An Update on Front-Seat Occupant Injury Rates in Frontal Crashes: Focus on Modern Vehicles

Chantal S. Parenteau, Amy Courtney, Ian C. Campbell, Edmund Lau

Abstract This study updated injury information in frontal collisions for current restraint technology. First, the rate of serious-to-fatally (MAIS3+F) injured lap-shoulder belted front-seat occupants involved in frontal motor vehicle crashes with airbag deployment was determined by model year groups as a function of frontal airbag regulatory changes (1989-1998, 1999-2005, and 2006+) using 1994–2015 NASS-CDS. The results a trend for reductions in injury rates with modern restraint technology.

Second, the distribution of exposed (MAIS 0+F) and serious-to-fatally (MAIS3+F) injured front seat occupants was assessed by crash severity for 2006+ MY vehicles equipped with modern technologies. Injury rates were also determined as a function of belt use to estimate belt effectiveness. The results showed that the rate of MAIS3+F injury increased with the vehicle's change in velocity. However, there was a marked increase in injury rate with delta V 64+ km/h compared to lower-severity crashes. Injury rates were consistently lower for belted than unbelted occupants, though seat belt effectiveness decreased from approximately 70% to 42% as delta V increased from 20 to 76 km/h.

In a third part of the study, an in-depth case review was conducted to identify the circumstances of frontal collisions resulting in fatality despite availability of advanced restraint systems, including severe crash conditions or a frail front occupant.

Keywords Frontal crashes, front seat occupants, serious injury, belt use, airbag deployments.

I. INTRODUCTION

For the last six decades, occupant protection in frontal crashes has been assessed. In the U.S., the National Highway Traffic Safety Administration (NHTSA) has evaluated front crash performance of motor vehicles via federal motor vehicle safety standards (FMVSS) certification and the New Car Assessment Program (NCAP). In the European Union, automotive safety regulations are enforced as the E.U. Whole Vehicle Type Approval following standards of the E.U. and the United Nations Economic Commission for Europe (UNECE). Vehicle manufacturers and organisations such as the Insurance Institute for Highway Safety (IIHS), Euro NCAP, Latin NCAP, ASEAN NCAP, Australasian NCAP, and others have also evaluated vehicle and occupant responses in frontal crashes.

Frontal test protocols and performance requirements have changed over time, resulting in modifications in vehicle structures and restraint designs and implementations. For example, airbags were first introduced in the 1970s but have been required in all cars, light trucks, and vans with model year 1999 or newer in North America. In 2000, NHTSA published a final rule as part of FMVSS 208, "the advanced airbag rule," requiring that airbags be designed with lower risk of serious airbag-induced injuries. In addition, airbags were to provide protection for all front-seat occupants by means of advanced airbag technology. The first phase-in commenced September 1, 2003. One of the tests required a frontal impact at 32 to 40 km/h into a rigid barrier with an unbelted 50th percentile male driver and 5th percentile adult female passenger anthropometric test device (ATD, or "crash test dummy"). The second phase-in commenced September 1, 2007 and required a 56 km/h rigid barrier test with a belted 50th percentile male ATD driver. As a result of changes in frontal test requirements, modifications were also made to other restraint system components. For example, front outboard seat belt systems of all cars and light truck vehicles sold in the U.S. after 2007 were equipped with pretensioners and load limiters though they were not required [1]. Whereas in the U.S. airbags have been required in all vehicles since 1999, in the E.U. airbags are not required by law. Notably, whereas frontal airbags in the U.S. are tested to protect an unbelted occupant under FMVSS 208, UNECE specifications focus on occupant protection for belted individuals.

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The effectiveness of new regulations, requirements, and safety technologies has been assessed. Brumbelow and Zuby [2] reported that structural and restraint system designs improved substantially since the introduction of consumer frontal crash test programs (IIHS offset test and NCAP tests). Kahane et al. [1] analysed data from NHTSA's Fatality Analysis Reporting System (FARS) from 1986 to 2011 and concluded that the combination of pretensioners and load limiters generally reduced the risk of fatality in passenger vehicles, crossover utility vehicles (CUVs), and minivans, but not in light truck-based vehicles (pickup trucks, sport utility vehicles (SUVs), and full-sized vans).

The effectiveness of restraint technologies may vary depending on crash-specific factors, such as severity, intrusion, contact distribution, and direction, as well as occupant-specific factors such as age, obesity, gender, and pre-existing reduced injury tolerance [3,4]. To identify factors associated with fatality in frontal crashes, Bean et al. [5] analysed data from the Crashworthiness Data System (CDS) from 2000 through calendar year 2007 and reviewed every case involving a frontal impact resulting in fatality to a belted driver or right-front passenger in model year 2000 or newer vehicles. They evaluated 122 cases and identified 49 as exceedingly severe, based on poor structural engagement and/or high speed, or involving unusual configurations that would be difficult to address through vehicle improvements. In particular, corner impacts, oblique crashes, impacts with narrow objects, and under-rides were identified as crash characteristics associated with occupant fatality. Specifically, they posited that airbags may be less effective in oblique frontal crashes, due to suboptimal engagement with the occupant, or in particularly severe crashes when the airbag bottomed out. In addition, the authors noted fatalities occurred when crashes were "quite severe or the occupants exceptionally vulnerable," even in then-current vehicles. The authors also reported that vulnerable occupants, including age (75 and older) and pre-existing medical conditions, were factors. They noted that some fatalities were with obese occupants.

The objective of the present study was to first compare injury rates for lap-shoulder belted front-seat occupants in outboard seating positions by various model year groups. Another objective was to document the frequency and rate of seriously injured front-seat occupants in modern (2006+ model year [MY]) vehicles involved in frontal crashes with airbag deployments. With this criterion, nearly all the cases included vehicles with advanced frontal airbags and lap and shoulder belts with pretensioners and load limiters for the front outboard occupants. Injury rate was further evaluated by crash severity (delta V) and belt use. In the third part of the study, forty-one individual cases involving fatality of belted front occupants in frontal crashes with airbag deployment were reviewed using an approach similar to that of Bean et al. [5] to evaluate whether similar rate factors were present.

II. METHODS

NASS-CDS data for calendar years 1994-2015 was used in this study. CDS data is based on a complex stratified sampling design, with clustering by primary sampling units (PSU), and corresponding sampling weights. The data was evaluated for light vehicles and grouped according to model year corresponding to major changes in airbag rollout: optional airbags (1989-1998), mandatory depowered airbags (1999-2005), or advanced airbags (2006-2016). Selection criteria included frontal impacts (GAD1 = 'F') with no rollover (ROLLOVER ≤ 0) and no occupant ejection (EJECTION = 0). Front seat occupants were determined as drivers (SEATPOS = 11) or right-front passengers (SEATPOS = 13) age 15 and older. Only cases with airbag deployments (BAGDEPLY = 1) were included. The resulting data set was analysed for impact severity (based on delta V), belt use, and injury severity.

Belt use was assessed using the manual belt and automatic belt variable. Occupants were identified as lap-shoulder belted (MANUSE = 4) or unbelted (MANUSE ≤ 1 and ABELTUSE < 1 or ABELTUSE = 2 for calendar years 2006-2009, and MANUSE = 0 or 1 for calendar years 2010 or greater).

The maximum injury severity was identified by the coded Maximum Abbreviated Injury Scale (MAIS) value. MAIS ranges from 0 to 6 and 9, where MAIS9 is an injury with unknown severity. Exposed occupants were defined as those with known MAIS (MAIS0-6) or with a fatality. The shorthand notation is MAIS0+F. A subgroup of seriously-to-fatally injured occupants was defined as those with MAIS3-6 or fatality, as fatalities can occur at any MAIS level. The shorthand notation is MAIS3+F. Crashes resulting in fatality were identified by the variable TREATMNT = 1, which represents that an occupant was fatally injured and not transported to the hospital, or by INJSEV = 4, which represents a fatality recorded by police.

National estimates for the number of crashes and occupant injuries were made using the ratio inflation factor (RATWGT) variable in the NASS-CDS. All calculations were based on weighted values. Cases with a ratio inflation factor equal to 0 or with a negative inflation ratio were excluded from the analysis. The rate that a serious injury occurred was determined by dividing the number of seriously-to-fatally injured occupants (MAIS3+F) by the number of exposed occupants (MAIS0+F).

Belt effectiveness was determined as the difference between the injury rates with unbelted and belted occupants divided by the injury rate with unbelted occupants.

Individual in-depth case reviews were completed for forty-one cases involving fatally injured, lap-shoulder belted, front seat-occupants in frontal crashes with airbag deployments. Additional information was considered, such as delta V, collision characteristics, occupant age and body mass index (BMI), and the location and source of maximum injury.

Procedures: SURVEYFREQ and SURVEYLOGISTIC procedures from SAS (Release 9.4 2020) were used in this study, which are designed specifically for the analysis of complex survey data. The SURVEYFREQ procedure uses the Rao-Scott chi-square test of association for contingency tables, which take into account the sampling design and adjust the observed and expected frequencies.

III. RESULTS

Effect of model year: Appendix A contains the number of weighted and unweighted non-ejected, lap-shoulder belted front-seat outboard occupants, 15+ years old in 1989+ MY vehicles with airbag deployment. The data reported in this study is based on weighted data. The data was analysed by model year groups. For exposed occupants, there were 2,728,355 in the 1989-1998 MY group, 2,005,179 in the 1999-2005 MY group and 1,124,179 in the 2006+ MY group. The corresponding numbers of serious-to-fatally injured (MAIS3+F) front seat occupants were 56,356, 52,327, and 31,522.

The NASS-CDS data were queried by crash severity. The crash severity was categorised into three delta V ranges: <32, 32-64, and >64 km/h (Figure 1), with the 32 to 64 km/h range selected to represent the range used in present regulatory testing. The results show a decreasing trend in the rate of serious to fatal injuries for belted front occupants in frontal crashes with delta Vs greater than 64 km/h, while the much lower rates for less severe crashes remained about the same.

