancy was the CR "IEA" (a decision error). During rear-end crashes/events (all multi-vehicle crashes/events), the CR "IEA" was rarely recorded in the LTCCS dataset but was observed frequently in ND crashes/events. The current study re-reviewed 100 randomly selected rear-end crashes/events in the ND dataset that were originally assigned the CR "IEA." Upon re-review, these 100 crashes/events were assigned a secondary contributing factor in an attempt to alleviate the discrepancy between the LTCCS and ND datasets (as the LTCCS coded the CR "*Following Too Closely*"). Not one of the secondary CRs was coded with *Following Too Closely*. This suggests the video data allowed data analysts in the ND dataset to observe something that was difficult to assess using the LTCCS data collection methodology.

The discrepancies in single-vehicle crashes/events in the LTCCS and ND datasets were more pronounced than during multi-vehicle crashes/events. Almost all the single-vehicle crashes/events in the ND dataset were coded with the CR "*Recognition Error*." This was not surprising as most of the single-vehicle crashes/events in the ND dataset were unintentional lane deviations; thus, these lower-severity events in the ND dataset skewed the data. Lastly, both multi-vehicle and single-vehicle LTCCS crashes were coded with the CR "*Vehicle-related*," more often than in the ND dataset (in fact, this CR was never coded in the ND dataset). This discrepancy illustrates the breadth in the LTCCS data collection approach. As the LTCCS obtained vehicle inspection reports, it was possible for them to rule out vehicle-related issues. This information was not available in the ND dataset unless visible in the video (e.g., tire blowout, smoking engine, etc.).

4.1.7 Summary

There were three primary sources, or explanations, for the discrepancies found in the different analyses outlined above. These include:

- Inclusion of the lowest severity event in the ND dataset (i.e., unintentional lane deviations).
- Higher-severity crashes in the LTCCS dataset compared to lower-severity crashes and non-crashes in the ND dataset.
- Data collection approaches.

The latter discrepancy can be subdivided into three categories, including:

- Accuracy in ND data collection to identify subtle driver behaviors and vehicle movements.
- Overall accuracy in ND data collection approach, compared to LTCCS approach, to accurately identify driver behavior and vehicle movements (i.e., no unknowns or catch-alls).
- Breadth of the LTCCS data collection approach to identify vehicle-related issues and crashes/events where the truck was struck.

Identifying these discrepancies and the sources of these discrepancies will inform future research efforts (and caveats) that compare LTCCS (or similar crash reconstruction methodologies) with ND data. However, given the discrepancies noted above, it appears that cross-comparisons between the LTCCS and ND data can be performed.

One of the primary issues in performing these cross-comparisons is the inclusion of unintentional lane deviations (found in the ND dataset). As indicated above, these types of events are very useful in identifying distraction-related and fatigue-related events. However, they should be excluded in comparisons involving higher-severity crashes as their inclusion skews the data. This was supported when the data were disaggregated by multi-vehicle and single-vehicle crashes/events. Although discrepancies existed in each disaggregation, the LTCCS and ND comparison involving only multi-vehicle crashes/events was more similar than the comparison involving single-vehicle crashes/events (which were predominantly unintentional lane deviations). Thus, when making cross-comparisons between the ND and LTCCS datasets, unintentional lane deviations should be removed unless the aim of the comparison is to assess distraction and/or fatigue. While unintentional lane deviations provide important information in distraction- and fatigue-related crashes/events, their prevalence in the ND dataset compared to high-severity crashes in the LTCCS may provide conflicting results.

Many of the variables that made subtle distinctions in their categorizations (i.e., pre-event movement and attempted avoidance maneuver) benefited greatly from the video data that were collected in the ND dataset, while some of the comparisons differed as a result of the inherent differences between a crash and non-crash (i.e., number of vehicles and CE).

Cross-comparisons between these two datasets are possible, but the differences in variable coding must be addressed. As there are more than 1,000 variables in the LTCCS, it would be difficult and beyond the scope of the current research project to indicate which variables would need to be re-coded. As it is rarely possible to re-code variables in the LTCCS, additional data reduction will need to be performed in the ND dataset to make these two datasets equal (i.e., the LTCCS variable "*Traffic Factor*," in the current study). This illustrates the unique strength of the ND data collection approach to assess new research questions (as the video and kinematic data are available for re-review).

4.1.8 Synthetic Odds Ratio: Following Too Closely

The synthetic odds ratio for *Following Too Closely* was the first attempt to use the crash frequency data from the LTCCS with exposure data from the ND dataset. The comparative analyses above suggested these types of cross-comparisons using the LTCCS and ND datasets were feasible. One of the significant limitations in the LTCCS was the lack of baseline data, which limits analyses using the LTCCS dataset to frequency counts. FMCSA published “relative risk” statistics regarding the associated factor "*Following Too Closely*" in the LTCCS; however, this calculation was based on a comparison between crashes where the truck was assigned the CR to crashes where the truck was not assigned the CR.[2,3] This analysis found that the associated factor "*Following Too Closely*" had a relative risk of 22.6. This relative risk estimate can be interpreted as meaning that truck drivers in the LTCCS were 22.6 times more likely to be assigned the CR if they were following too closely, than if they were not.

This does not address the risk of following too closely, as there were no non-crashes in the LTCCS dataset (i.e., baseline or control events). The current study assessed the feasibility of combining the LTCCS and ND data to construct a synthetic risk ratio estimate. This type of analysis requires certain assumptions prior to being performed, including:

- The data collected from both datasets were accurate.

- The behavior(s) during baseline epochs in the ND dataset were representative of the general driving population.
- Any differences in coding between the datasets were reconciled.

These estimates should be viewed with an appropriate level of skepticism given that the LTCCS and ND datasets were inherently different. The results of the synthetic odds ratio analysis confirmed that for truck drivers, following too closely significantly increased the odds of being involved in a crash by 1.34 times.

Crash-relevant conflicts in the ND dataset were used to calculate the odds ratio. This was necessary, as the sensor suite used to detect crashes/events in the ND dataset would, by definition, define an instrumented truck following too closely as a safety event. These do not represent normal (or baseline) driving; thus, the point estimate and confidence interval in this calculation should be considered a lower limit estimate (as one would expect fewer instances of following too closely under normal or baseline driving conditions, thereby raising the odds ratio). However, given this caveat, this analysis proved it was possible to use the ND dataset to calculate the baseline exposure of a given behavior and to use the LTCCS dataset to calculate the crash exposure to the same behavior. The analysis also demonstrated some of the difficulties that could be encountered in calculating a synthetic risk ratio estimate.

4.1.9 Pilot Study of the Crash Trifecta Concept

The concept of the crash trifecta is not a new concept. It has been well established in the transportation safety field that crash genesis involves a convergence of several, if not many factors.(4) For example, speeding has been shown to extend the distance necessary to stop a vehicle and increase the distance a vehicle travels while the driver reacts to a dangerous situation.(5) Thus, in many cases, speeding is not as dangerous unless it is accompanied by a dangerous traffic situation (such as an unexpected event). Of course this is an oversimplification as speeding on a curve is by itself dangerous and leads to many crashes.(5) The same relationship can be made when considering distracted drivers. The risk of driving while distracted is greatest when the driver is performing a non-driving task and an unexpected event occurs (thereby reducing the time necessary to respond to the situation). Thus, the crash trifecta concept implies that the probability of a crash given the three crash trifecta elements is greater than the probability of a crash given only one of the crash trifecta elements.

