REAL-WORLD ANALYSIS OF FATAL REAR-END CRASHES

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ABSTRACT

In March 2011, the National Highway Traffic Safety Administration (NHTSA) published its Vehicle Safety Rulemaking and Research Priority Plan 2011 – 2013, which described the projects that are the agency's priority in the rulemaking and research areas in those calendar years. Programs that are priorities or will take significant agency resources included the development of performance criteria and objective tests to support the identification of effective advanced safety technologies that provide a warning of an impending forward collision and/or automatically brake the vehicle.

In support of the Forward Collision Avoidance and Mitigation project listed in the priority plan, an analysis of real-world crash data was conducted to determine the scope of the crash problem and examine the factors that contribute to rear-end crashes in light vehicles. A review of the 2003 – 2012 National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) was conducted for rear-end crashes involving a fatal occupant.

For each crash identified, a review of the accompanying investigation was conducted using a methodology similar to that described by Bean, et al. [2009]. The authors were then able to identify crash characteristics associated with occupants sustaining fatal injuries in rear-end crashes. For each case, primary and secondary factors were assigned as crash attributes which contributed to the fatal injuries to an involved occupant. This review suggests that fatal rear-end crashes are generally attributed to excessive speed at the time of impact. In order to address these crashes with a forward collision avoidance system, a crash alert warning must be timely and any automatic emergency braking must be aggressive to significantly reduce the impact speed to mitigate the severity or prevent the crash from occurring.

INTRODUCTION

According to NHTSA's Traffic Safety Facts 2012, fatal crashes increased by 3.1 percent from 2011 to 2012, and the fatality rate rose to 1.13 fatalities per 100 million vehicle miles of travel in 2012. The injury rate increased by 6.7 percent from 2011 to 2012, to 80 persons injured per 100 million vehicle miles of travel in 2012. However, the occupant fatality rate (including motorcyclists) per 100,000 population, which declined by 22.7 percent from 1975 to 1992, decreased by 31.1 percent from 1992 to 2012, and the occupant injury rate (including motorcyclists) per 100,000 population, which declined by 13.6 percent from 1988 to 1992, decreased by 37.8 percent from 1992 to 2012. Of the more than 5.6 million police-reported motor vehicle crashes that occurred in the United States in 2012, 29 percent of those crashes (1.63 million) resulted in an injury, and less than 1 percent (30,800) resulted in a death [NHTSA, 2014].

Rear-end type crashes (i.e., front of a motor vehicle striking the rear of another vehicle) are the most frequent first harmful event and account for approximately 33 percent of all crashes including collisions with a motor vehicle in transport, fixed object, non-fixed object and non-collisions such as rollovers. Specifically where the first harmful event was a rear-end crash there were 1,827 fatal, 518,000 injury and 1,327,000 property damage only crashes in 2012 [NHTSA, 2014].

Prior studies have focused on quantifying the size and the identification of trends in rear-ends crashes through the use of descriptive statistics. One study used NHTSA's 1992 – 1996 National Automotive Sampling System-General Estimates System (NASS-GES), which is a weighted sample database of police reported crashes, to identify the relative frequency of 10 major rear-end pre-crash scenarios [Najm, 1998]. Using the coded data, these scenarios identified the pre-crash dynamic state of the involved vehicles by roadway curvature. The rear-end crash data were sorted by injury severity, roadway surface condition and posted speed. The intent of the study was to define the crash problem from a dynamic crash scenario level for safety benefits estimation.

A follow up study analyzed the same NASS-GES years of data, and provided a statistical description of the scenarios discussed in the previous paper [Wiacek, 1999]. The statistics presented encompassed driver characteristics of the following vehicle, including avoidance maneuver attempted before impact, crash contributing factors, driver age, and gender; vehicle body types involved in these rear-end pre-crash scenarios; and initial travel speeds of the following vehicle under various posted speed limits. The results of the study were intended to be useful for estimating the safety benefits of rear-end crash avoidance technologies for crash number reduction and severity mitigation.

These studies have been used to assess the benefits of rear-end crash avoidance technologies, from field operational tests and also as the basis for evaluating these systems in a test environment. An independent evaluation of an Automotive Collision Avoidance System (ACAS) was conducted with vehicles equipped with forward collision warning and adaptive cruise control [Najm, 2006]. The goals of the independent evaluation were to characterize ACAS performance and capability; achieve a detailed understanding of ACAS safety benefits; and assess driver acceptance of ACAS. Utilizing data from the field tests and the crash scenarios defined above, the study estimated that ACAS, as an integrated system of forward collision warning and adaptive cruise control functions, has the potential to prevent about 6 to 15 percent of all rear-end crashes depending on the source of crash data used for safety benefits estimation.

A more recent study that used the NASS-GES data identified and described a new typology of pre-crash scenarios for crash avoidance research [Najm, 2007]. This new typology consists of pre-crash scenarios that depict vehicle movements and dynamics as well as the critical event occurring immediately prior to crashes involving at least one light vehicle. Specifically, the study identified the 37 most frequent crash scenarios; many of these crash types involved rear-end collision scenarios. Of the 37 groupings used to describe the overall distribution of pre-crash scenario types, the Lead-Vehicle-Stopped, Lead-Vehicle-Decelerating, and Lead-Vehicle-Moving-at-Lower-Constant-Speed crashes represented in the 2004 GES data were found to be the 2nd, 4th, and 12th most common crash scenarios overall, respectively, and were the top three rear-end pre-crash scenarios.