At delta Vs of 64 km/h or greater, the rate of serious-to-fatal injury for was 74.1% (1989-1998 MY), 62.0% (1999-2005 MY), and 52.0% (2006-2016 MY). There was a reduction of injury rate by 12.1% (95% confidence interval [CI]: -8.1% - 32.4%) between vehicles in MY 1989-1998 and those from MY 1999-2005. Similarly, occupants in 2006 or later MY vehicles also had a 10.0% (95% CI: -29.4% - 49.4%) reduction in injury rate compared with occupants in 1999 to 2005 MY vehicles. Vehicle crashes at that high level of crash severity were uncommon, accounting for less than 1% of all crashes (Table A1).

The rate of serious-to-fatal injury was 7.2% in the 1989-98 MY group, 6.9% in 1999-05 MY group, and 6.6% in the 2006+ MY group. There was a reduction of injury rate by 0.56% (95% CI: -3.63% - 4.14%) between vehicles in MY 1989-1998 and those from MY 1999-2005 and by 0.31% (95% CI: -4.63% - 5.25%) between 2006 or later MY vehicles and those from MY 1999-2005. Although there are observable reductions in the injury rate among newer model vehicles, these changes were not statistically significant as shown by the wide confidence interval. Injury statistics estimated from very limited data corresponds to a large degree of variance. Thus, even though the results do suggest a continued improvement in occupant protection in newer model vehicles, such reduction was not statistical significant. Further analysis using additional years of data may help confirm and validate the observed results.

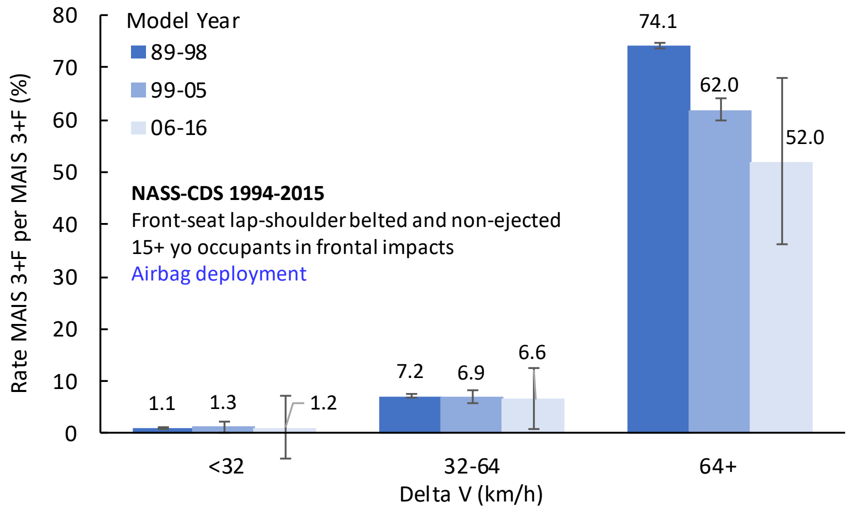

Fig. 1. Serious-to-fatal injury rate as a function of delta V and vehicle model year groups (NASS-CDS 1994-2015).

Effect of crash severity with modern airbags: Appendix A also contains the number of weighted and unweighted non-ejected, front-seat outboard occupants, 15+ years old in 2006+ MY vehicles with airbag deployment. Figure 2 shows the cumulative frequency by crash severity. The crash severity was categorised into the following ranges: <16, 16-<24, 24-<32, 32-<40, 40-<48, 48-<56, 56-<64, 64-<72, and 72+ km/h. Crashes with a delta V less than 24 km/h accounted for 52% of exposed occupants and 10% of serious-to-fatally injured occupants in tow-away crashes with airbag deployments.

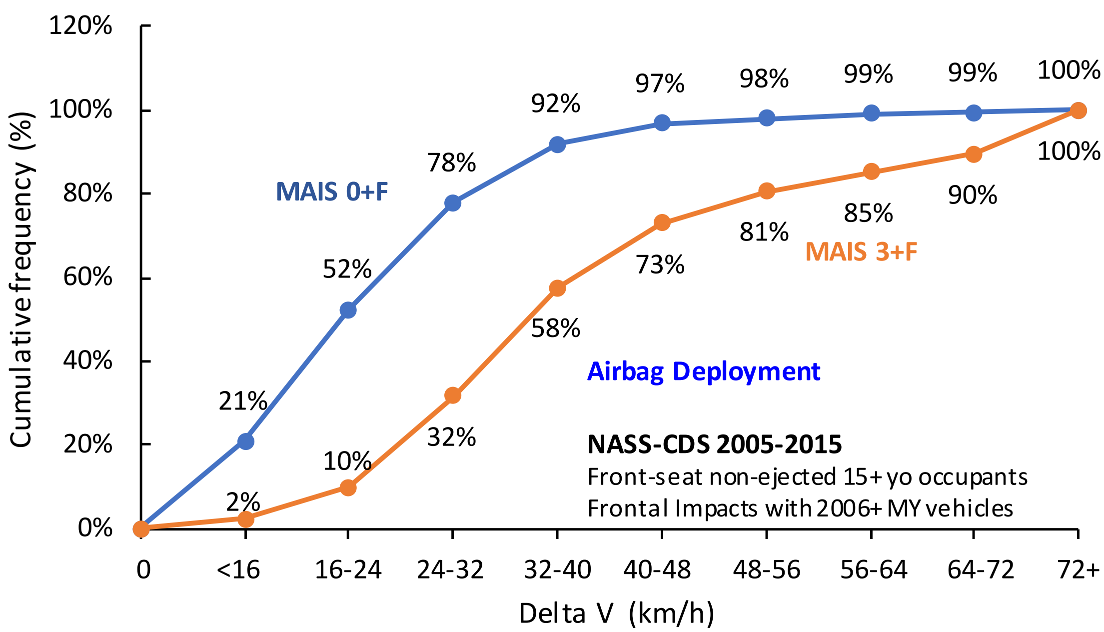

Fig. 2. Cumulative frequency of exposed (MAIS0+F) and serious-to-fatally (MAIS3+F) injured front-seat occupants in frontal impacts by crash severity.

Injury rate by belt use and crash severity with modern airbags: The injury rates were assessed by crash severity by dividing the number of serious-to-fatally injured occupants (MAIS3+F) with the number of exposed occupants (MAIS0+F). Figure 3 shows the rate of serious-to-fatally injured front-seat occupants by crash severity ranges and belt use. The injury rate increased with crash severity and was always higher for unbelted occupants.

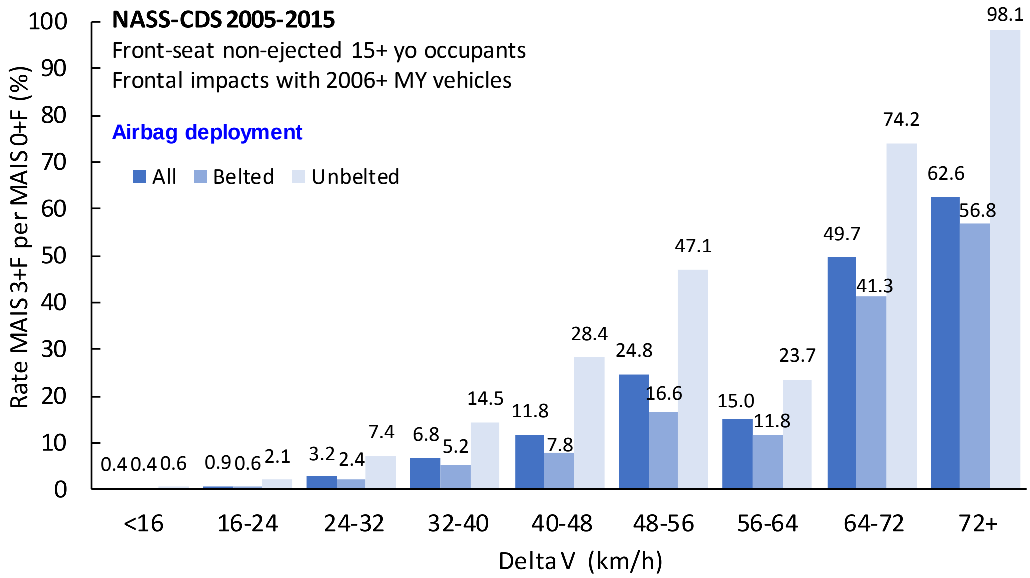

Fig. 3. Rate of serious-to-fatally injured front-seat occupants in frontal impacts.

Belt effectiveness with modern airbags: In this study, belt effectiveness was defined as the percent difference between the rate of MAIS3+F injuries in crashes with unbelted occupants compared to belted occupants. Figure 4 shows the belt effectiveness for injured front-seat occupants in frontal crashes with airbag deployments by crash severity. The delta V represents the median delta V for each crash severity range. Belt effectiveness for delta V less than 16 km/h was omitted due to a small sample size (< 10 unweighted cases, Appendix A). The effectiveness decreased with an increase in delta V. The effectiveness was 69.9% in the 16-24 km/h delta V range and 42.1% in delta Vs greater than 72+ km/h. A linear regression model was fitted through the results. The result suggests an apparent trend with decreasing belt effectiveness with increasing crash severity. This simple linear regression is only performed as a qualitative illustration of the suggested trend in the observed data. It is not a statistically optimised relationship, in that the belt effectiveness data, being estimated from sampling quantities, has inherent sampling variance which is not taken into account in the simple linear regression. Furthermore, belt effectiveness was assessed as the difference between the injury rates with unbelted and belted occupants divided by the injury rate with unbelted occupants and is thus a composite of two quantities, each subject to sampling variation. Thus, the variance of the belt effectiveness measures is not obvious and difficult to estimate. A formal derivation of the variance of the belt effectiveness is beyond the scope of the present analysis.