The crash trifecta concept seems intuitive, but until recently, it has been very difficult to measure an unexpected traffic event. The video data in the ND dataset affords data analysts an opportunity to make a subjective interpretation on whether the crash/event involved an unexpected traffic event, while information on the other two crash trifecta elements, transient inattention and at-risk driving behavior, are readily available through video review. Again, the operational definition of an unexpected traffic event in the current study was made via a subjective interpretation by data analysts. As data analysts did not have access to each driver's thoughts nor was each driver who was involved in the crash/event interviewed, the operational definition used for unexpected traffic events may not be entirely valid. However, the goal of this small pilot study was to explore the crash trifecta concept and the reliability estimates shown above indicated that data analysts were following the operational definition.

While only 2.6 percent of the ND crashes/events had none of the crash trifecta elements present, 39.6 percent had one of the crash trifecta elements present, 47.5 percent had two of the crash trifecta elements present, and 10.3 percent had all three elements present. Although limited in sample size, there was a trend in the percent of all three crash trifecta elements being present as the severity level of the crash/event increased. This was a very interesting finding (albeit with a very limited sample size) that suggests higher-severity crashes/events involve the convergence of multiple elements, while lower-severity crashes/events may best be described via a unitary element (such as a CR). This pilot study of the crash trifecta concept demonstrated the need for further research to study the presence of the crash trifecta elements in the remaining ND dataset crashes/events.

4.2 POSSIBLE LIMITATIONS

The primary limitation in the current study was also the primary method of comparison used to evaluate trends in the datasets (i.e., descriptive statistics); while this information was needed to identify discrepancies, inferences made by the authors regarding the sources of these discrepancies were subjective. To fully understand the limitations in the LTCCS and ND data collection approaches, a direct comparison of the same crashes/events needs to be conducted using each data collection method. There are a few isolated examples of these types of comparisons in the 100-Car Study[6] and ND truck studies.[7,8] When available, PARs were compared with ND data to assess the validity of the PARs. Most of these comparisons revealed errors in the PAR; however, there were very few of these comparisons and the methodology employed in the LTCCS was arguably more rigorous than the methodology used by State police.

The synthetic odds ratio calculation that was performed on the associated factor "*Following Too Closely*" used crash-relevant conflicts from the ND dataset as a measure of exposure rather than baseline epochs. This was required as this associated factor of interest (*Following Too Closely*) was a key component in identifying possible crashes/events in the ND dataset; thus, by definition, any act of following too closely was a crash/event. This likely affected the odds ratio by artificially lowering it, thereby underestimating the risk of tailgating. As indicated above, the synthetic odds ratio for this particular factor should be viewed as a conservative estimate.

Much like the comparative analyses, the pilot study on the crash trifecta concept relied on descriptive analyses. Without an appropriate estimate of exposure to the various elements of the crash trifecta, it was difficult to calculate the risk accurately, as the risk may be associated with the presence of these elements. This pilot study was also limited by its small sample size (n = 272). However, there did appear to be enough evidence in the crash trifecta concept to warrant further investigation.

5. NEXT STEPS

With the enormous amounts of data contained in the LTCCS and ND datasets, it is important to continue to find methods to extract usable information. The following are potential future research topics that were developed during this study:

- Further investigation of the crash trifecta concept, with possible risk ratio estimates using the presence of crash trifecta elements in baseline epochs.
- Direct comparison of crashes/events using the ND and LTCCS data collection approaches. While possible, this type of study would be an expensive and time-consuming undertaking. However, future and ongoing ND studies, including the 250 truck and 2,500 car studies, could compare police-reported crashes using ND data and PARs.
- Additional synthetic odds ratio analyses using crash data from the LTCCS and exposure data from the ND datasets.
- Additional research on the consequences of meta-analytic methods to combine data collected using ND and post-hoc techniques.

Each of the proposed studies provides an opportunity for a more complete understanding of truck crash genesis and potential countermeasures.

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APPENDIX A: DATA REDUCTION PROTOCOLS

PROTOCOL FOR CASE REVIEW OF REAR-END EVENTS

The CR, *Inadequate Evasive Action* (IEA), was defined as a situation where a driver perceives a threat, but makes an inadequate evasive action in response to that threat. This can include the driver braking insufficiently or only braking, when both braking and steering are called for. This was an infrequent CR in the Large Truck Crash Causation Study (LTCCS), but was commonly observed in the Naturalistic Driving (ND) datasets. ND has the advantage of seeing the driver's response to the threat, but the disadvantage of not seeing vehicle mechanical conditions (e.g., brakes) that might have contributed to the inadequate response. Explorations of IEA in rear-end crashes will provide insight into driver responses to crash threats. Accordingly, ND rear-end IEA events will be analyzed and observed to determine salient characteristics. You will need to determine the secondary contributing factor for these ND events (excluding the assigned CR for the event). These secondary contributing factors will then be compared to the CRs from the LTCCS.

This document specifies the protocol for assessing the primary contributing factor.

Loading DART:

1. Load DART.
2. Open the collection that corresponds to the trigger that will be opened (ThirtyFourTruck or EightTruck).
3. Logon (Password is VTTI).
4. Switch to the LTCCS reduction (User → Change Reduction → CVO Distraction).

Figure 3. Screenshot. Screen capture showing appropriate collection and reduction.

Open Trigger for Analysis:

1. In DART, load Query Tool.
2. Load the collection specific "LTCCS_IEA Events" query.
3. Click on Go.
4. Open the one of the Triggers listed in the results.

Set Up Views:

You will need the following views:

1. View → Video and Play Controller.
2. View → Triggers.
3. View → VORAD1 → Headway.
4. View → Network → Speed.

Once you have arranged your windows the way you want them, save your View Setup for use during the next time you log in (User → View Setups → Add). A sample View Setup is below. Other views may be used as needed. Other information (e.g., Road Alignment, Weather, etc.) for the event will also be provided to the reductionist to inform the selection of the Secondary Contributing Factor.