The prior studies have been instrumental in developing test procedures to evaluate the forward collision warning systems installed on late-model passenger vehicles. The test maneuvers described were designed to emulate the top three most common rear-end pre-crash scenarios reported in the 2004 NASS-GES data base. The test procedures continue to be the basis for evaluating advanced rear-end crash avoidance technologies, including those that automatically apply the foundation brakes to decelerate the vehicle to avoid or mitigate the severity of a potential crash.

The findings of the studies discussed primarily relied on NASS-GES police accident report based on coded data for high-level understanding of the frequency of rear-end crash specific characteristics. However, a detailed clinical analysis of the rear-end crash environment and injury causation using the NASS-CDS investigation data will help to provide a more thorough understanding and guide system performance to prevent or mitigate the severity of fatal crashes. This crash database is a nationally representative sample of tow-away crashes that occur on U.S. roads. Every year, detailed information on vehicle damage, injury, and injury mechanism is collected on about 4,500 of these light passenger motor vehicle crashes. The data consists of over 600 variables that describe crash events, damage to vehicle, crash forces involved, injuries to the victim and injury causation mechanisms for frontal, side, rear, and rollovers crashes. The work presented in this paper represents one of the steps necessary to better understand the rear-end crash problem.

METHODOLOGY

Using a technique similar to Bean, et al. [2009], a detailed review of real-world rear-end crashes was conducted where an occupant sustained fatal injuries in an involved vehicle. The review focused on coded and non-coded data (photographs, summaries, crash diagrams, etc.), and resulted in the identification of critical factors contributing to the fatal injuries in rear-end crashes. The cases were selected from the NASS-CDS database for the years 2003 to 2012. The following parameters were required for a crash to be included in the data set:

- The crash was fatal (AIS level 6)
- The crash was coded as forward impact into a parked vehicle, rear-end, or forward impact of vehicles going in the same direction on the same trafficway (accident type 11 or 20-43)
- The subject vehicle (SV) was a passenger vehicle (bodytype 1-49)
- The SV general area of damage in the first crash event was frontal (General area of damage=F for accseq=1)
- The pre-impact location of the SV was "stayed in original travel lane" (preiloc=1)
- The SV pre-event movement was "going straight", "decelerating in traffic lane", "accelerating in traffic lane", "starting in traffic lane", or "passing or overtaking another vehicle" (premove=1,2,3,4, or 6)
- The lead vehicle (LV) preimpact location was "no driver present" or "stayed in original travel lane" (preiloc=0 or 1)
- The LV pre-event movement was "no driver present", "going straight", "decelerating in traffic lane", "accelerating in traffic lane", "starting in traffic lane", "stopped in traffic lane", "passing or overtaking another vehicle", or "disabled or parked in travel lane" (premove 0-7)
- There were no restrictions on restraint use or travel speed

Thirty eight cases that involved 39 fatalities were identified in the data set that met the above criteria. The cases were then divided amongst the authors, who summarized each case using a standard format. The authors then assessed the primary, secondary, and (if applicable) other factors associated with the fatal injury sustained by the vehicle occupant. A factor, in this context, is an event or condition present at or after the time of impact that probably and logically increased the likelihood that this specific impact would be fatal to an occupant. Factors related to the fatality were deemed primary or secondary, depending on the nature of their causative effects. The distinction between primary and secondary factors is similar to what was described by Rudd, et al. [2009].

The following section provides descriptions of the factors associated with injury causation assigned to the crashes in this data set:

Improperly Restrained Occupant: The occupant's injuries were directly associated with not utilizing the restraint system (i.e., seat belt) provided in the vehicle and/or the vehicle may not have been equipped with an air bag at the seating position in question. For nearly every occupant that was classified as being improperly restrained, the crash severity was deemed to be survivable.

Medical Condition: The driver of the subject vehicle lost consciousness just prior to the event because of an identified medical problem.

Speed of Striking Vehicle: The velocity of the subject vehicle at the time of impact (i.e., closing speed) was identified to have contributed to a high change in velocity and subsequent fatal injuries for an involved vehicle.

Second Event the Most Harmful Event: The primary source of the occupant's fatal injury was not directly attributed to the first event which was the rear-end impact. However, the fatal injury was attributed to a more harmful event that occurred directly after the initial rear-end impact.

Multiple Vehicles Involved: For an involved vehicle, the fatal injuries sustained by an occupant were attributed to the nature of the crash involving multiple impacts with multiple vehicles. For example, the subject vehicle was first involved in a minor rear-end crash by impacting a lead vehicle, however, it was subsequently impacted in the rear, which contributed to the fatal injuries.

Post-Crash Fire: The subject vehicle sustained a post-crash fire resulting from the rear-end impact, which caused or contributed to the fatal injuries. Generally, the crash severity as measured by rear-end crush was significant.