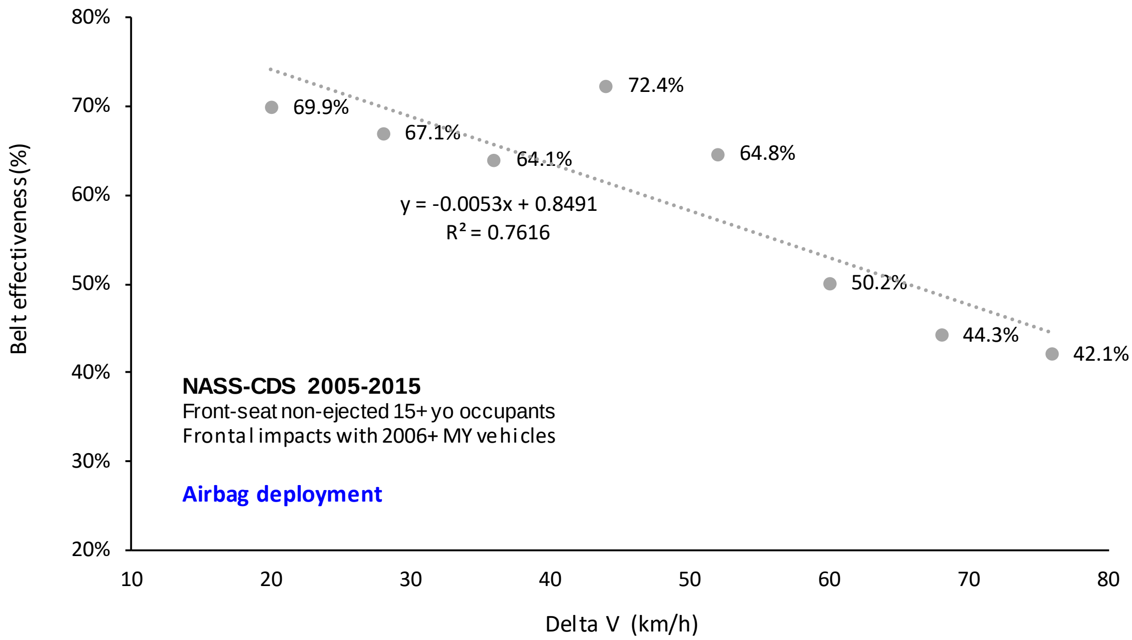

Fig. 4. Belt effectiveness by delta V for frontal impacts with airbag deployment in vehicles MY 2006 or newer involving non-ejected front occupants age 15 or older.

In-depth case review of fatalities with modern airbags: To better understand why lap-shoulder belted front seat occupants may be fatally injured with advanced restraints in a frontal crash, individual cases were reviewed. Appendix B summarises the cases. A total of 41 cases involving a front outboard occupant age 15 or older were identified that involved a frontal collision, with no rollover or ejection, resulting in fatality (MAIS6+F) despite seat belt use and air bag deployment. These cases were evaluated individually using methods similar to those reported by Bean et al. [5]. Information such as delta V, collision characteristics, occupant age and body mass index (BMI), and the location and source of maximum injury was considered. Three of these cases involved a medical event for the driver which resulted in the crash; one case did not appear to involve any fatality upon review, despite the indication of least one of the coding variables.

Of the remaining 37 cases, 15 (40.5%) involved a delta V over 64 km/h. Eleven cases (29.7%) were considered severe crashes due to narrow offset impacts, consistent with the categorisation of Bean et al. Seven (18.9%) involved an impact with a tall, narrow object such as a tree or utility pole. Nine (24.3%) involved multiple impacts. Only one was reported as an oblique impact.

TABLE I

Summary of crash and occupant characteristics identified in frontal crashes involving fatality of a belted front occupant of a MY 2006+ vehicle, based on coded information in NASS-CDS cases.

		Number	Percentage (%)
Sample size		37**	
Crash Factor*			
Severity	delta V ≥ 64 km/h	15	40.5
Configuration	Narrow offset	11	29.7
	Oblique Impact	1	2.7
	Tall, Narrow Object	7	18.9
Other (includes multiple impacts)		9	24.3
Occupant Factor*			
Age	≥ 65 years	12	32.4
	≥ 75 years	7	18.9
Obesity (BMI)	≥ 30 kg/m^2	14	37.8
	≥ 40 kg/m^2	2	5.4

*More than one factor may apply to a decedent

** Excluding 3 cases with medical events and 1 case with incorrect coding in police report

Twelve (32.4%) of the remaining 37 decedents were age 65 years or older. Bean et al. used 75 years as an age-related vulnerability threshold. In the present study, seven (18.9%) of the decedents were 75 or older. Fourteen decedents (37.8%) had a BMI over 30 kg/m^2, which is classified as obese according to the U.S. Centers for Disease Control and Prevention (CDC), with two of those having BMI over 40 kg/m^2, which is considered Class 3 obesity.

In 12 decedents (32.4%), the thorax was the most severely injured area, and the injury source for these cases was mostly coded as steering wheel, with one case coded as seat belt and one as the instrument panel. In 11 decedents (29.7%), the head was identified as the most severely injured area of the body. The coded sources of fatal head injuries varied widely and included the front header, A-pillar, roof rail, B-pillar, steering wheel, center instrument panel, or contact with the striking vehicle. In two cases, the neck or cervical spine sustained the most severe injury, one coded as due to the seat belt and another coded as due to the seat back support. In two cases, the abdomen sustained the most severe injury, one coded as due to interaction with the steering wheel and another coded as due to the seat belt. In three cases, the lower extremity or pelvis was the most severely injured area, coded as due to interaction with the lower instrument panel. In six cases, the fatal injury was unspecified or unknown; of these, three decedents were age 76, 77, and 90; one case involved a post-crash vehicle fire; and two cases had no injury information.

IV. Discussion

Frontal crashes are the most common type of crashes resulting in serious-to-fatal injuries. As a result, focus has been placed on frontal occupant safety including countermeasure development. Although the effectiveness of frontal airbags as a supplemental restraint system to reduce injury potential has been assessed since they have been required by law [1,6,7], legislative changes and design refinements to frontal airbag systems have occurred over time. Advanced airbags were phased into the U.S. market between model years 2003 and 2007. After 2007, all passenger and light truck vehicles sold in the U.S. included front outboard lap and shoulder belts with pretensioners and load limiters.

In this study, NASS-CDS data were analysed for outboard front-seat occupants involved in frontal crashes. The data were first analysed by three model year groupings, with the 2006+ MY grouping selected to contain advanced restraint technologies. The results support that these technologies have been effective at reducing rates of serious-to-fatal injuries in high severity frontal crashes (delta V > 64 km/h, Figure 1). The rate of serious-to-fatal injuries for frontal impacts with delta V > 64 km/h was nearly 30% lower for MY 2006+ vehicles than for MY 1989-1998 vehicles. Engineering design involves optimisation of many simultaneous factors, and it is notable that there was no increase in injury rates for less severe frontal crashes with the introduction of advanced frontal airbags, lap and shoulder belt pretensioners, and load limiters.

The data was then queried for model year 2006 onward to focus on injury rates in vehicles with advanced restraint systems, namely, after the majority of vehicles on U.S. roads had advanced airbags. The results indicated that more than half of tow-away frontal crashes with airbag deployment involved a delta V less than 24 km/h. In comparison, Yaek et al. [8] reported that more than 70% of frontal collisions involved a delta V less than 24 km/h; however, that study included non-airbag deployment cases.

Data from the present study suggest that more than half of front-seat occupants involved in a tow-away frontal crash were seriously-to-fatally injured at a delta V greater than 40 km/h. In the U.S., FMVSS 208 testing is conducted at 48 km/h, and NCAP testing is conducted at 56 km/h. The present data suggests that 98% of all tow-away frontal collisions involving advanced airbag deployments occurred at delta Vs below 56 km/h. Therefore, the speeds currently used in regulatory and consumer crash testing in the U.S. encompass the vast majority of frontal collisions.

In December of 2015 [9], the NHTSA released a request for comment (RFC) pertaining to a proposed modification of the NCAP program, to implement a 90 km/h frontal oblique collision using an oblique moving deformable barrier (OMDB) weighing 2,486 kg (5,480 lb) and THOR 50th percentile male ATDs. The results of the present NASS-CDS analysis suggest that a 90 km/h delta V frontal collision represents a delta V greater than 99% of all frontal collisions with advanced airbag deployment. The present analysis did not select only for small overlap or oblique crash modalities. The effect of mass ratio between the striking and struck object was not specifically analysed; the OMDB in the proposed NCAP modification simulates a heavy adverse object.

Overall, the present results showed that serious-to-fatal injury rates increased with crash severity. The severe-to-fatal injury rates were near 100% in frontal crashes with delta V > 72 km/h. These findings are consistent with a recent study by Kim et al. [10] that subjected identical vehicles to moderate overlap frontal collisions at delta Vs of 72.9 km/h, 87.7 km/h, and 99.0 km/h. At higher speeds, compartment intrusion and injury metrics all increased. Earlier published studies not focusing on advanced airbags showed that serious injuries were likely to occur at delta Vs above about 60 km/h, despite airbag deployment and belt use [11, 12]. Viano and Parenteau [13] reported that the rate of serious injury (MAIS3+F) for a belted front occupant with front airbag deployment in 1997-2007 model year vehicles was approximately 75% in a frontal collision with delta V of 64-72 km/h. Of note, all of these prior studies involved vehicle models produced before the complete rollout of advanced restraint technologies. In the present study investigating vehicles produced after the rollout of advanced restraint technologies, the rate of serious-to-fatal injury (MAIS3+F) was 41.3 ± 12.2% at delta Vs of 64-72 km/h. The lower rate of serious-to-fatal injuries in more modern vehicles may be attributed at least in part to advanced restraint technologies.

The data from this study also showed that more than 10% of front-seat occupants sustained a serious-to-fatal injury at delta Vs less than 24 km/h. Viano and Parenteau [13] reviewed NASS-CDS electronic cases involving severely injured front-seat occupants involved in frontal crashes with a delta V less than 24 km/h. They noted that most crashes at these speeds that met the inclusion criteria for NASS CDS involved multiple impacts; additional impacts may have occurred after airbag deployment, and/or occupants may have been out-of-position at the time of an injurious impact. That study did not examine occupant factors that may have increased injury rate.