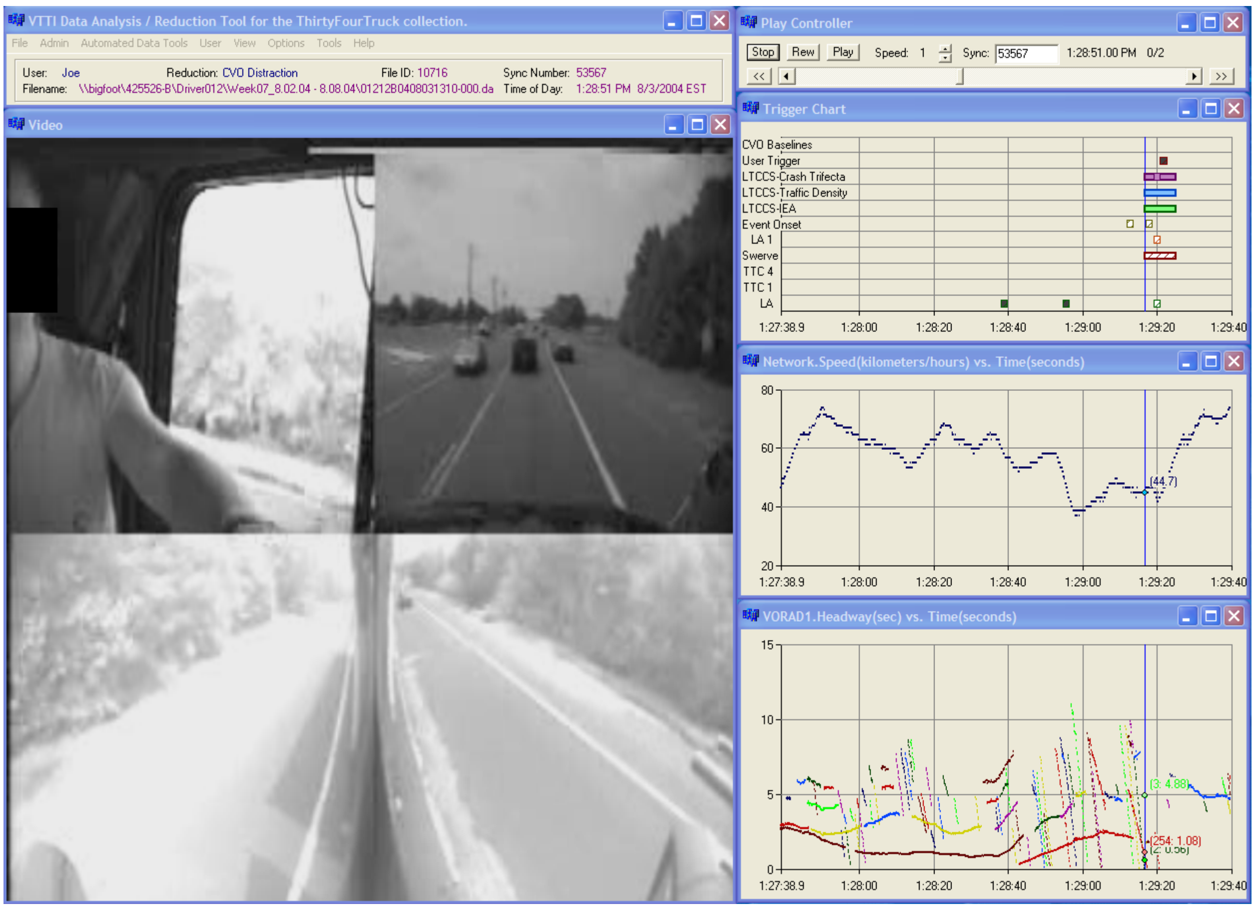

Figure 4. Screenshot. Screen capture showing appropriate views for reduction.

Analyze Trigger:

1. Open the Question Reduction window by right clicking on the event and selecting the “Case Review of Rear-End Events” option. The questions screen will appear.

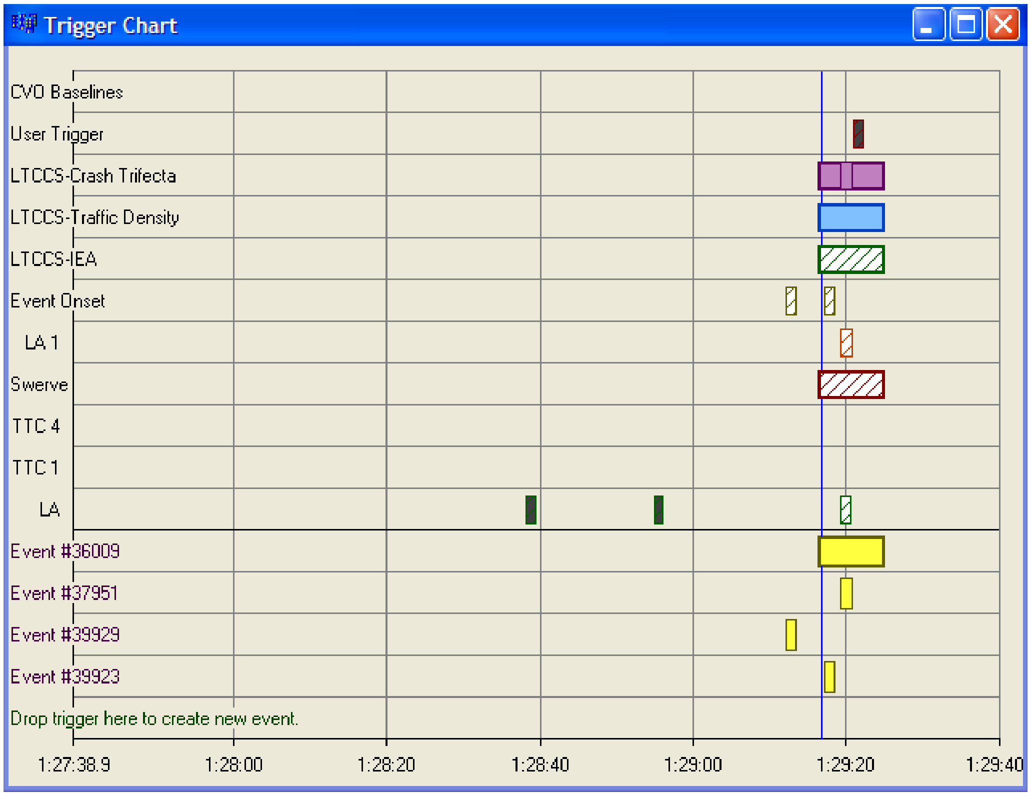

Figure 5. Screenshot. Screen capture showing trigger chart.

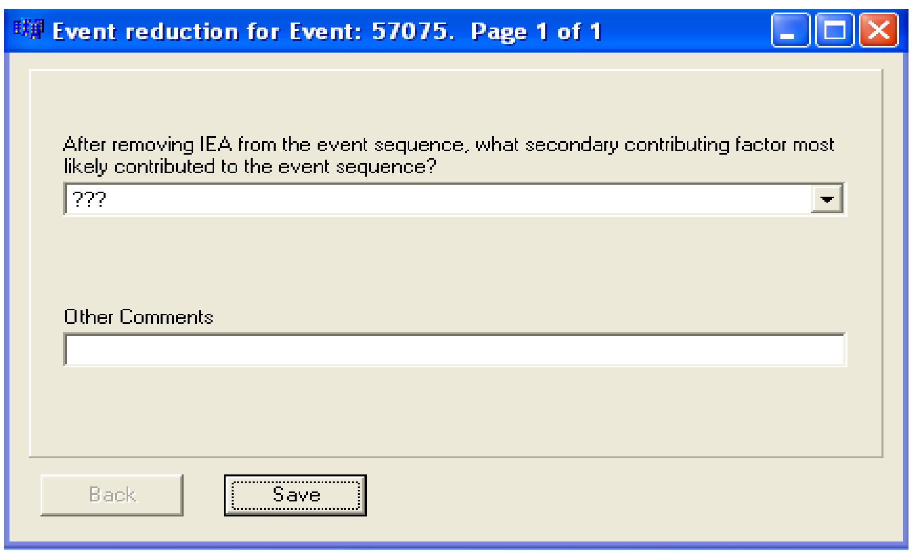

Figure 6. Screenshot. Screen capture showing reduction question to be answered.