Struck Vehicle Comparable Size or Smaller: The NASS-CDS coded mass of the struck vehicle was either similar or less than the striking vehicle in the crash. This factor attempts to identify crashes where mass incompatibility between the striking and struck vehicle contributed to the severity of the crash outcome for the struck vehicle.

Truck-Trailer Underride: The striking subject vehicle experienced severe underride with intrusion extending generally into the greenhouse area of its occupant compartment, leading to fatal injuries. For the cases reviewed in this study, the type of rear-impact guards present on the trailers was unknown, and there was likewise no measure of their performance in the crash. The key is poor structural interaction with the crash partner.

Alcohol Involvement: The driver of an involved striking vehicle was determined to have had high Blood Alcohol Concentrations (BAC). This was only assigned as a factor if it was determined that alcohol consumption contributed to the cause of the crash, such as when the striking vehicle driver was under the influence of alcohol. When the BAC was known, it was well above the 0.08 legal limit.

Given the case-review nature of this work, no statistical analyses have been performed on the data, and no assessment of injury risk can be performed since case weights were not used.

RESULTS

The cases were first grouped by common factors that were assessed to have been relevant to the severity of all the rear-end crashes reviewed. A high-level grouping of the factors for all the cases is presented in Table 1. For all the fatal cases analyzed, the primary factor associated with 27 of the 38 cases reviewed was the Speed of the Striking Vehicle. This was assessed to be the most frequent primary factor in the fatal crash event. For all the crashes, the most frequently occurring secondary factor was Struck Vehicle Comparable Size or Smaller followed by Truck-Trailer Underride. Lastly, alcohol involvement was identified in 14 of the cases.

Table 1.
Summary of Rear-End Crashes by Factor.

Factor	Primary Factor	Secondary Factors	Other Factor	Totals
Improperly Restrained Occupant	4	0	1	5
Medical Condition	1	0	0	1
Speed of Striking Vehicle	27	0	0	27
Second Event the Most Harmful Event	6	0	0	6
Multiple Vehicles Involved	0	0	4	4
Post-Crash Fire	0	0	3	3
Struck Vehicle Comparable Size or Smaller	0	18	0	18
Truck-Trailer Underride	0	13	1	14
Alcohol Involvement	0	3	11	14

What follows is a more detailed analysis of the primary and secondary factors, and the corresponding crash characteristics and associated injury. A summary of the data is presented in Table 2 and a summary of all of the factors associated with each individual case involved in this assessment is provided in the Appendix.

Table 2.
Rear-End Crash Grouped by Common Primary and Secondary Factors.

Primary Factor	Secondary Factor	Cases
Speed of Striking Vehicle	Struck Vehicle Comparable Size or Smaller	14
Speed of Striking Vehicle	Truck-Trailer Underride	13
Second Event the Most Harmful Event	NA	6
Improperly Restrained Occupant	Struck Vehicle Comparable Size or Smaller	4
Medical Condition	NA	1

Fatal Occupant in Lead Vehicle Struck by a Similar or Larger Vehicle

The most frequently occurring primary and secondary factor combination was the Speed of Striking Vehicle and Struck Vehicle Comparable Size or Smaller. This combination accounted for 14 of the cases reviewed. In these cases, the striking vehicle, impacted a vehicle with a similar mass or smaller at a high rate of speed. In this grouping, the fatal occupants were always in the struck vehicle. In these types of crashes the fatally injured occupant in the struck vehicle generally sustained head and/or neck injuries such as a brain stem laceration or cervical spine cord laceration sourced to the head restraint. In all but two crashes, the fatality was in the front seat. In Case Nos. 2006-9-168 and 2007-41-38 the fatal occupant was in the rear. It should be noted that in both of these crashes, the front occupants sustained moderate to minor injuries. The photos in Figure 1 illustrate the severity of the impacts.

Figure1. NASS-CDS Case No. 2006-9-168 Struck Vehicle (left) and Case No. 2007-41-38 Struck Vehicle (right).

For this type of crash, on average, the severity as measured by the NASS-CDS estimated Delta-V for the striking and struck vehicle was 46 km/h and 62 km/h, respectively. On average the striking vehicle was 400 kg heavier than the struck vehicle. The highest mass differential was 1,296 kg. The average maximum measured crush for the struck vehicle was 122 cm. It should also be noted that three cases involved a post-crash fire in the struck vehicle resulting in fatal burns. For the two crashes where the crush was measured, the maximum crush was 121 cm and 123 cm (Case Nos. 2006-2-12 and 2008-79-62).

The injuries for the striking vehicle were generally minor, especially when the occupant(s) were properly restrained and the vehicle was equipped with frontal air bags. Most occupants sustained minor bruising or abrasions. In five crashes there were no reported injuries in the striking vehicle. On average the Delta-V for the striking vehicle was 46 km/h, which is lower than the NHTSA's New Car Assessments Program's frontal crash test speed that results in a 56 km/h Delta-V.

In five cases, alcohol was involved for the driver of the striking vehicle, and it was also reported to be dark out in 11 cases. Lastly, for eight cases, it was reported that the lead vehicle was stopped prior to impact.