The results of this study continue to support that lap-shoulder belts are effective in reducing injury rates, consistent with prior work [13,14,15]. Despite this fact, lap and shoulder belts, even with pretensioners and load limiters, do not prevent all serious injuries. Belt effectiveness decreases with increasing crash severity. In the present study, the rate of serious-to-fatal injuries for front seat occupants was 70% lower for belted vs. unbelted occupants for frontal crashes with delta Vs between 16 and 24 km/h. The rate of serious-to-fatal injuries in front seat occupants was 44% lower for belted vs. unbelted occupants for frontal crashes with delta Vs between 64 and 72 km/h.

To better understand why belted, front-seat occupants may be fatally injured in frontal crashes despite advanced airbags and seatbelts in modern vehicles (MY 2006+), individual cases were reviewed, using a method similar to that described by Bean et al. [5]. Three occupants were coded as having a medical event that resulted in their death rather than the crash; the cases were excluded in the analysis since medical events should not be considered when evaluating the effectiveness of injury mitigation technology in a fatal crash. Another case was excluded due to miscoding in the police report. Evaluation of the remaining 37 occupants in the present study showed that some of the crash conditions and occupant characteristics may have influenced the injury outcome despite use of advanced restraint systems, consistent with the earlier study by Bean et al. [5].

Unlike the findings of Bean et al. [5], the individual case review identified only one case involving an oblique impact. The effect of over-ride and under-ride was not analyzed. The case review also did not include any cases with a heavy vehicle as the adverse vehicle.

Bean et al. [5] and others have noted occupant contact with the A-pillar in small-overlap frontal crashes despite airbag deployment, with and without substantial intrusion [16,17]. They elucidated differences between small-overlap and large overlap frontal crashes using crash and vehicle crush characteristics from cases in the NASS-CDS and CIREN databases. They reported an increased incidence of head, chest, spine, and hip/pelvis injuries in small-overlap compared to large-overlap frontal crashes. The authors suggested that altered vehicle kinematics compared to large overlap frontal impacts and resulting altered occupant trajectories relative to the vehicle interior, may help explain the increased injury rate.

This study further supports prior research that a particularly dangerous crash condition occurs when a vehicle strikes a narrow object such as a tree or pole at a location between its longitudinal frame rails, a "between-rails collision." Under these crash conditions, even advanced restraint technologies may not be able to prevent serious injury. Frontal, between-rails collisions are associated with an increased risk of injury compared to a full frontal or an offset frontal collision of similar delta V [18,19]. Scullion et al. [20] estimated that a between-rails frontal impact had a risk of AIS3+ injury that was 2.4 times higher than a full frontal or offset frontal impact. A study based on the Total HUman Model for Safety (THUMS) [21] found that, with frontal airbag deployment, the chest deflection of the driver was approximately 20-25% higher in a between-rails collision with delta V of 64 km/h compared to a full frontal or offset frontal collision.

Occupant vulnerability was evaluated by age and obesity in the case review. Information regarding any other specific pre-existing factors associated with occupant vulnerability was not available. Sixteen of 37 fatally injured occupants were female (43.2%). About a third of the fatally injured occupants were 65 or older. Older occupants are more at risk of injury than young occupants because of their fragility [22,23] and decreases in muscle and bone strength [24]. In this study, about a third had BMIs greater than 30 kg/m2; this is similar to the U.S. population in general [25]. Obese occupants are at higher risk of mortality from serious blunt trauma injuries [26, 27]. Only 4 of the 14 cases involving death to obese occupants had delta Vs above 64 km/h (28.5%); by comparison, 15 of 37 cases in the total sample (40.5%) involved delta Vs above 64 km/h.

In particular, older occupants have higher risk for serious chest injuries [28,29]. Older occupants have a lower thoracic injury threshold and sustain more rib fractures than younger occupants [30-32]. In this study, 12 of the front-seat occupant fatalities resulted from thoracic injury; ten of these involved delta Vs above 65 km/h; four involved occupants age 65 or older. The source of thoracic injury was mostly coded as the steering wheel. While an independent review of injury mechanisms was beyond the scope of this study, relationships between age, belt load, and risk of rib fractures developed by Foret-Bruno et al. [30-31] and others, injury patterns demonstrated by Duma et al. [33] and others in frontal sled tests, and computer modeling results [21], support that serious-to-fatal thoracic injuries in older occupants may more often be due to interaction with the shoulder belt rather than the steering wheel.

The results of this study indicate that development in restraint technologies over the last 20 years has resulted in improved supplemental occupant protection in frontal collisions, especially at higher severities. It is clearly essential that occupants continue to properly utilise the lap and shoulder belt. Nevertheless, the effectiveness of advanced restraint technologies decreases with crash severity, and serious-to-fatal injuries may occur.

In this study, NASS-CDS data were analysed. CDS data remains an important resource for vehicle safety analysis and provides insights into vehicle safety trends and issues. Nonetheless, the use of the CDS has its limitations. First and foremost, the sampling in the CDS is limited and only involves the collection of fewer than 5000 crashes of any severity each year. Because of the limited sample size in high severity crashes, it is difficult to have precise estimates of injury rate and seat belt effectiveness at high delta Vs.

V. CONCLUSIONS

Most prior studies on frontal airbag effectiveness using field accident data have been conducted including older restraint system designs. Here, the NASS-CDS field accident dataset was used to assess advanced airbag performance. Lap and shoulder belts supplemented by advanced frontal airbags are effective in reducing front occupant injury rate in frontal crashes. However, their effectiveness decreased as delta V increased, particularly above 64 km/h. A review of individual cases involving a front-seat occupant with fatality provided additional insight by categorising contributing factors such as severe crash conditions or a frail front occupant.

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VII. APPENDICES

Appendix A: Number of exposed (MAIS 0+F) and serious-to-fatally (MAIS 3+F) injured front-seat occupants involved in frontal crashes with airbag deployments.

Table A1: Exposed (MAIS0+F) and serious-to-fatally (MAIS3+F) injured front-seat occupants in frontal impacts with airbag deployments by model year rnages and crash severity.

Delta V	**MAIS 0+F**			**MAIS 3+F**			**Rate MAIS 3+F (%)**		**95% Confidence**	
(km/h)	**Unwgt**	**wgt**	**se**	**Unwgt**	**wgt**	**se**	**wgt**	**se**	**Limits (%)**	
	MY 1989-1998			MY 1989-1998			MY 1989-1998			
<32	4,562	2,393,731	240,514	224	26,353	4,090	1.1	0.14	0.80	1.40
32-64	1,577	325,791	32,094	342	23,456	2,847	7.2	1.1	4.8	9.62
64+	125	8,833	1,749	82	6,547	1,434	74.1	6.1	61.11	87.14
Total	6,264	2,728,355	253,981	648	56,356	7,488				
	MY 1999-2005			MY 1999-2005			MY 1999-2005			
<32	4,708	1,633,668	128,520	205	20,502	4,892	1.3	0.27	0.68	1.8
32-64	1,671	360,565	52,549	352	25,040	3,981	6.9	1.2	4.3	9.6
64+	156	10,947	1,725	109	6,785	1,062	62.0	5.8	49.6	74.3
Total	6,535	2,005,179	148,689	666	52,327	8,438				
	MY 2006+			MY 2006+			MY 2006+			
<32	2,444	874,504	89,153	87	10,171	3,601	1.2	0.47	0.16	2.2
32-64	935	239,124	31,813	135	15,867	5,494	6.6	2.0	2.4	10.9
64+	99	10,552	2,807	55	5,484	2,255	52.0	15.9	18.1	85.9
Total	3,478	1,124,179	113,552	277	31,522	5,525				

Table A2: Exposed (MAIS0+F) and serious-to-fatally (MAIS3+F) injured front-seat occupants in frontal impacts with advanced airbag deployments (MY 2006+) by crash severity and belt use.

Delta V	MAIS 0+F			MAIS 3+F			Rate MAIS 3+F (%)		95% Confidence	
(km/h)	Unwgt	wgt	se	Unwgt	wgt	se	wgt	se	Limits	
Front-seat occupants with airbag deployment										
<16	668	285,202	47,472	16	1,177	543	0.413	0.188	0.01	0.81
16-24	1,235	429,555	34,948	51	3,811	1,255	0.887	0.297	0.25	1.52
24-32	1,023	346,393	42,669	79	11,019	3,171	3.18	0.90	1.27	5.10
32-40	628	192,738	20,326	80	13,151	4,092	6.82	1.91	2.76	10.89
40-48	312	64,898	13,368	69	7,679	2,479	11.83	4.48	2.28	21.39
48-56	165	15,909	3,196	51	3,947	1,073	24.81	7.10	9.67	39.95
56-64	109	15,128	4,383	42	2,275	505	15.04	4.87	4.67	25.41
64-72	49	4,403	1,174	25	2,188	579	49.70	10.18	27.99	71.41
72+	88	8,469	2,491	61	5,303	2,055	62.62	16.32	27.84	97.40
Total	4,277	1,362,695	119,918	474	50,551	509				
[illegible]										
<16	564	233,411	33,793	12	903	440	0.387	0.177	0.01	0.76
16-24	1,035	349,764	45,565	26	2,212	662	0.633	0.215	0.17	1.09
24-32	845	291,328	37,742	49	7,055	3,431	2.42	1.26	0.00	5.11
32-40	500	163,986	21,155	46	8,529	4,284	5.20	2.26	0.37	10.03
40-48	243	52,256	11,732	40	4,090	1,034	7.83	2.89	1.68	13.98
48-56	114	11,425	2,877	24	1,896	783	16.59	7.47	0.68	32.50
56-64	78	11,457	3,798	25	1,352	490	11.80	3.63	4.06	19.54
64-72	32	3,280	814	13	1,355	469	41.32	12.22	15.28	67.36
72+	67	7,273	2,485	42	4,129	2,174	56.78	20.13	13.87	99.69
Total	3,478	1,124,179	113,552	277	31,522	5,525				
Unbelted front-seat occupantswith airbag deployment										
<16	99	42,409	12,534	3	255	219	0.600	0.537	0.00	1.75
16-24	191	71,657	16,761	23	1,507	672	2.10	0.920	0.14	4.07
24-32	172	53,915	15,036	30	3,964	1,215	7.35	2.74	1.52	13.19
32-40	126	28,191	6,900	33	4,083	1,376	14.48	5.22	3.36	25.61
40-48	67	12,562	5,494	28	3,562	2,011	28.35	17.26	0.00	65.15
48-56	49	4,336	1,439	26	2,041	875	47.07	10.67	24.34	69.81
56-64	30	3,602	1,070	16	853	319	23.69	11.52	0.00	48.25
64-72	17	1,124	501	12	833	359	74.16	12.46	47.60	100.00
72+	21	1,196	643	19	1,174	643	98.13	1.44	95.07	100.00
Total	772	218,992	47,771	190	18,272	3,751				

Grey: Unweighted cases < 10

Appendix B: Individual NASS-CDS cases involving a fatally injured front-seat occupant of a 2006+ MY vehicle involved in a frontal crash with frontal airbag deployment.