Secondary Contributing Factor Question (CR):

- The secondary contributing factor question reduction will appear in the pop-up menu.
- All of the events that will be reviewed for this reduction have the CR of IEA. You are to mark the secondary contributing factor listed below that best describes the factor that most contributes to the event sequence excluding the CR IEA. More specifically, after

removing the IEA from the event sequence, what secondary contributing factor most likely contributed to the event sequence? You are to review the V1 driver behaviors to inform your decision. A list of the driver behaviors can be found in the following spreadsheet:

- BehaviorInfo_LTCCSReduction.xls.
- You will examine the 10 seconds prior to the trigger to obtain all of the needed information. The secondary contributing factors are listed below.

Secondary Contributing Factors:

- DRIVER-RELATED FACTOR: Critical Non-performance Errors.
  - Sleep, that is, actually asleep.
  - Heart attack or other physical impairment of the ability to act.
  - Other critical nonperformance (Specify).
  - Unknown critical nonperformance.
- DRIVER-RELATED FACTOR: Recognition Errors
  - Inattention (i.e., daydreaming).
  - Internal distraction.
  - External distraction.
  - Inadequate surveillance (e.g., failed to look, looked but did not see).
  - Other recognition error.
  - Unknown recognition error.
- DRIVER-RELATED FACTOR: Decision Errors.
  - Too fast for conditions to be able to respond to unexpected actions of other road users.
  - Too slow for traffic stream.
  - Misjudgment of gap or other's speed.
  - Following too closely to respond to unexpected actions.
  - False assumption of other road user's actions.
  - Illegal maneuver.
  - Failure to turn on headlamps.
  - Aggressive driving behavior.
  - Other decision error.
  - Unknown decision error.
- DRIVER-RELATED FACTOR: Performance Errors.
  - Too fast for curve/turn.

- Panic/Freezing.
- Overcompensation.
- Poor directional control e.g., failing to control vehicle with skill ordinarily expected.
- Other performance error.
- Unknown performance error.
- Type of driver error unknown.

- VEHICLE-RELATED FACTOR.
  - Tires/wheels failed.
  - Brakes failed.
  - Steering failed.
  - Cargo shifted.
  - Trailer attachment failed.
  - Suspension failed.
  - Lights failed.
  - Vehicle related vision obstructions.
  - Body, doors, hood failed.
  - Jackknifed.
  - Other vehicle failure.
  - Unknown vehicle failure.
- ENVIRONMENT-RELATED FACTOR: Highway Related.
  - Signs/signals missing.
  - Signs/signals erroneous/defective.
  - Signs/signals inadequate.
  - View obstructed by roadway design/feature.
  - View obstructed by other vehicles.
  - Road design—roadway geometry (e.g., ramp curvature).
  - Road design—sight distance.
  - Road design—other.
  - Maintenance problems (potholes, deteriorated road edges, etc.).
  - Slick roads (low-friction road surface due to ice, loose debris, any other cause).
  - Other highway-related condition.
- ENVIRONMENT-RELATED FACTOR: Weather-related.
  - Rain, snow.
  - Fog.

- Wind gust.
- Other weather-related condition.

- ENVIRONMENT-RELATED FACTOR: Other.
  - Glare.
  - Blowing debris.
  - Other sudden change in ambience.
  - Degraded braking capability.
  - Transmission/engine failure.
  - No secondary contributing factor.
  - Unknown secondary contributing factor.

Other Comment: If further explanation is necessary, please include an explanation here.

PROTOCOL FOR CRASH TRIFECTA

The crash trifecta consists of three separate, but converging events, including:

1. Unsafe pre-incident behavior or maneuver (e.g., speeding, tailgating, unsafe turn).
2. Transient driver inattention (which may be related to driving, such as mirror use, or unrelated, such as reaching for an object).
3. An unexpected traffic event, such as unexpected stopping by the vehicle ahead.

Not every element of the crash trifecta occurs in every incident, but often two or all three may be present. The value of the crash trifecta concept, and convergence concepts of crash causation, is that it provides a structure for understanding the complexities of crash genesis. Both the LTCCS and ND studies to date have emphasized the CR as a primary proximal cause. Other factors have been identified as associated factors, but neither approach has identified contributing factors in a systematic way. That is, no factor other than the CR has been specified as directly contributing to event genesis.

To analyze and demonstrate the crash trifecta concept, ND samples of 100 RE-LVS, 100 RE-LVM, and 100 road departure events will be analyzed and re-reviewed to determine the frequency and type of each of the crash trifecta elements. They will be classified in terms of the joint presence or absence of the three-trifecta elements. Unexpected traffic event is the element of the crash trifecta that cannot be found in previous performed data reduction.

This document specifies the protocol for assessing an unexpected traffic event.

Loading DART:

1. Load DART.
2. Open the collection that corresponds to the trigger that will be opened (ThirtyFourTruck or EightTruck).
3. Logon (Password is VTTI).
4. Switch to the LTCCS reduction (User → Change Reduction → CVO Distraction).

Figure 7. Screenshot. Screen capture showing appropriate collection and reduction.

Open Trigger for Analysis:

1. In DART, load Query Tool.
2. Load the collection specific “LTCCS_CrashTrifecta Events” query.
3. Click on Go.
4. Open the one of the Triggers listed in the results.

Set Up Views:

You will need the following views:

1. View → Video and Play Controller.
2. View → Triggers.
3. View → Network → Speed.
4. View → VORAD1 → Headway.

Once you’ve arranged your windows the way you want them, save your View Setup for use during the next time you log in (User → View Setups → Add). A sample View Setup is shown below. Other views can be used as needed.