An example of this crash type is Case No. 2007-82-15. A 1994 Geo Prism (1,065 kg) was disabled and stopped in the same lane ahead of a 2002 Jeep Liberty (1,912 kg). The front of the Jeep impacted the back of the Geo resulting in 127 cm of crush in the rear (Figure 2.) For both of these vehicles the Delta-V was not computed. However, the maximum frontal crush measured on the Jeep was only 10 cm. The posted speed on the roadway was 97 km/h. The driver of Geo sustained a fatal brain stem laceration sourced to the head restraint, and the front passenger sustained a flailed chest sourced to the seat. The crash occurred at 03:44 with the conditions being coded as dark but lighted and with clear atmospheric conditions. The driver of the striking vehicle had a 0.08 BAC.

Figure 2. NASS-CDS Case No. 2007-82-15 Struck Vehicle (left) and Striking Vehicle (right).

Fatal Occupant in Striking Vehicle Impacting Heavy Vehicle

The second most frequently occurring primary and secondary factor combination was the Speed of Striking Vehicle and Truck-Trailer underride. This combination accounted for 13 of the 38 cases reviewed. In all of these cases, the striking vehicles were traveling at a high rate of speed and impacted the rear of a large truck and/or trailer where the driver of the striking vehicle sustained the fatal injuries. It was generally observed that speed along with insufficient structural interaction between the two vehicles resulted in underride and significant intrusion into the occupant compartment. For these crashes the severity as measured by the change in velocity (Delta-V) was not computed by NASS-CDS due to the crash being out of scope of the computing software. In this type of crash, the striking vehicle's driver sustained fatal injuries that were sourced to the intruding interior components or direct contact with the rear surface of the truck-trailer. Of the cases reviewed, it was found that for five of the 13 crashes the drivers of the striking vehicle had an elevated BAC. Seven cases occurred when it was dark. In eight of the cases, the struck vehicle was coded as stopped. In these cases, there was a significant speed differential between the vehicles at the time of impact.

For example, in Case No. 2003-73-129, a 1989 Chevrolet Cavalier impacted the rear of a 1998 International truck tractor pulling a trailer, which was slowing due to traffic congestion. The time of the crash was reported as 06:44 where it was dark and no adverse atmospheric-related driving conditions. The driver of the Chevrolet sustained a brain stem laceration sourced to direct contact with the rear of the struck vehicle. Figure 3 illustrates the severity of the damage to the striking vehicle.

Figure 3. NASS-CDS Case No. 2003-73-129.

Second Event Was the Most Harmful Event

Six cases were classified with a primary factor of the Second Event was the Most Harmful Event. For these cases the most harmful event that resulted in the fatal injuries was preceded by a minor rear-end impact. In five of the six cases, the most harmful event was a subsequent rollover, and one case resulted in a front-to-front head on impact with another vehicle. Of the five rollover crashes, three occupants were ejected. All but one crash occurred when it was dark out, and in two cases the driver of the striking vehicle had an elevated BAC. None of the struck vehicles was coded as stopped.

For two of the cases (Nos. 2006-81-79 and 2009-72-43), the striking vehicle was attempting to change lanes when it struck the rear of a lead vehicle resulting in a loss of control for an involved vehicle. The loss of control resulted in a rollover and ejection of an occupant causing fatal injuries. In Case No. 2006-81-79, the ejected occupant was the unrestrained driver of the striking vehicle and in Case No. 2009-72-43, the rear seat unrestrained occupant of the struck vehicle was ejected.

For example, in Case No. 2007-50-006, a 2007 Chevrolet Impala was traveling south on a urban roadway. A 2003 Mazda Pickup was traveling south in front of the Chevrolet on same roadway. The front of the Chevrolet contacted the back of the Mazda. The Chevrolet appeared to have lost control, departed the roadway, struck a utility pole, and rolled over. The crash occurred at 16:38. It was daylight but raining. The unrestrained driver of the striking vehicle (Figure 4) sustained a fatal brain stem laceration. It was unknown if the front seat passenger was restrained, but the occupant sustained only minor abrasions. The frontal air bags deployed in the event. No injuries were reported for the driver of the struck vehicle. As Figure 4 shows, there was negligible damage to the Mazda.

Figure 4. NASS-CDS Case No. 2007-50-6 Striking Vehicle (left) and Struck Vehicle (right).

Case No. 2006-49-23, was unique in that the fatal occupant was not involved in the initial rear-end impact. A 1998 Ford Windstar impacted the rear of a 2002 Toyota Corolla. The Ford, after impacting the Toyota, drove off of the roadway to the left and across the median into oncoming traffic. A 2003 Nissan Altima was traveling in the opposite direction. The front of the Ford impacted the front of the Nissan. The driver of the Nissan sustained fatal brain stem injuries (Figure 5). The driver of the Ford also sustained serious head injuries.

Figure 5. NASS-CDS Case No. 2006-48-23 Other Vehicle.

After assessing these cases, it was determined that if not for the rear-end impact, an involved vehicle would not have experienced the second event which resulted in the fatal injuries.