Table B1: Vehicle/crash summary

	Case				Factors: Occupant			Factors: Crash/Vehicle			Vehicle					
#	Case wgt	Year	PSU	Case ID	Age	Obesity	Severity	Corner/ Oblique	Tall, Narrow	Other	MY	Make	Model	CDC	Delta V (km/h)	Crash Description
1	8.17	2006	9	59		x				x	2006	Ford	Escape	92FYEW04, 99F99999	61	Head-on collision with 1997 Chevrolet Malibu; rotated 90 degrees and contacted a metal guardrail
2	19.39	2006	41	132	x					x	2006	Toyota	Highlander	06BDEW02, 12FDEW01	17, 22	Rear impact from 1990 Ford E-150 van followed by frontal impact into 2002 Ford Explorer/Bronco
3	34.46	2006	75	22			x		x		2006	Mitsubishi	Eclipse	12FZAW06	105	struck a tree
4	118.769	2007	5	21			x			x	2006	Honda	Pilot	12FDEW05, 99F99999	67	Narrow offset with 2004 Honda Accord , then head-on with 2001 Nissan Maxima
5	48.80	2008	2	143	x	x	x				2007	Hyundai	Elantra	11FDEW04	81	Head-on collision with 1998 Ford Ranger
6	38.93	2009	73	74			x				2008	Honda	Civic	12FDAW06	99	Head-on collision with 2007 Dodge Charger
7	21.11	2009	73	84		x	x				2007	Chevrolet	Malibu	11FLAE09	31	Front left struck front left of 2000 Dodge Durango
8	7.03	2009	82	10	x	x				x	2007	Honda	CRV	12FYEW03, 12F99999	45	Frontal collision with 2002 Toyota Highlander ; rotated counter-clockwise then continued traveling and the front struck a wooden planter barrier
9	9.94	2010	49	170			x				2007	Chevrolet	Tahoe	12FDEW05	83	Struck concrete bridge support
10	20.28	2010	41	170	x						2007	Cadillac	CTS	12FDEW02, 01RBEW01	40, 6	Front contacted right side of 2007 Toyota Camry, which rotated and contacted right rear
11	25.17	2011	4	95	x						2006	Hyundai	Sonata	12FDEW05	61	Struck a concrete bridge support
12	163.69	2011	48	96	x				x		2007	Nissan	Altima	12FZEN03, 12FREE05	45	Struck a timber utility pole, continued and struck a tree
13	12.26	2011	49	139		x		x			2008	Ford	Focus	11FLAE09	55	Struck concrete pillar overpass support
14	28.99	2012	6	73			x				2011	Volkswagen	Jetta	12FLEE05	19	Front left struck a pole then contacted back end of parked, unknown vehicle
15	18.64	2012	9	20	x						2010	Ford	Edge	71FDEW03, 09LZEW02	21, 7	Struck the right side of a Ford E-Series van, which rotated and struck the left side
16	4.90	2012	49	28			x				2007	Chevrolet	Corvette	01FDEW01	18	Struck a concrete traffic barrier
17	82.21	2012	13	60		x	x				2007	Ford	Focus	12FLEE08	30	Struck front right of 1986 Chevrolet pickup truck
18	37.35	2012	43	140			x				2009	Toyota	Corolla	12FDAW06	138	Head-on collision with 2012 Ford Windstar
19	44.49	2012	43	194		x	x				2007	Lexus	ES	11FDEW04	90	Head-on collision with 2000 Cadillac Eldorado
20	12.21	2012	49	63		x	x		x	x	2007	Honda	Accord	12FYEW04	64	Contacted a speed limit sign then struck a large tree
21	38.44	2013	43	38		x	x			x	2006	Acura	TL	12FZAW06, 12F99999, 00TYDW04, 12FRWN01	147	Impacting the right curb then a telephone junction box, then impacted a tree, rolling up the tree so that the roof impacted the same tree, then rotated around the tree and came to rest on the roadside
22	163.45	2013	48	10		x	x				2007	Chevrolet	Pickup	12FLEE09	19	Front left struck 2005 Jeep Cherokee
23	163.45	2013	48	76			x		x		2013	Kia	Soul	12FDEW06	140	Struck concrete bridge pillar then caught fire
24	10.43	2013	49	7		x	x				2010	Volkswagen	Passat	72FYAW06	41	Struck a concrete bridge support
25	9.15	2013	49	85		x	x				2007	Mazda	CX-7	12FDEW05	92	Head-on collision with a 2003 Dodge Dakota
26	9.15	2013	49	85			x				2007	Mazda	CX-7	12FDEW05	92	Head-on collision with a 2003 Dodge Dakota
27	5.22	2013	49	105			x				2007	Toyota	Corolla	12FYEW05	89	Head-on collision with 2002 Chevrolet S10 Blazer
28	58.70	2013	78	93	x		x			x	2010	Buick	Lacrosse	12FDEW03, 12F99999, 12FDEW01, 12RDES01, 12LDES01, 12FDGS09	37	Struck a chain link fence, a delineator post, and a rock embankment (damage to left front)
29	230.00	2014	45	71	x	x					2007	Kia	Amanti	12FDEW01	27	Head-on collision with a 2010 Mazda 3
30	167.65	2014	48	75		x					2007	Ford	Ranger	12FDEW02	46	Struck rear of 2011 Ford Escape
31	134.01	2014	76	97			x				2009	Hyundai	Accent	12FYAW06	105	head-on collision
32	197.90	2015	11	60	x				x		2013	Volkswagen	Passat	12FDEW03	68	struck a 94 cm tree
33	21.99	2015	12	45					x		2008	Chevrolet	Impala	12FCEN04	56	struck a large tree
34	32.41	2015	73	35	x				x		2012	Toyota	Rav-4	12FCEN03	39	struck a tree
35	43.76	2015	75	22						x	2013	Toyota	Prius	12LZES01, 12FLWN03, 12FLEN99, 00TYLN02, 12RFES01, 12RZES01, 12FDEW03	63	Impacted on the left side by a 2012 Subaru Outback; departed left side of road and left front wheel impacted center median divider; as it crossed the median, it impacted a sign post, which broke and impacted the windshield; also impacted a delineator post with the front and then the right plane. Then crossed over into oncoming travel lane and impacted a 2009 Subaru Outback head-on
36	36.61	2015	75	60			x			x	2007	Jeep	Cherokee	12FRAE08, 09L99999, 12FRWN03, 12F99999, 12FRWN09	19	Departed right side of the road onto an island; struck a delineator; struck the curb with its right front wheel; struck the island's curb with its right rear wheel; struck a traffic light pole; rotated and contacted a delineator post with its left side
37	75.08	2015	78	8	x		x				2006	Ford	Fusion	12FYEW06	57	Head-on collision with 2006 Ford F-series pickup truck
	Medical event reported as causing the crash															
38	37.37	2010	75	70						x	2006	Subaru	Impreza	12FDEW02	31	Went down an embankment, and struck a boulder
39	31.57	2011	43	78						x	2006	Dodge	Stratus	12FZEN03	63	Struck a tree
40	77.83	2014	75	57	x					x	2008	Chevrolet	Malibu	12FLEW02, 12F99999, 12F99999, 12F99999, 00TPRN02, 12FREE09, 12FLWN03, 20UFDW02, 12F99999	29	Struck a sign-post, then a mound of dirt and large rocks; then struck a sign post which broke and struck the top of the vehicle; then re-entered the roadway for 0.5 miles, then departed the right side and impacted a guardrail, then re-entered the roadway and impacted the left side of a 2000 Toyota Avalon
	Non-fatally injured - incorrectly listed as K in police report															
41	7.03	2009	82	89							2007	Toyota	Corolla	12FLEE09	10	Concrete jersey barrier