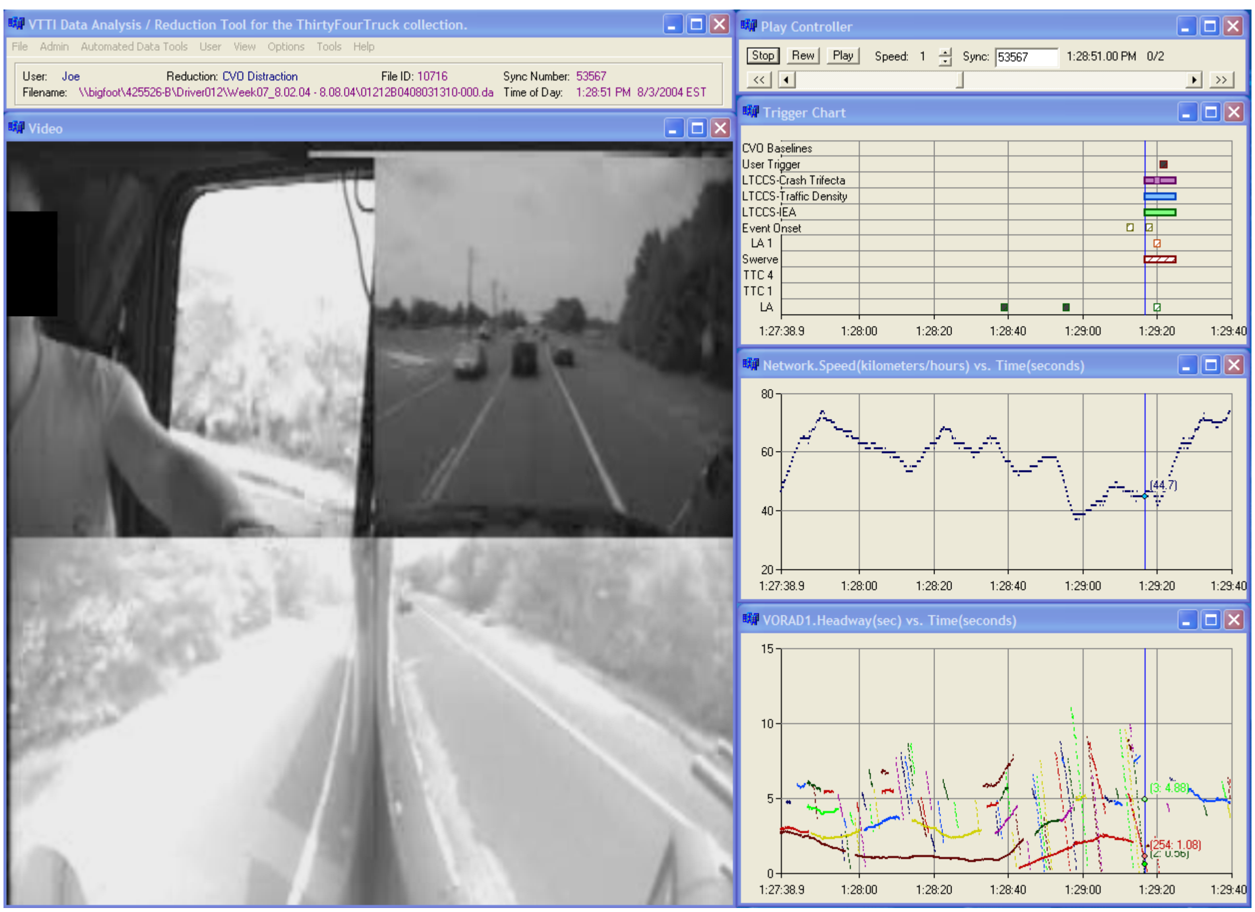

Figure 8. Screenshot. Screen capture showing appropriate views for reduction.

Analyze Trigger:

5. Open the Question Reduction window by right clicking on the event and selecting the "Crash Trifecta" option. The questions screen will appear.

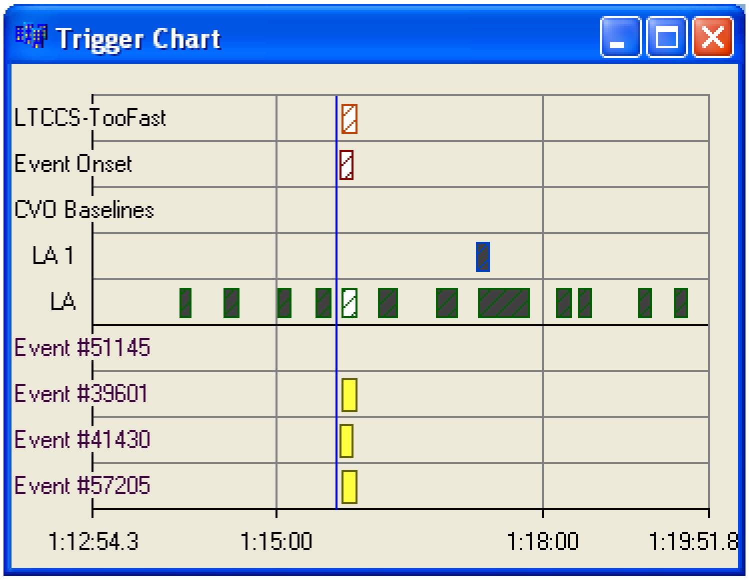

Figure 9. Screenshot: Screen capture showing trigger chart.

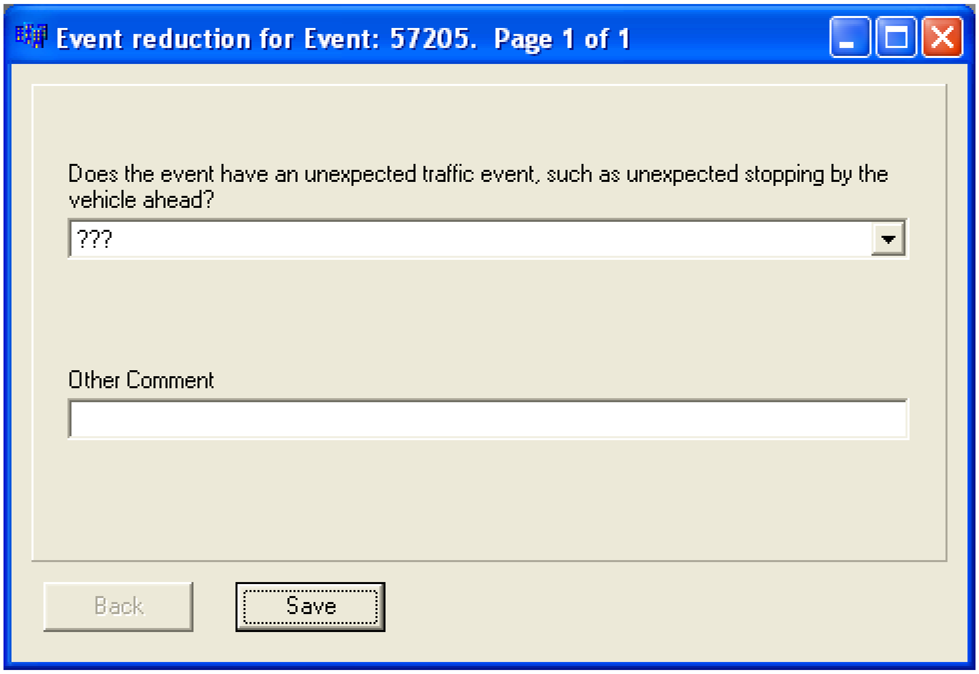

Figure 10. Screenshot. Screen capture showing reduction questions to be answered.

Unexpected Traffic Event Question:

- Select the unexpected traffic event question reduction from the pop-up menu.

- You are to determine if there was an unexpected traffic event. An unexpected traffic event indicates that something unexpected occurred during the event. This could indicate movement by another vehicle/object/animal that is unexpected and/or an unexpected event due to a lack of attention (i.e., inattention). You will examine the 10 seconds prior to the trigger to obtain all of the needed information and then indicate if an unexpected traffic event was present:

  1. Yes.
  2. No.
  3. Unable to determine.

PROTOCOL FOR HIGH TRAFFIC DENSITY EVENTS

The principal traffic density variable used in ND studies has been Level of Service (LOS), which is a subjective variable that classifies the degree of restriction of vehicle movement due to the presence of other vehicles on the roadway. Case reviewers viewed each event and classified the overall amount of traffic during that time. In a six-level classification scheme, LOSs included: light "A" means free-flow traffic, medium "B" means flowing with some restrictions, and heavy "C"–"F") means various degrees of restricted traffic flow.

The LTCCS did not employ the LOS variable. Investigators could not directly estimate the level of traffic density, but they did record whether traffic was a factor in the crash. The Traffic Factor variable (USDOT, 2006, p.401) indicated whether any traffic-related factors were coded for the subject truck. Traffic-related factors were determined in the LTCCS by the case reviewer using all available information inputs, with the primary source being the driver interview, the PAR, and researchers' on-scene investigation. In order to reconcile these differences, randomly selected epochs from each of the six LOS levels will be selected and reviewed to determine if any traffic factors were present.

This document specifies the protocol for assessing the high traffic density factors.

Loading DART:

4. Load DART.
5. Open the collection that corresponds to the trigger that will be opened (ThirtyFourTruck or EightTruck).
6. Logon (Password is VTTI).
7. Switch to the LTCCS reduction (User → Change Reduction → CVO Distraction).