Improperly Restrained Occupant

Of the 38 cases analyzed, four were identified by the primary and secondary factors of Improperly Restrained Occupant and Struck Vehicle Comparable Size or Smaller. In these cases, the fatal occupant was in the striking vehicle. It was assessed that based upon the crash severity as measured by Delta-V and the crush on the striking vehicle, if the occupant was properly restrained with a lap and shoulder belt and the vehicle had frontal air bags the occupant would have likely survived the event. For all the crashes where it was computed, the estimated Delta-V for the striking vehicles was approximately 56 km/h or below. In all cases, the fatal front seat occupant sustained a severe brain stem injury. Three out of the four crashes occurred when it was dark out. Only one crash involved alcohol use for the driver of the striking vehicle.

In Case No. 2003-12-199, the fatal occupant was the front seat passenger and the vehicle was not equipped with a passenger side frontal air bag and the seat belt was not used. The passenger sustained fatal head injuries from contact with the windshield. However, the driver, who was restrained, only sustained minor skin abrasions. In Case No. 2003-49-133, the driver was wearing a seat belt at the time of the crash but the vehicle was not equipped with a frontal air bag. The driver sustained fatal head injuries from contact with the steering wheel.

Case No 2012-11-112, is an example of a multi-vehicle crash where the striking 2003 Dodge Ram impacted a stopped 2001 Hyundai Santa Fe, which then struck a stopped 2000 Freightliner. The crash occurred at 07:55 on a clear day. The severe impact resulted in a Delta-V of 60 km/h for the Dodge and 86 km/h for the Hyundai.

The unrestrained driver of the Dodge sustained brain stem injuries sourced to the steering wheel. The frontal air bags in the vehicle did not deploy. It should be noted that the 60 km/h Delta-V may overestimate the severity of the impact especially after observing the crush in Figure 6. Max crush was measured to be 34 cm but it was not uniform across the bumper.

The injuries for the Hyundai's front occupants were not coded. It is only noted in the case that they were incapacitating injuries. Given the severe nature of this crash for the Hyundai, even though the occupants did not sustain fatal injuries, the crash is consistent with the Fatal Occupant in Lead Vehicle Struck by a Larger Vehicle category discussed above. The severity was also aggravated by the Hyundai impacting the rear of a larger vehicle after being struck by the Dodge. It should be noted that in some multi-vehicle crashes the crash severity is intensified because the struck vehicle is not pushed out of the way but is constrained by a vehicle it impacted. This leads to the vehicle having to absorb more of the crash forces.

Figure 6. NASS-CDS Case No. 2012-11-112 Striking Vehicle (left) and Struck Vehicle (right).

Medical Condition

In one relatively minor crash (Case No. 2009-79-44) an 84-year old unrestrained driver of a striking vehicle sustained fatal cervical spine injuries. However, according to the supplemental information associated with the case, there was a possibility that the driver of the striking vehicle suffered a stroke (cerebrovascular accident with infarct and hemorrhage) that led to the rear-end vehicle crash. There was no evidence of braking at the scene and no avoidance maneuver was attempted by the driver.

DISCUSSION

Fatal Occupant in Lead Vehicle Struck by a Similar or Larger Vehicle

Generally, in this rear-end crash type that resulted in a fatality in the struck vehicle, impact speed and mass were significant contributors to the amount of crush in the subject vehicle. The data showed on average the maximum measured crush for the struck vehicle was 122 cm and one case the vehicle experienced 155 cm of crush (Case No. 2011-49-41).

To understand the severity of these crashes, limited data was reviewed from crash tests that were conducted in accordance to the FMVSS No. 301 "Fuel system integrity" test procedure. NHTSA had conducted a number of crash tests on vehicles manufactured after 2005. The FMVSS No. 301 test specifies that the stationary test vehicle is impacted in the rear by a 1,367 kg deformable barrier, with a 70 percent overlap at, 80 km/h. The test does not specify that the maximum crush is measured post-impact. However, in 38 tests for which the vehicle crush was recorded for research purposes, the maximum crush varied from 11 cm for 2008 Volkswagen Touareg to 84.4 cm for 2013 Toyota Avalon Hybrid. The average maximum crush from all vehicles in the tests was 52.7 cm.

The crush in the rear-end fatal crashes on average is double the amount of maximum crush as measured in the FMVSS No. 301 test condition. It also should be mentioned that in eight of the 15 crashes the lead vehicle was stopped, which is consistent with FMVSS No. 301 test procedure. These crashes are thus exceedingly severe in nature, meaning that for a forward collision avoidance system to be effective, the alert would need to be timed to warn the driver early enough to significantly reduce the travel speed. Similarly, an automatic emergency braking system would need to be aggressive enough to reduce the travel speed to either prevent the crash from occurring or to reduce the impact severity well below the NASS-CDS estimated Delta-V of 62 km/h for the struck vehicle in this analysis.

Fatal Occupant in Striking Vehicle Impacting Heavy Vehicle

Rear-end crashes that involve a light vehicle striking a large tractor-trailer combination vehicle at a high rate of speed are generally characterized by the severity of the upper-body intrusion in the striking vehicle and serious head injury often attributed to direct contact with the struck vehicle. There also is an apparent lack of structural engagement between the two vehicles. It would also appear that in these crashes, if an underride guard was present, it could not withstand the force of the crash, leading to the rear of the heavy vehicle interacting with the A-pillar and upper compartment of the striking vehicle. This crash type has been identified in a prior analysis but not in the context of rear-end crashes (Bean, 2009). This crash type composed almost half of the cases analyzed.