Table B2: Occupant Summary

Case				Front-seat occupant						Fatal Injury					Other notable injuries	
Case wgt	Year	PSU	Case ID	Loc	Sex	Age (yrs)	Height (cm)	Weight (kg)	BMI	Body Region	Coded Source	MAIS	Injury Description	# AIS		
8.17	2006	9	59	D	M	35	157	88	35.7	head	near side roof rail	6	brain stem laceration	17	aortic laceration	
19.39	2006	41	132	D	M	73	180	83	25.6	neck	seat back support	5	cervical cord contusion	8		
34.46	2006	75	22	P	M	27	193	86	23.1	thorax	right instrument panel and below	5	heart laceration/ perforation	1		
118.769	2007	5	21	D	F	48	175	87	28.4	thorax	steering wheel	6	heart avulsion	33	aortic laceration	brain swelling
48.80	2008	2	143	D	M	66	186	105	30.4	thorax	steering wheel	5	multiple rib fractures with hemopneumothorax	22	aortic laceration	liver laceration
38.93	2009	73	74	P	F	25	163	54	20.3	abdomen	seat belt	4	abdominal aorta tear	22	iliac artery tear	cerebrum injury
21.11	2009	73	84	D	F	40	178	142	44.8	head	other front of vehicle	5	brain stem injury involving hemorrhage	18	intraventricular hemorrhage	subarachnoid hemorrhage
7.03	2009	82	10	D	F	65	180	116	35.8	lower ext	lower instrument panel	4	amputation above knee	33	diaphragm rupture with herniation	massive stomach laceration
9.94	2010	49	170	D	M	29	185	77	22.5	thorax	steering wheel	6	heart laceration/ perforation	15	multiple rib fractures	hemothorax
20.28	2010	41	170	D	F	78	157	69	28.0	abdomen	steering wheel	4	liver laceration	16		
25.17	2011	4	95	D	F	73	173	86	28.7	thorax	steering wheel	3	rib fractures	22	lung contusion	
163.69	2011	48	96	D	F	75	152	54	23.4	head	left B-pillar	3	cerebral hematoma	21	bilateral hemothorax	lumbar spine burst fracture
12.26	2011	49	139	D	M	35	170	93	32.2	head	left A-pillar	6	brain stem laceration	33	heart laceration	lung laceration
28.99	2012	6	73	D	F	22	157	50	20.3	head	left roof rail	4	brain edema	15	liver laceration	lower extremity fractures
18.64	2012	9	20	P	F	77	-	-								
4.90	2012	49	28	D	M	33	-	-								
82.21	2012	13	60	D	M	37	175	120	39.2	head	exterior of other vehicle	4	basal skull fracture	37	multiple rib fractures	open femur fracture, pelvic fracture
37.35	2012	43	140	D	F	28	160	59	23.0	thorax	steering wheel	2	sternum fracture	11	lower extremity fractures	
44.49	2012	43	194	D	F	55	173	102	34.1	thorax	seat belt	3	thoracic injury not specified	16	left upper and bilateral lower extremity fractures	
12.21	2012	49	63	D	F	67	155	62	25.8	head	steering wheel	5	brain stem injury involving hemorrhage	28	mesentary laceration	diaphragm rupture with herniation
38.44	2013	43	38	D	M	43	188	114	32.3	head	front header	3	head injury not specified	12	hemopneumothorax	R forearm fracture
163.45	2013	48	10	D	M	57	185	127	37.1	pelvis	lower instrument panel	5	pelvic ring fracture	18	multiple rib fractures	upper and lower extremity fractures
163.45	2013	48	76	D	F	53	175	82	26.8	-	-	1		3	upper and lower extremity fractures	
10.43	2013	49	7	D	M	41	183	127	37.9	thorax	steering wheel	4	lung laceration	25	diaphragm rupture	upper and lower extremity fractures
9.15	2013	49	85	D	M	57	170	97	33.6	head	steering wheel	6	brain stem transsection	36	heart laceration	thoracic spine cord laceration
9.15	2013	49	85	P	F	48	-	-		head	right instrument panel	5	basilar artery laceration	26	skull base fracture, vault fracture	aortic laceration, sternum, lung, pelvic ring fx, etc.
5.22	2013	49	105	D	M	23	157	63	25.6	thorax	steering wheel	6	heart laceration/perforation	43	liver laceration	brain stem injury involving hemorrhage, spinal fractures, multiple rib fractures, upper and lower extremity fractures
58.70	2013	78	93	P	M	76	163	79	29.7							
230.00	2014	45	71	D	M	72	160	93	36.3	c-spine	seat belt	5	cord contusion, cervical spine	5		
167.65	2014	48	75	D	M	61	173	129	43.1	lower ext	lower instrument panel	5	proximal intertrochanteric femur fracture	17	pelvic ring, open comminuted tibia, fibula fractures	sternum, rib, lumbar spine transverse process fractures
134.01	2014	76	97	D	M	26	183	86	25.7	thorax	steering wheel	2	multiple rib fractures	3	unspecified cervical spine injury	
197.90	2015	11	60	D	F	76	155	64	26.6	thorax	steering wheel	3	multiple rib fractures, sternum fracture	19		
21.99	2015	12	45	D	M	28	185	96	28.0	head	center instrument panel	3	cerebral hematoma	18	intestinal contusions	
32.41	2015	73	35	D	M	79	188	86	24.3	thorax	steering wheel	3	hemopneumothorax	9	multiple rib fractures	upper extremity fracture
43.76	2015	75	22	D	M	-	-	73		head			head injury not specified			
36.61	2015	75	60	P												
75.08	2015	78	8	1	F	90	157	48	19.5							
Medical event reported as causing the crash																
37.37	2010	75	70	D	M	46	188	113	32.0		medical event					
31.57	2011	43	78	D	M	48	188	126	35.6		medical event					
77.83	2014	75	57	D	M	82	-	-			medical event					
Non-fatally injured - incorrectly listed as K in police report																
7.03	2009	82	89	D	M	26							(not fatal)			

D: Driver, P: Right-front passenger, F: Female, M: Male, BMI: Body mass index

2006-09-059 – 2006 Ford Escape

Head-on collision with 1997 Chevrolet Malibu (ΔV 61 km/h, PDOF 12 o'clock) then rotated 90 degrees and contacted a metal guardrail

35 y/o male driver; BMI 30.4 kg/m^2; MAIS6 head injury; source coded as near side roof rail; also aortic laceration

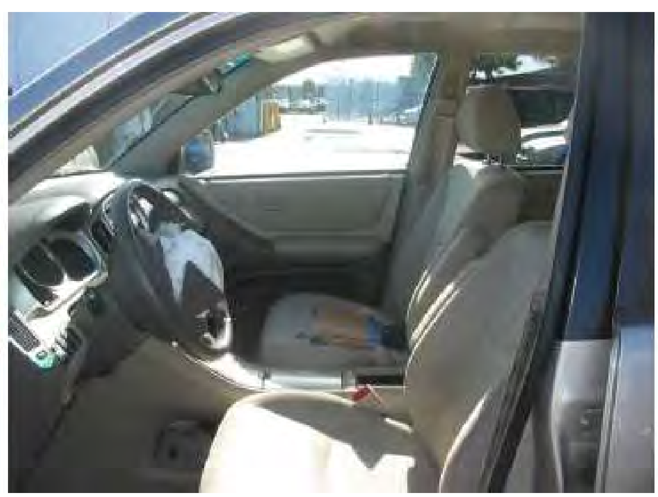
Vulnerable Occupant: BMI ≥ 30 kg/m^2; Other: Multiple Impacts

2006-41-132 – 2006 Toyota Highlander

Rear impact from 1990 Ford E-150 van (ΔV 17 km/h, PDOF 6 o'clock) followed by frontal impact into 2002 Ford Explorer/Bronco (ΔV 22 km/h, PDOF 12 o'clock)

73 y/o male driver, MAIS5 neck injury; source coded as seat back support

Vulnerable Occupant: Age ≥ 65

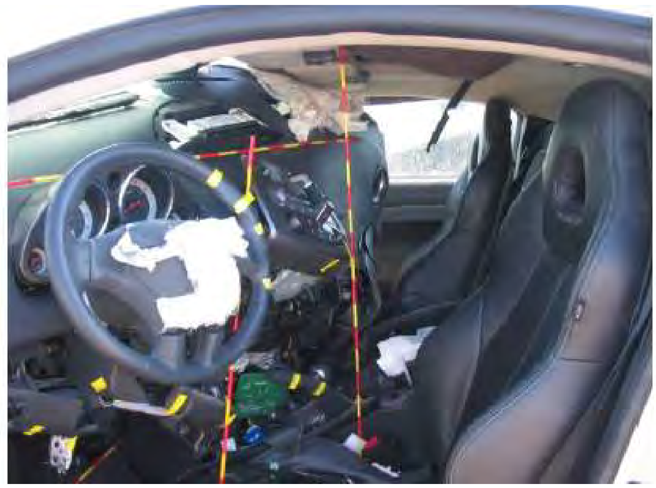


2006-75-022 – 2006 Mitsubishi Eclipse

Departed the left side of curved roadway and left wheels struck a curb; vehicle continued off the roadway and the front struck a tree (ΔV 105 km/h, PDOF 12 o'clock). The vehicle then rotated clockwise and came to rest in contact with the tree.

27 y/o male front passenger; MAIS5 injury to thorax; source coded as right instrument panel and below

Exceedingly Severe Crash: ΔV ≥ 64 km/h; Tall, Narrow Object: Tree



2007-05-021 – 2006 Honda Pilot

Front left of the vehicle was contacted by the front left of a 2004 Honda Accord (ΔV 67 km/h, PDOF 12 o'clock); the vehicle rotated counter-clockwise and contacted the front of a 2001 Nissan Maxima (ΔV and PDOF not coded).