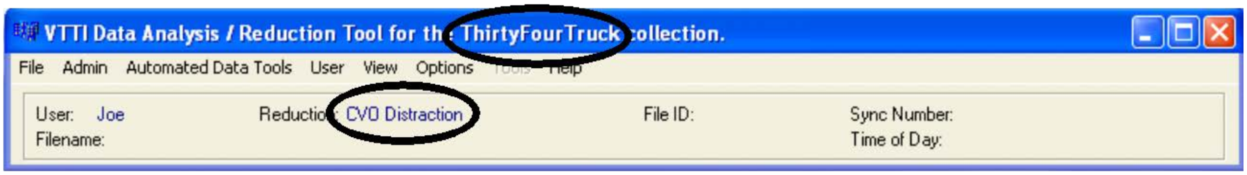

Figure 11. Screenshot. Screen capture showing appropriate collection and reduction.

Open Trigger for Analysis:

8. In DART, load Query Tool.
9. Load the collection specific "LTCCS_TrafficDensity Events" query.
10. Click on Go.
11. Open the one of the Triggers listed in the results.

Set Up Views:

You will need the following views:

1. View → Video and Play Controller.
2. View → Triggers.
3. View → Network → Speed.
4. View → VORAD1 → Headway.

Once you've arranged your windows the way you want them, save your View Setup for use during the next time you log in (User → View Setups → Add). A sample View Setup is shown below. Other views can be used as needed.

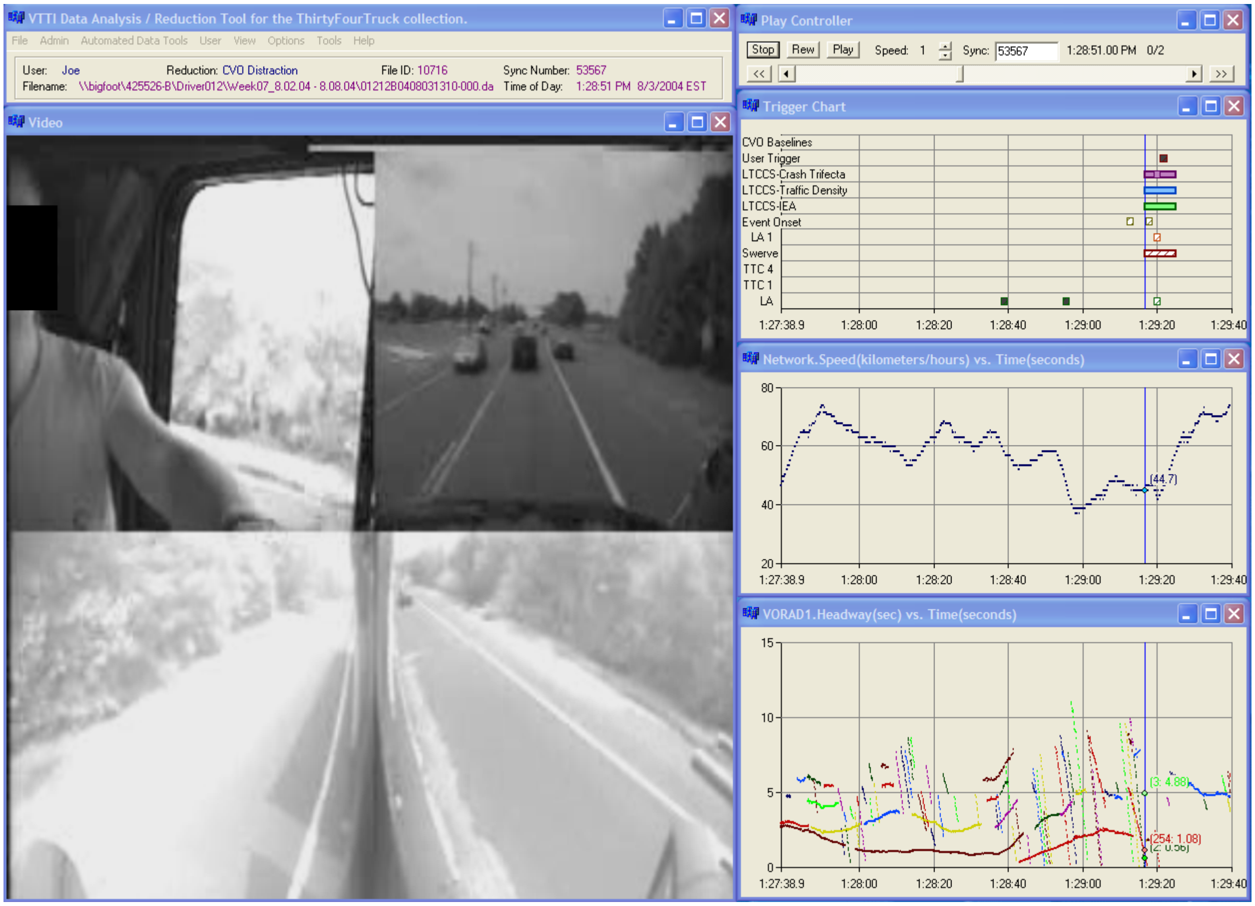

Figure 12. Screenshot. Screen capture showing appropriate views for reduction.

Analyze Trigger:

1. Open the Question Reduction window by right-clicking on the event and selecting the “Traffic Density” option. The questions screen will appear.

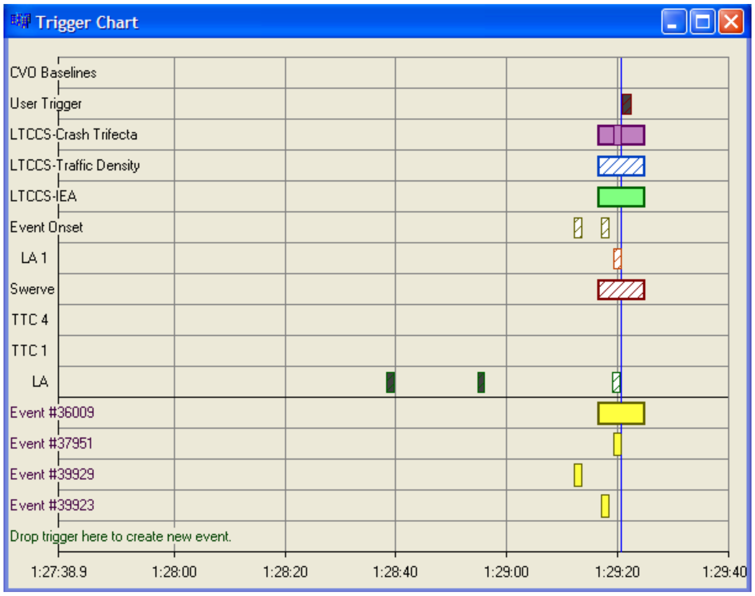

Figure 13. Screenshot. Screen capture showing trigger chart.