There are a number of considerations to be examined from the perspective of utilizing rear-end crash avoidance technologies and determining the potential benefits. Five of the 13 drivers of the striking vehicle had an elevated BAC, seven cases occurred when it was dark and the struck vehicle was coded as stopped in eight of the cases. For intoxicated drivers, it is unknown how effective a warning may be. However, these systems would need to be robust enough to track a stopped or slowing vehicle in the night at a high rate of speed. In order to have changed the outcome of these particular crashes, automatic emergency braking systems would need to properly identify a stopped large truck sitting higher off the ground with a large rear overhang and underride guard, and have sufficient authority to mitigate or prevent the crash. The system would require enough braking authority to avoid the crash even if the driver is intoxicated; i.e., be able to intervene without driver action or involvement.

Second Event was the Most Harmful Event

These particular crashes were of interest because an initial rear-end impact set off a series of events that resulted in a fatality in an involved vehicle. Generally the rear-end crash was minor but still significant enough for an involved vehicle to lose control, which in turn led to a more harmful event. In five of the six cases, the initial rear-end impact led to a rollover. Whether the fatality was in the struck or striking vehicle was a matter of circumstance at the time of the crash. Of importance was the fact that, if not for the initial minor rear-end impact, the more harmful event would not have occurred. From a benefits standpoint, a rear-end crash avoidance system could be effective in preventing the initial rear-end crash, and thus the more harmful event.

Improperly Restrained Occupant

For all the crashes where it was assessed that the occupant sustained fatal injuries because the occupant was improperly restrained, the crash was likely survivable. In Case Nos. 2003-12-199 and 2003-49-133, because the vehicles were older and not designed to the current FMVSS, the occupants were not afforded the protection from frontal air bags. For occupants not wearing a lap and shoulder belt, it is not known how a rear-end crash avoidance warning and an automatic emergency braking system would have changed the outcome of the crash. A warning would have had to be extremely effective in causing the driver to react to prevent the crash from occurring as would an automatic emergency braking system. Even with an automatic emergency braking system that reduced the speed at impact, an occupant could still sustain serious injuries if not properly restrained. The estimated Delta-V for the striking vehicles was approximately 56 km/h or below for these crashes. For these reasons it is unknown how a crash avoidance system will predictably reduce injury levels unless the crash is avoided entirely.

Medical Condition

Only one case (Case No. 2009-79-44) was identified where a medical condition caused a minor crash where the occupant sustained fatal injuries. This case is noted only because this type of crash, though rare, does occur in the real-world. When assessing potential benefits of rear-end crash avoidance systems, various medical conditions can potentially cause a driver to lose consciousness and cause a crash, in which case a crash avoidance alert may be ineffective. However there may be some benefit for systems with automatic emergency braking that will prevent the crash or reduce the overall severity.

EDR NASS-CDS Analysis

A supplemental analysis of the NASS-CDS data was conducted to better understand the pre-crash dynamic states of the involved vehicles in rear-end crashes. Cases were selected where both the striking and struck vehicles were equipped with an Event Data Recorder (EDR). There were no other constraints placed on the case selection such as belt usage or injury severity. For the fatal cases, there was a very limited amount of EDR data available for the involved vehicles because they were generally not equipped with the device and the analysis had to rely on the coded or computed data from the investigation. This analysis attempts to better understand (1) pre-crash relative speed prior to impact, (2) if the striking vehicle's driver made any avoidance maneuver (such as braking), and (3) if the struck vehicle was stopped or decelerating to a stop prior to impact, and compares the data to how they were coded by the NASS-CDS investigator.

An EDR generally captures approximately five seconds of data prior to algorithm enable (AE) and approximately one hundred milliseconds or more during a crash. AE generally activates at the onset of a crash. An EDR reports AE as T-0 of a crash event and subsequently reports the pre-crash data such as vehicle speed and brake activation status from that reference and generally at one second increments prior to AE. After the crash, the EDR will capture the severity of the event as longitudinal Delta-V in the case of front-to-rear crashes.

The cases were analyzed using a common approach and similar format to the fatal cases. An initial cut of the 2003 through 2012 NASS-CDS data identified 29 cases with paired EDR data for both the striking and struck vehicles. A lot of focus was placed on assessing the EDR data for both vehicles to verify that the data were captured in the relevant crashes. For example, the air bags would likely not deploy in the struck vehicle. In this vehicle, the EDR may have captured data, but because the air bags did not deploy, the data were not locked and could have been overwritten by the time the investigation was conducted. The data captured needed to make sense in the context of the physical evidence from the investigation.