48 y/o female driver; MAIS6 thoracic injury; source coded as steering wheel

Exceedingly Severe Crash: Narrow Offset, ΔV ≥ 64 km/h; Other: Multiple Impacts

2008-02-143 – 2007 Hyundai Elantra

Head-on collision with 1998 Ford Ranger (ΔV 81 km/h; PDOF 11 o'clock)

66 y/o male driver; BMI 30.4 kg/m^2; MAIS5 thorax injury; source coded as steering wheel

Exceedingly Severe Crash: ΔV ≥ 64 km/h; Vulnerable Occupant: Age ≥ 65, BMI ≥ 30 kg/m^2

2009-73-074 – 2008 Honda Civic

Head-on collision with 2007 Dodge Charger (ΔV 99 km/h; PDOF 12 o'clock);

25 y/o female driver; MAIS4 Abdomen injury; source coded as seat belt

Exceedingly Severe Crash: ΔV ≥ 64 km/h

2009-73-084 – 2007 Chevrolet Malibu

Front left of vehicle struck front left of 2000 Dodge Durango (ΔV 31 km/h; PDOF 11 o'clock)

40 y/o female driver; BMI 44.8 kg/m^2; AIS5 Head injury; source coded as other front of vehicle

Exceedingly Severe Crash: Narrow Offset; Vulnerable Occupant: BMI ≥ 30 kg/m^2

2009-82-010 – 2007 Honda CR-V

Frontal collision with 2002 Toyota Highlander (ΔV 45 km/h; PDOF 12 o'clock); rotated counter- clockwise then continued traveling and the front struck a wooden planter barrier (ΔV not coded; PDOF 12 o'clock)

65 y/o female driver; BMI 35.8 kg/m^2; MAIS4 Lower Extremity injury; source coded as lower instrument panel

Vulnerable Occupant: Age ≥ 65; BMI ≥ 30 kg/m^2; Other: Multiple Impacts

2009-82-089 – 2007 Toyota Corolla

Vehicle departed the left side of the roadway and impacted the center concrete Jersey barrier (ΔV 10 km/h; PDOF 12 o'clock)

26 y/o male driver; anthropometry not reported; MAIS2 Head injury; source coded as non-contact

Coding Error - Not Fatal

2010-41-170 – 2007 Cadillac CTS

Front of vehicle contacted right side of 2007 Toyota Camry (ΔV 40 km/h; PDOF 12 o'clock); the Camry rotated clockwise and the right front contacted the right rear of the CTS (ΔV 6 km/h; PDOF 1 o'clock)

78 y/o female driver; MAIS4 Abdomen injury; source coded as steering wheel

Vulnerable Occupant: Age ≥ 65

2010-49-170 – 2007 Chevrolet Tahoe

Vehicle departed the left side of the roadway and impacted a concrete bridge support (ΔV 83 km/h; PDOF 12 o'clock)

29 y/o male driver; MAIS6 Thorax injury; source coded as steering wheel

Exceedingly Severe Crash: ΔV ≥ 64 km/h

2010-75-070 – 2006 Subaru Impreza

Vehicle departed the right side of the road, went down an embankment, and struck a boulder (ΔV 31 km/h; PDOF 12 o'clock)

46 y/o male driver; BMI 32.0 kg/m^2; Fatality ruled as disease

Other: Medical Event; Vulnerable Occupant: BMI ≥ 30 kg/m^2

2011-04-095 – 2006 Hyundai Sonata

Vehicle departed the left side of the roadway and impacted a concrete bridge support (ΔV 61 km/h; PDOF 12 o'clock)

73 y/o female driver; MAIS3 Thorax injury; source coded as steering wheel

Vulnerable Occupant: Age ≥ 65

2011-43-078 – 2006 Dodge Stratus

Vehicle departed the left side of the road and struck a tree (ΔV 63 km/h; PDOF 12 o'clock)

48 y/o male driver; BMI 35.6 kg/m^2; Fatality ruled as disease

Other: Medical Event; Tall, Narrow Object; Vulnerable Occupant: BMI ≥ 30 kg/m^2

2011-48-096 – 2007 Nissan Altima

Vehicle departed the right side of the roadway and contacted a timber utility pole (ΔV not coded; PDOF 12 o'clock); vehicle continued and contacted a tree (ΔV 45 km/h; PDOF 12 o'clock);

75 y/o female driver; MAIS3 Head injury; source coded as left B-pillar

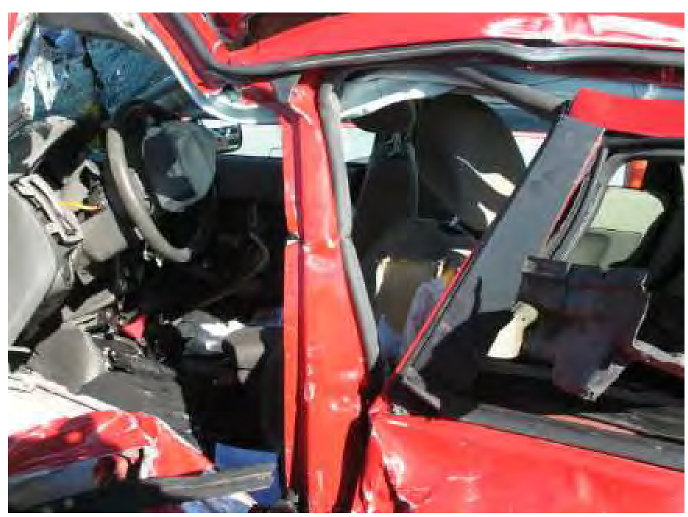
Vulnerable Occupant: Age ≥ 65; Tall, Narrow Object

2011-49-139 – 2008 Ford Focus

Vehicle departed the right side of the road and its front left corner struck a concrete pillar supporting a freeway overpass (ΔV 55 km/h; PDOF 11 o'clock)

35 y/o male driver; BMI 32.2 kg/m^2; MAIS6 Head injury; source coded as left A-pillar Corner and/or Oblique Impact;

Vulnerable Occupant: BMI ≥ 30 kg/m^2



2012-06-73 – 2011 Volkswagen Jetta

Front left of vehicle made contact with a pole then continued and contacted the back end of a parked, unknown vehicle (ΔV 19 km/h; PDOF 12 o'clock)

22 y/o female driver; MAIS4 Head injury; source coded as left roof rail

Exceedingly Severe Crash: Narrow Offset

2012-09-020 – 2010 Ford Edge

Vehicle struck the right side of a Ford E-Series van (ΔV 21 km/h; PDOF 2 o'clock); the van's right side then contacted the Edge's left side (ΔV 7 km/h; PDOF 3 o'clock)

77 y/o female passenger; anthropometry not reported; Injury and source not reported

Vulnerable Occupant: Age ≥ 65

2012-13-060 – 2007 Ford Focus

Front of vehicle made contact with front right side of approaching 1986 Chevrolet Pickup truck that rotated on a wet roadway (ΔV 30 km/h; PDOF 12 o'clock)

37 y/o male driver; BMI 39.2 kg/m^2; MAIS4 Head injury; source coded as exterior of other vehicle

Exceedingly Severe Crash: Narrow Offset; Vulnerable Occupant: BMI ≥ 30 kg/m^2


2012-43-140 – 2009 Toyota Corolla

Head-on collision with 2012 Ford Windstar (ΔV 138 km/h; PDOF 12 o'clock)

28 y/o female driver; MAIS2 Thorax injury; source coded as steering wheel

Exceedingly Severe Crash: ΔV ≥ 64 km/h


2012-43-194 – 2007 Lexus ES

Head-on collision with 2000 Cadillac Eldorado (ΔV 90 km/h; PDOF 11 o'clock)

55 y/o female driver; BMI 34.1 kg/m^2; MAIS3 Thorax injury; source coded as seat belt

Exceedingly Severe Crash: ΔV ≥ 64 km/h; Vulnerable Occupant: BMI ≥ 30 kg/m^2

2012-49-028 – 2007 Chevrolet Corvette

Vehicle began to rotate counter-clockwise and departed the left side of the roadway; the front of the vehicle struck the concrete traffic barrier (ΔV 138 km/h; PDOF 1 o'clock)

28 y/o female driver; MAIS2 Thorax injury; source coded as steering wheel

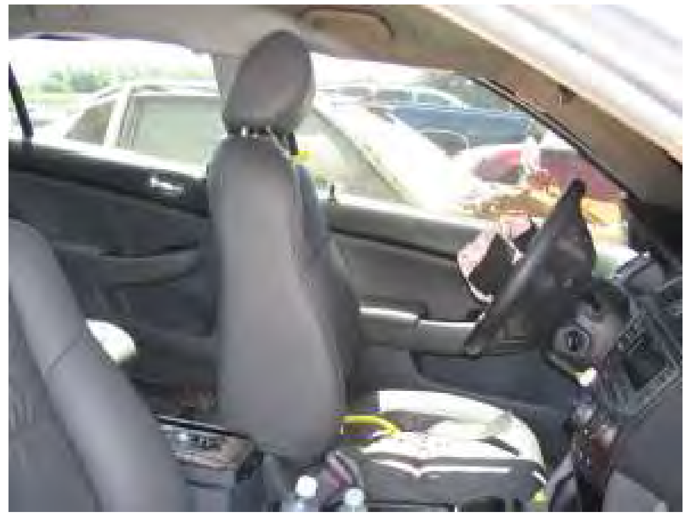
Exceedingly Severe Crash: ΔV ≥ 64 km/h

2012-49-063 – 2007 Honda Accord

Vehicle departed right side of roadway and contacted a speed limit sign (ΔV not reported; PDOF 12 o'clock), then continued approximately 50 meters and contacted a large tree (ΔV 64 km/h; PDOF 12 o'clock)

67 y/o female driver; MAIS5 Head injury; source coded as steering wheel

Exceedingly Severe Crash: ΔV ≥ 64 km/h, Narrow Offset; Vulnerable Occupant Age ≥ 65; Other: Multiple Impacts



2013-43-038 – 2006 Acura TL

Vehicle departed right side of the roadway, impacting the curb, then the front impacted a telephone junction box, then impacted a tree, rolling up the tree so that the roof impacted the same tree, then rotated around the tree and came to rest on the roadside (tree impact: ΔV 147 km/h; PDOF 12 o'clock)

43 y/o male driver; BMI 32.3 kg/m^2; MAIS3 Head, Thorax injury; source coded as front header

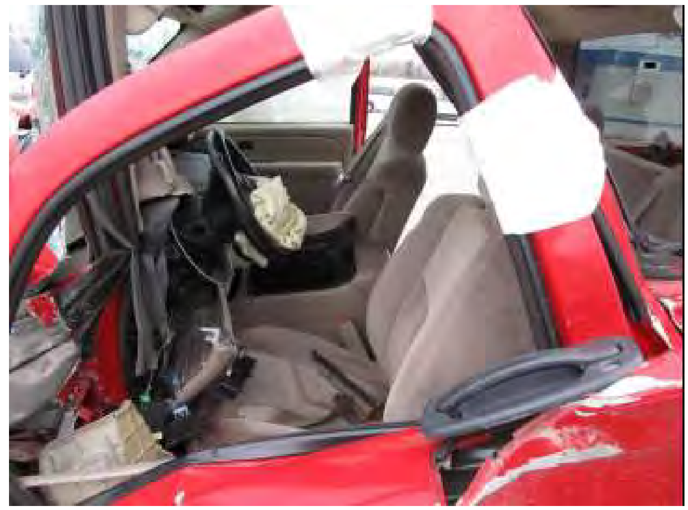
Exceedingly Severe Crash: ΔV ≥ 64 km/h; Vulnerable Occupant: BMI ≥ 30 kg/m^2, Other: Multiple Impacts

2013-48-010 – 2007 Chevrolet Pickup Truck

Head-on collision with 2005 Jeep Cherokee (ΔV 19 km/h; PDOF 12 o'clock)

57 y/o male driver; BMI 37.1 kg/m^2; MAIS5 Pelvic injury; source coded as lower instrument panel

Exceedingly Severe Crash: Narrow Offset; Vulnerable Occupant BMI ≥ 30 kg/m^2



2013-48-076 – 2013 Kia Soul

Vehicle traveled into the median and struck a bridge pillar (ΔV 140 km/h; PDOF 12 o'clock). The vehicle then caught fire.