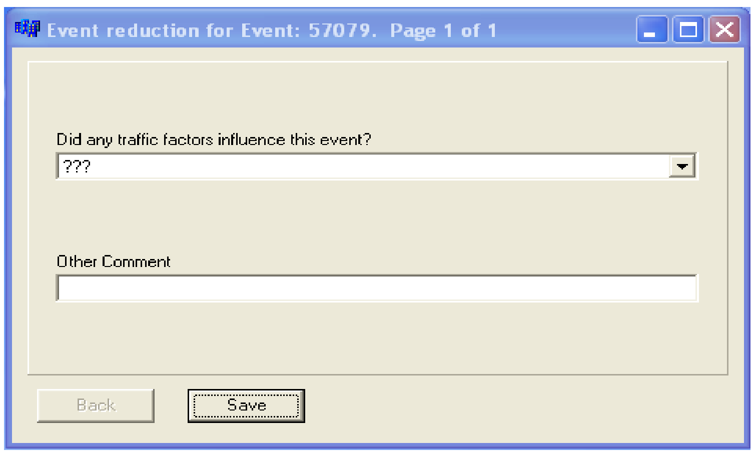

Figure 14. Screenshot. Screen capture showing reduction questions to be answered.

Traffic Factor Question:

- The high traffic density factor question reduction will appear in the pop-up menu.
- You are to determine if any traffic factors influenced the event. Indicate if the traffic volume or the actions of other traffic users present during the event contributed to the event (e.g., V1 or V2 maneuver in response to traffic or slower and/or stopped traffic). You will examine the 10 seconds prior to the event to obtain all of the needed information and then indicate if the traffic was a factor during the event:

  1. Yes.
  2. No.
  3. Unable to determine.

- **Other Comment:** If further explanation is necessary, please include an explanation here.

PROTOCOL FOR EXCESSIVE SPEED: TOO FAST FOR CURVE/TURN

Existing ND data capture the CR of “too fast for conditions” but not “too fast for curve/turn.” Therefore, comparisons involving these two different types of excessive speed would require disaggregation of ND speed-related events. Roadway alignment was a coded variable in the ND dataset, thus, “Too fast” events occurring on curves will be reviewed to confirm that the excessive speed was curve-related rather than other-road-user-related.

This document specifies the protocol for assessing the Too Fast for Curve/Turn CR.

Loading DART:

4. Load DART.
5. Open the collection that corresponds to the trigger that will be opened (ThirtyFourTruck or EightTruck).
6. Logon (Password is VTTI).
7. Switch to the LTCCS reduction (User → Change Reduction → CVO Distraction).

Figure 15. Screenshot. Screen capture showing appropriate collection and reduction.

Open Trigger for Analysis:

8. In DART, load Query Tool.
9. Load the collection specific “LTCCS_TooFast Events” query.
10. Click on Go.
11. Open the one of the Triggers listed in the results.

Set Up Views:

You will need the following views:

1. View → Video and Play Controller.
2. View → Triggers.
3. View → Network → Speed.

Once you’ve arranged your windows the way you want them, save your View Setup for use during the next time you log in (User → View Setups → Add). A sample View Setup is shown below. Other views can be used as needed.

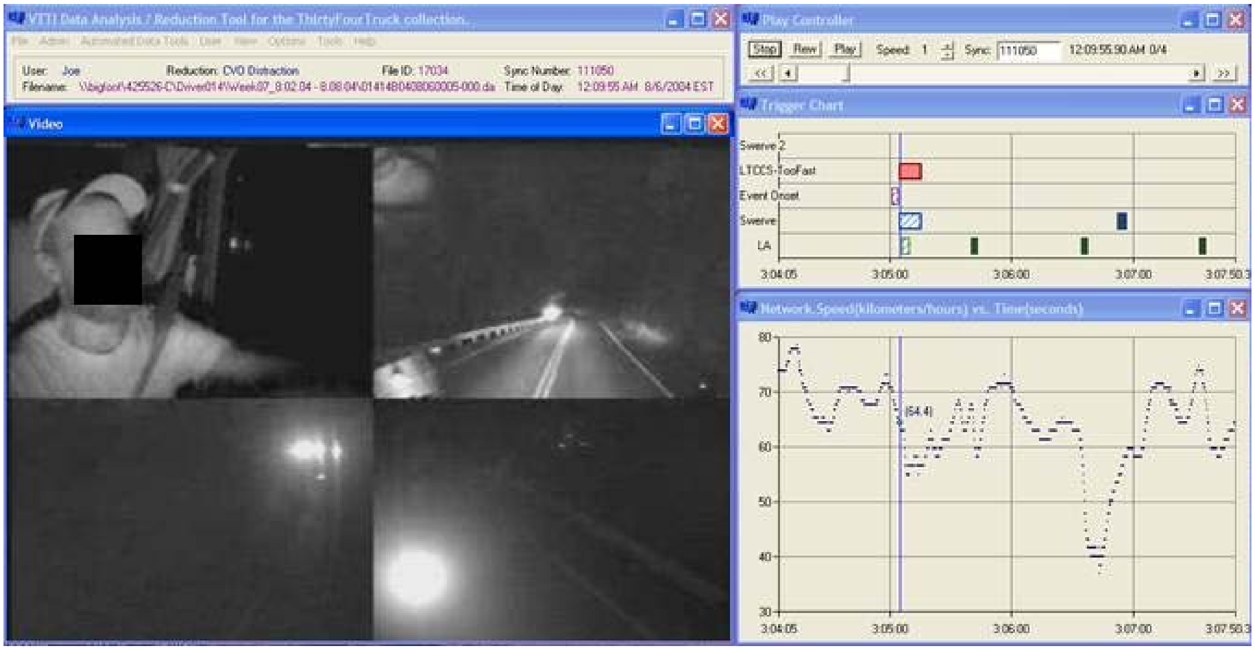

Figure 16. Screenshot. Screen capture showing appropriate views for reduction.

Analyze Trigger:

4. Open the Question Reduction window by right clicking on the event and selecting the “Too Fast for Conditions” option. The questions screen will appear.

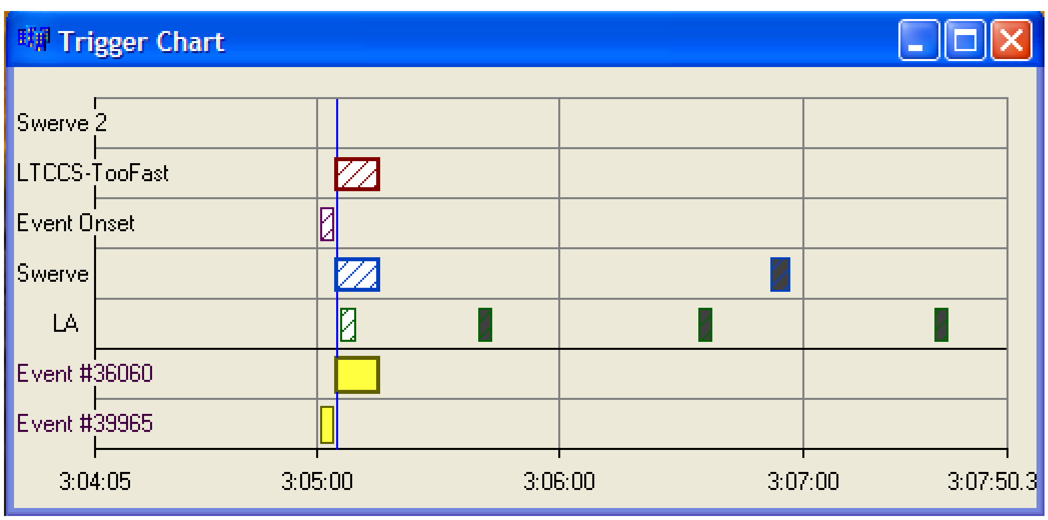

Figure 17. Screenshot. Screen capture showing trigger chart.