After an assessment of the EDR data, 19 cases were verified to have relevant data for both the struck and striking vehicles. The following is a summary of the results from the analysis:

- Average. Longitudinal Delta-V for striking vehicle was 19 km/h
    - Frontal air bag deployed in 10 crashes for the striking vehicle
- Average: Longitudinal Delta-V for struck vehicle, when known, was 17 km/h
- Average relative speed at T-1 with respect to AE prior to impact was 45 km/h
- In 8 cases the striking driver did not brake prior to impact, or AE
- In 7 cases the striking driver was braking prior to impact (longer than one second prior to AE)
- In 4 cases the striking driver applied the brakes at T-1 but not earlier
- In 1 case the struck lead vehicle was accelerating from a stop
- In 3 cases the struck lead vehicle was decelerating to a stop than impacted
    - NASS-CDS reported 2 cases where the struck vehicle was stopped
    - NASS-CDS reported 1 case where the struck vehicle was decelerating
- In 2 cases the struck lead vehicle was stopped
    - NASS-CDS reported both vehicles as stopped
- In 13 cases lead vehicle was decelerating
    - NASS-CDS reported 7 cases where the lead vehicle was stopped

The EDR vehicle speed and Delta-V data collected from these crashes suggest these were generally low severity events, which were further verified from the coded injury data. Almost all of the crashes occurred at a posted speed of 72 km/h or below. Only one AIS 3 wrist fracture injury was reported. For all other cases, injuries were either coded as unknown (not reported) or no injuries.

Of interest were the cases where the EDR data showed the struck lead vehicle was decelerating to a slower speed or decelerating to a stop at impact and NASS-CDS coded the vehicle as stopped. In a majority of the cases the driver of the striking vehicle did not brake or braked late prior to impact.

This analysis was conducted with the limited EDR data available. This analysis should be revisited when more paired EDR cases are available. Figure 7 plots the severity of the event for the struck vehicle. In 10 of the cases, the EDR did not record Delta-V. This is likely attributed to the way the EDR was designed, waking up from the impact but the crash was not severe enough to record Delta-V or of the type to deploy the frontal air bags since the vehicle was impact in the rear. Only pre-crash information was recorded. From the available data, the most frequent change in velocity range was between 9 km/h and 16 km/h, in four cases.

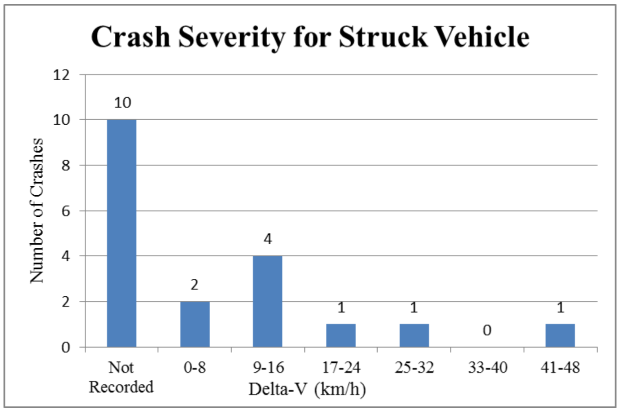

Figure 7. EDR-Captured Crash Severity for Struck Vehicle.

For the striking vehicle, all EDRs recorded a Delta-V (Figure 8). All the vehicles sustained a Delta-V at or below 56 km/h with 15 vehicles experiencing a Delta-V between 9 km/h and 40 km/h. When compared to the NCAP frontal crash Delta-V of 56 km/h, the crashes were of a low to moderate severity impact. This is also consistent with the low level of injuries experienced by the occupants.

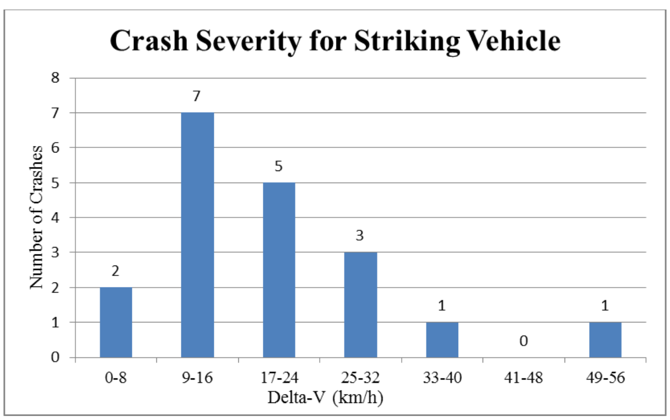

Figure 8. EDR-Captured Crash Severity for Striking Vehicle.

Of importance is the relative impact speed between the striking and struck vehicles (closing speed) when considering test conditions to measure the effectiveness of forward crash avoidance system with automatic emergency braking. The vehicle velocity used in this analysis was the vehicle speed captured by the EDR at T-1 second prior to AE. From Figure 9, all but one of the crashes occurred at closing speeds below 80 km/h. A majority of the crashes occurred with a relative impact speed of between 33 and 56 km/h. Again, this is limited data, but at these speeds, occupants in the vehicles were not injured. In Case No. 2006-12-123 where the relative impact speed was 102 km/h, the EDR captured Delta-V for the striking and struck vehicle were 51 and 48 km/h, respectively. The occupants of both vehicles sustained only minor injuries. To bound this discussion, in the crashes where the primary and secondary factor were the Speed of Striking Vehicle and Struck Vehicle Comparable Size or Smaller, on average the Delta-V resulting in the fatal injuries for the struck vehicle was 62 km/h.