53 y/o female driver; Injury and source not specified

Exceedingly Severe Crash: ΔV ≥ 64 km/h; Tall, Narrow Impact

2013-49-007 – Volkswagen Passat

Vehicle traveled off the right side of the roadway and struck a concrete bridge support (ΔV 41 km/h; PDOF 12 o'clock)

41 y/o male driver; BMI 37.9 kg/m^2; MAIS4 Thorax injury; source coded as steering wheel

Exceedingly Severe Crash: Narrow Offset; Vulnerable Occupant BMI ≥ 30 kg/m^2

2013-49-085 – 2007 Mazda CX-7 – Occupant 1

Head-on collision with a 2003 Dodge Dakota (ΔV 92 km/h; PDOF 12 o'clock)

57 y/o male driver; BMI 33.6 kg/m^2; MAIS6 Head injury; source coded as steering wheel

Exceedingly Severe Crash: ΔV ≥ 64 km/h; Vulnerable Occupant: BMI ≥ 30 kg/m^2

2013-49-085 – 2007 Mazda CX-7 – Occupant 2

Head-on collision with a 2003 Dodge Dakota (ΔV 92 km/h; PDOF 12 o'clock)

48 y/o female passenger; BMI 33.6 kg/m^2; MAIS5 Head injury; source coded as right instrument panel

Exceedingly Severe Crash: ΔV ≥ 64 km/h; Vulnerable Occupant BMI ≥ 30 kg/m^2

2013-49-105 – 2007 Toyota Corolla

Head-on collision with a 2002 Chevrolet S10 Blazer (ΔV 89 km/h; PDOF 12 o'clock)

23 y/o male driver; MAIS6 Thorax injury; source coded as steering wheel

Exceedingly Severe Crash: ΔV ≥ 64 km/h

2013-78-093 –2010 Buick Lacrosse

Vehicle left the right side of the roadway and struck a chain link fence, a delineator post, and a rock embankment (ΔV 37 km/h; PDOF 12 o'clock)

76 y/o male passenger; Injury and source not specified

Vulnerable Occupant: Age ≥ 65; Exceedingly Severe Crash: Narrow Offset; Other: Multiple Impacts

2014-45-071 – 2007 Kia Amanti

Head-on collision with a 2010 Mazda 3 (ΔV 27 km/h; PDOF 12 o'clock)

72 y/o male driver; BMI 36.3 kg/m^2; MAIS5 Neck injury; source coded as seat belt

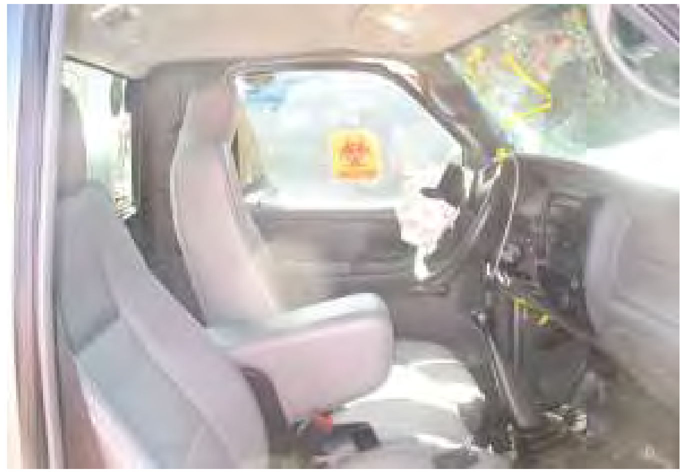
Vulnerable Occupant: Age ≥ 65, BMI ≥ 30 kg/m^2

2014-48-075 – 2007 Ford Ranger

A 2011 Ford Escape and 2007 Ford Escape were stopped in traffic; the Ranger impacted the rear of the 2007 Escape and pushed it into the rear of the 2011 Escape (ΔV 46 km/h; PDOF 12 o'clock)

61 y/o male driver; BMI 43.1 kg/m^2; MAIS5 Lower Extremity injury; source coded as lower instrument panel

Vulnerable Occupant: BMI ≥ 30 kg/m^2

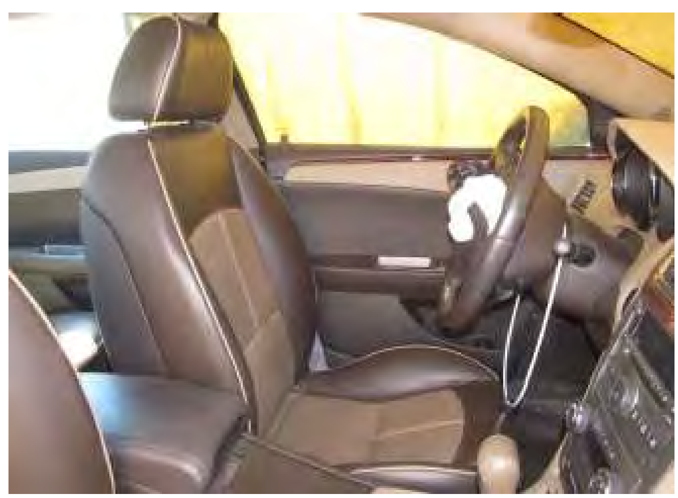


2014-75-57 – 2008 Chevrolet Malibu

Vehicle departed the right side of the road and impacted a sign-post, then a mound of dirt and large rocks; then it continued and struck a sign post which broke and struck the top of the vehicle; then the vehicle re-entered the roadway for 0.5 miles, then departed the right side of the road and impacted a guardrail, then re-entered the roadway and impacted the left side of a 2000 Toyota Avalon (ΔV 29 km/h; PDOF 12 o'clock)

82 y/o male driver; Anthropometry not coded; Injury and source not coded

Other: Medical Event, Multiple Impacts; Vulnerable Occupant: Age ≥ 65



2014-76-097 – 2009 Hyundai Accent

Frontal offset collision with 1997 Chevrolet S-10 Blazer (ΔV 105 km/h; PDOF 12 o'clock)

26 y/o male driver; MAIS2 Thorax injury; source coded as steering wheel

Exceedingly Severe Crash: ΔV ≥ 64 km/h

2015-11-060 – 2013 Volkswagen Passat

Vehicle departed the right side of the roadway and contacted a 94 cm tree (ΔV 68 km/h; PDOF 12 o'clock)

76 y/o female driver; MAIS3 Thorax injury; source coded as steering wheel

Tall, Narrow Object; Vulnerable Occupant: Age ≥ 65; Exceedingly Severe Crash: ΔV ≥ 64 km/h

2015-12-045 – 2008 Chevrolet Impala

Vehicle rotated counter-clockwise and departed the left side of the roadway then contacted a large tree (ΔV 56 km/h; PDOF 12 o'clock)

28 y/o male driver; MAIS3 Head injury; source coded as center instrument panel

Tall, Narrow Object

2015-73-035 – 2012 Toyota Rav-4

Vehicle departed the right side of the roadway and struck a tree (ΔV 39 km/h; PDOF 12 o'clock)

79 y/o male driver; MAIS3 Thorax injury; source coded as steering wheel

Tall, Narrow Object; Vulnerable Occupant: Age ≥ 65

2015-75-022 – 2013 Toyota Prius

Vehicle impacted on the left side by a 2012 Subaru Outback, then departed the left side of the road and the left front wheel impacted the center median divider; as it crossed the median, it impacted a sign post, which broke and impacted the windshield; the vehicle also impacted a delineator post with the front and then the right plane. The vehicle then crossed over into the oncoming travel lane and impacted a 2009 Subaru Outback in a head-on configuration (ΔV 63 km/h; PDOF 12 o'clock) (ΔVs not coded for impacts 1-6; PDOFs for impacts 1-3, 5-7 12 o'clock; PDOF for impact 4 coded as "00").

Male driver, age not specified; Head injury not specified; source not coded

Other: Multiple Impacts

2015-75-060 – 2007 Jeep Cherokee

Vehicle departed the right side of the road onto an island and struck a delineator, then struck the curb with its right front wheel, then struck the island's curb with its right rear wheel, then struck a traffic light pole (ΔV 19 km/h; PDOF 12 o'clock); it rotated and contacted a delineator post with its left side. (Other ΔVs not coded; other PDOFs 12 o'clock except final contact PDOF 9 o'clock).

Front passenger, age and sex not coded; MAIS injury and source not coded

Exceedingly Severe Crash: Narrow Offset; Other: Multiple Impacts

2015-78-008 – 2006 Ford Fusion

Head-on collision with 2006 Ford F-Series pickup truck (ΔV 57 km/h; PDOF 12 o'clock)

90 y/o female driver; MAIS injury and source not coded

Vulnerable Occupant: Age ≥ 65; Exceedingly Severe Crash: Narrow Offset