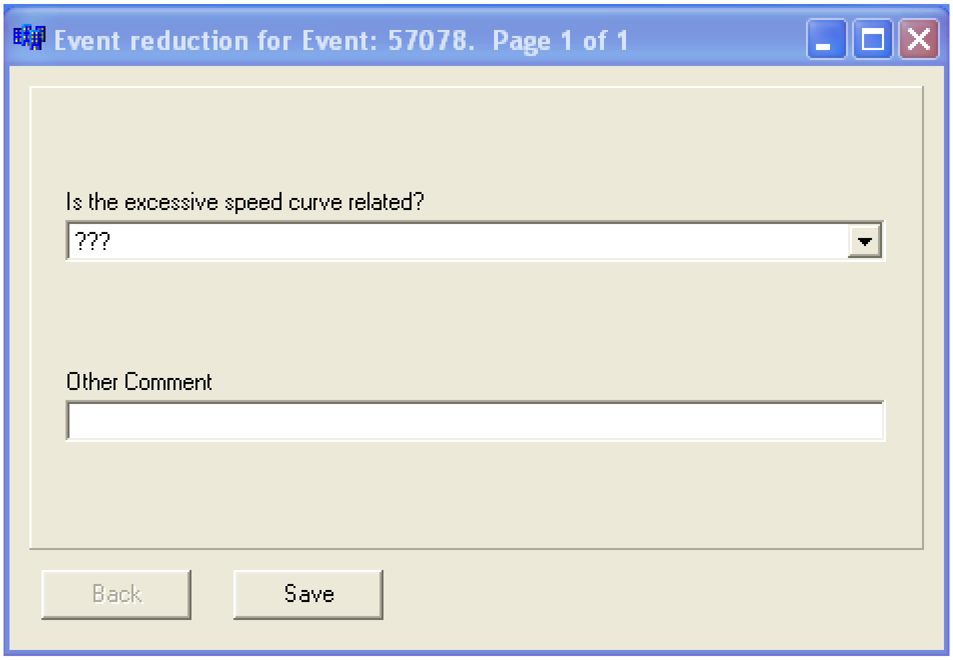

Figure 18. Screenshot. Screen capture showing reduction questions to be answered.

Too Fast for Curve/Turn Critical Reason Question:

- The excessive speed question reduction will appear in the pop-up menu.
- All of the events that will be reviewed for this reduction have the CR of “Too fast for conditions.” You are to determine if the excessive speed was curve-related (e.g., as a result of the geometry of the road) rather than other-road-user-related (e.g., excessive speed, distraction that results in late and/or inefficient braking). You will examine the 10 seconds prior to the event to obtain all of the needed information and then indicate if the excessive speed during the curve was:

  1. Curve-related.
  2. Other-road-user-related.
  3. Other.
  4. Unable to determine.

Other Comment:

If further explanation is necessary, please include an explanation here.

PROTOCOL FOR DATA REDUCTION RELIABILITY

In any new data reduction that involves subjective interpretations of video and quantitative data, reliability estimates of data analysts' subjective judgments are crucial. These reliability analyses will verify that different data analysts have followed the data reduction protocols (i.e., inter-rater reliability) and that each data analyst has consistently followed the data reduction protocol (i.e., intra-rater reliability). Approximately 30 percent of the new events reduced in the current project will be used for both intra- and inter-rater reliability statistics. Percent agreement reliability estimates will be used as this is the most stringent assessment of reliability (i.e., either 0 percent to 100 percent agreement).

Reliability Events:

1. At least 30 percent of the events in each reduction will be randomly selected.
2. A senior staff member will then reduce all randomly selected reliability events.
3. These event will then be loaded into DART's intra- or inter-rater reliability feature:
    a. Load DART.
    b. Open the collection that corresponds to the events that will be opened (ThirtyFourTruck or EightTruck).
    c. Log on.
    d. Switch to the LTCCS reduction (User → Change Reduction → CVO Distraction).
    e. Open reliability feature (Admin → Reduction Level Tools → Special Reduction. → Question Inter-rater or Question Intra-rater).
    f. Load events into reliability feature either manually or from a file.

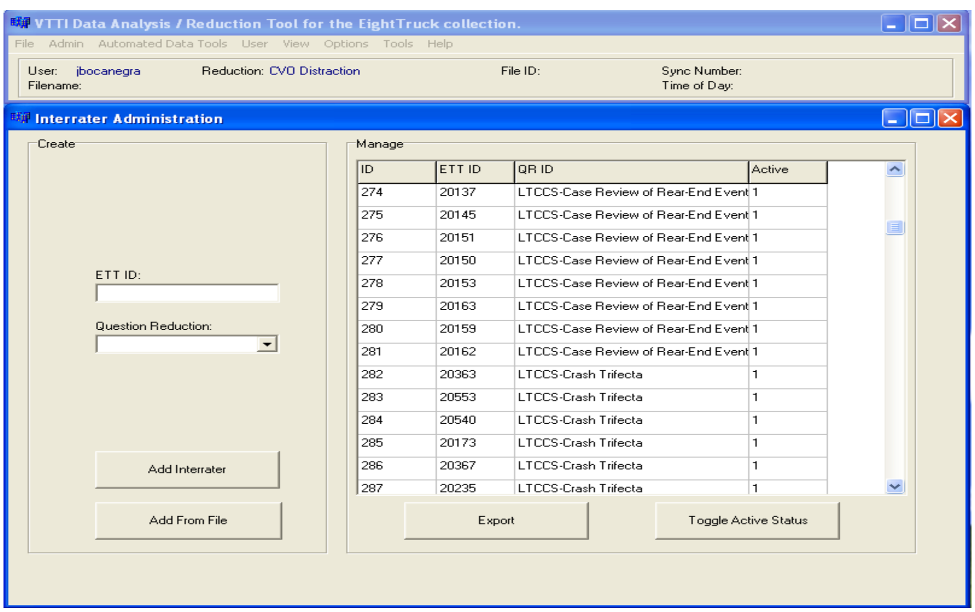

Figure 19. Screenshot. Screen capture showing DART's intra- and inter-rater reliability feature.

Analyst Training:

The data analyst will be given training, where a senior staff member will go over the data reduction protocol in detail. At this time, the senior staff member will review several examples and the analyst will be free to ask any questions regarding data reduction. Once the training is complete, the analyst will be given five "test" events for each reduction. These events will be reviewed by a senior staff member; if the analyst misses more than one event, he/she will be given feedback regarding the incorrect events, retrained, and then asked to reduce five additional "test" events. This process will be continued until the analyst answers four or more of the events correctly. Note that the training and "test" events did not include any events in the current four reductions.

The analyst will then be allowed to reduce the first 20 events in each reduction after which the senior staff member will review the inter-rater events. If the analyst has continued to correctly answer 90 percent of these events, he/she will be allowed to review the next 50 events. However, the data analyst will receive feedback on the missed events and receive additional training if his/her scores are below 90 percent; then the analyst will be allowed to review the next 20 events. The senior staff member will review all incorrectly answered events. This process will continue until the reduction is complete. If at any time during the reduction a data analyst's answers score below 60 percent in the inter-rater reliability, the analyst will be asked to redo all of the events in the previous iteration.

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