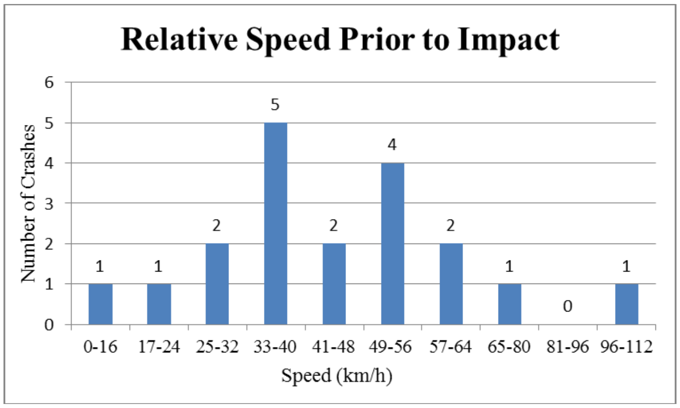

Figure 9. EDR-Captured Relative Speed Prior to Impact.

CONCLUSION

This paper did not focus on crash causation except to note alcohol involvement as a factor and the one case where a medical condition apparently caused the fatal crash. When reviewing these cases, it was initially concluded for every case except for those mentioned above, it appeared driver inattention or distraction was the likely cause of these fatal crashes. Given the frequency it was decided that the factors should focus on vehicle attributes and crash dynamics contributing to the fatal crash. This approach would also compliment the prior studies discussed earlier by providing a more detailed analysis of the fatal real-end crash problem.

This analysis showed, for a properly restrained occupant to sustain fatal injuries in a rear-end impact the striking vehicle must impact the struck vehicle at an excessive relative speed resulting in a high Delta-V. Which vehicle sustains the fatality is generally a factor of size and mass difference between the involved vehicles. The fatality was shown to occur in the striking vehicle when it impacts a large truck. Conversely the fatality is in a smaller struck vehicle when impacted by a larger vehicle at a high rate of speed. In general, for all of the crashes analyzed the fatal occupant sustained fatal head injuries in the smaller vehicle. It should also be noted that minor rear-end crashes can cause a loss of control for an involved vehicle resulting in a second, more harmful event such as a rollover.

The EDR data provided insight into the vehicle dynamics of rear-end crashes. The crashes were generally not severe and involved property damage only. It is recognized that the data analyzed was limited, but this analysis should be expanded as more paired EDR data is available. However, the data does provide some initial baseline conditions for an average rear-end crash and further evidence that the fatal rear-end crashes are extremely aggressive events. The results of this analysis could be used to assess the performance of vehicles equipped with advanced rear-end crash avoidance technologies and estimate the safety benefits in the real-world.

Lastly, what the analysis identified was fatal rear-end crashes are generally attributed to excessive speed at the time of impact. In order to address these crashes in the real-world, a forward collision avoidance system must provide a timely alert and automatic emergency braking must be aggressive to significantly reduce the impact speed to mitigate the severity or prevent the crash from occurring.

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Appendix

NASS-CDS Case No.	Primary Factor	Secondary Factor	Other Factor(s)
2003-49-133	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	Alcohol Involved Truck-Trailer Underride
2003-12-199	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	
2012-11-112	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	Multiple Vehicles Involved
2012-49-36	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	
2009-79-44	Medical Condition		
2006-49-123	Second Event the Most Harmful Event (Rollover)	Alcohol Involvement	
2007-50-6	Second Event the Most Harmful Event (Rollover)	Alcohol Involvement	
2006-49-23	Second Event the Most Harmful Event (Head on impact)		
2009-4-166	Second Event the Most Harmful Event (Rollover)		
2009-72-43	Second Event the Most Harmful Event (Rollover)		
2006-81-79	Second Event the Most Harmful Event (Rollover)	Alcohol Involvement	
2003-74-130	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2006-49-120	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2006-50-105	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2011-49-41	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Muliple Vehicles Involved Alcohol Involved
2012-9-72	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2010-82-137	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Multiple Vehicle Involved
2006-2-12	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Post Crash Fire
2006-3-49	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Post Crash Fire
2008-79-62	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Muliple Vehicles Involved Post Crash Fire
2006-9-168	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2005-50-116	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2007-41-38	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2007-82-15	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2010-79-89	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2003-73-129	Speed of Striking Vehicle	Truck-Trailer Underride	
2005-72-129	Speed of Striking Vehicle	Truck-Trailer Underride	
2005-81-48	Speed of Striking Vehicle	Truck-Trailer Underride	
2005-9-189	Speed of Striking Vehicle	Truck-Trailer Underride	
2006-48-161	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2007-50-108	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2007-73-37	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2009-49-178	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2009-73-144	Speed of Striking Vehicle	Truck-Trailer Underride	
2009-9-99	Speed of Striking Vehicle	Truck-Trailer Underride	
2010-11-240	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2012-49-160	Speed of Striking Vehicle	Truck-Trailer Underride	
2011-73-83	Speed of Striking Vehicle	Truck-Trailer Underride	Improperly Restrained Occupant