# Influence of Advanced Airbags on Injury Risk during Frontal Crashes

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## Abstract

The combination of airbag and seatbelt is considered to be the most effective vehicle safety system. However, despite the widespread availability of airbags and a belt use rate of over 85% U.S. drivers involved in crashes continue to be at risk of serious thoracic injury. One hypothesis is that this risk may be due to the lack of airbag deployment or the airbag 'bottoming-out' in some cases, causing drivers to make contact with the steering. The objective of this study is to determine the influence of various advanced airbags on occupant injury risk in frontal automobile crash.

The analysis is based upon cases extracted from the National Automotive Sampling System Crashworthiness Data System (NASS/CDS) database for case years 1993-2011. The approach was to compare the frontal crash performance of advanced airbags against depowered airbags, first generation airbags, and vehicles with no airbag equipped. NASS/CDS steering wheel deformation measurements were used to identify cases in which thoracic injuries may have been caused due to steering wheel impact and deformation. The distributions of injuries for all cases were determined by body region and injury severity. These distributions were used to compare and contrast injury outcomes for cases with frontal airbag deployment for both belted and unbelted drivers.

Among frontal crash cases with belted drivers, observable steering wheel deformation occurred in less than 4% of all cases, but accounted for 29% of all serious-to-fatally injured belted drivers and 28% of belted drivers with serious thoracic injuries (AIS3+). Similarly, observable steering wheel deformation occurred in approximately 13% of all cases with unbelted drivers involved in frontal crashes, but accounted for 58% of serious-to-fatally injured unbelted drivers and 66% of unbelted drivers with serious thoracic injuries. In a frontal crash, the factors which were statistically significant in the probability of steering wheel deformation were: longitudinal delta-V, driver weight, and driver belt status. Seatbelt pre-tensioner and load limiters were not significant factors in influencing steering wheel deformation. Furthermore, belted drivers in vehicles with no airbag equipped were found to have 3 times higher odds of deforming the steering wheel, as compared to driver in similar crash scenario. Similarly, unbelted drivers were found to have 2 times greater odds of deforming the steering wheel in vehicles with no airbags equipped as compared to vehicles with advanced airbag. The result also showed no statistically significant difference in the odds of deforming the steering wheel between depowered and advanced airbag. After controlling for crash severity, and driver weight, the study showed that crashes with steering wheel deformation results in greater odds of injury in almost all body regions for both belted and unbelted drivers. Moreover, steering wheel deformation is more likely to occur in unbelted drivers than belted drivers, as well as higher severity crashes and with heavier drivers.

Another potential factor in influencing driver crash injury is the knee airbag. After comparing the odds of injury between vehicles with and without knee airbags equipped, belted drivers in vehicles equipped with knee airbag were found to have statistically smaller odds of injury in the thorax, abdomen, and upper extremity. Similarly, the findings showed that unbelted drivers benefited from knee airbag through statistically significant lower odds of chest and lower extremity injuries. However, the results should be considered with caution as the study is limited by its small sample of vehicles with knee airbags.

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# 1 INTRODUCTION

Seatbelts and airbags are the two primary components of the safety system that protects a vehicle occupant against the rapid deceleration experienced by occupants in a frontal crash. Researches in active safety systems and real world crash scenarios over the years have provided valuable ground work to improve occupant safety in automobiles [1], [2], [3], [4], [5]. However, despite mandatory airbag equipment in modern vehicles, and increase in seatbelt usage to approximately 85% in the United States as shown in Figure 1, occupants are still at risk of fatal and serious injuries. According to the National Highway Traffic Safety Administration (NHTSA), approximately 5,338,000 people were involved in police-reported traffic crashes in 2011, which resulted in 32,367 fatalities. Of these traffic fatalities, over 4,000 were associated with motorcycle operators, who are particularly at risk of serious injury or fatality [6], [7], [8]. Over 22,000 fatalities involved passenger vehicles, and over half (51%) of the occupant fatalities occurred in vehicles that sustained frontal damage [9].

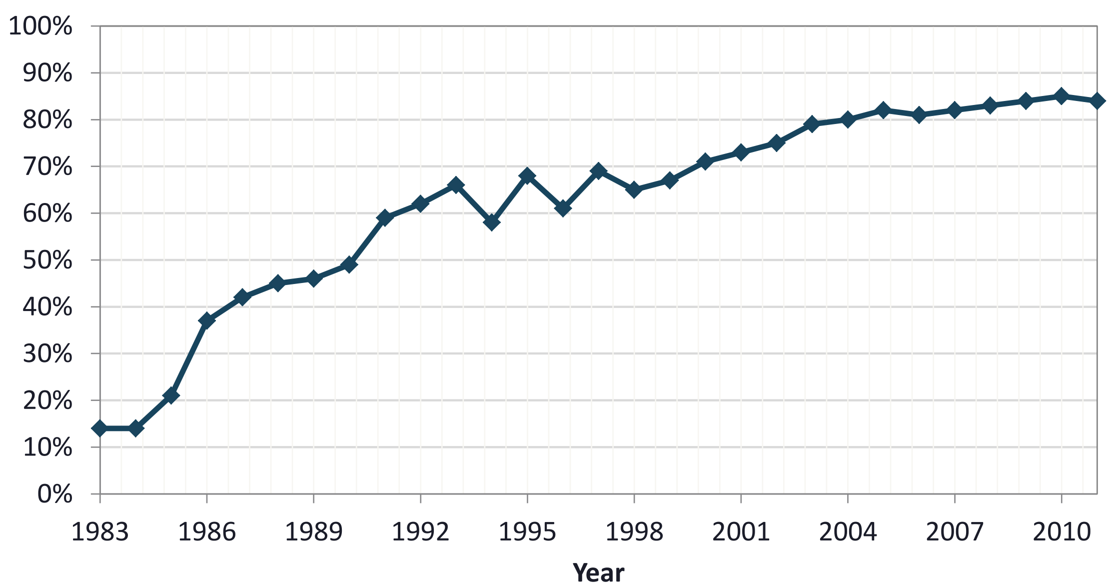


**Figure 1. U.S. Seatbelt Usage Rate** [10]

## 1.1 AIRBAGS

A typical airbag system in vehicles encompasses several components, as shown in Figure 2. In the event of a significant crash, the sensors at various locations of the vehicle detect a significant change in acceleration, and alert the airbag control module to ignite the propellant, which then inflates the airbag. NHTSA estimates that, from 1987 to 2011, 34,757 lives were saved by frontal airbags [10]. In a study published in 1991, Viano reported that airbags have an estimated effectiveness of 18% in preventing driver fatalities, and in cases where the airbag is used in conjunction with lap and should belts, the effectiveness of the safety system is estimated to be as high as 46% [11]. Since its introduction to passenger vehicles, the design of frontal airbags has evolved through several generations.

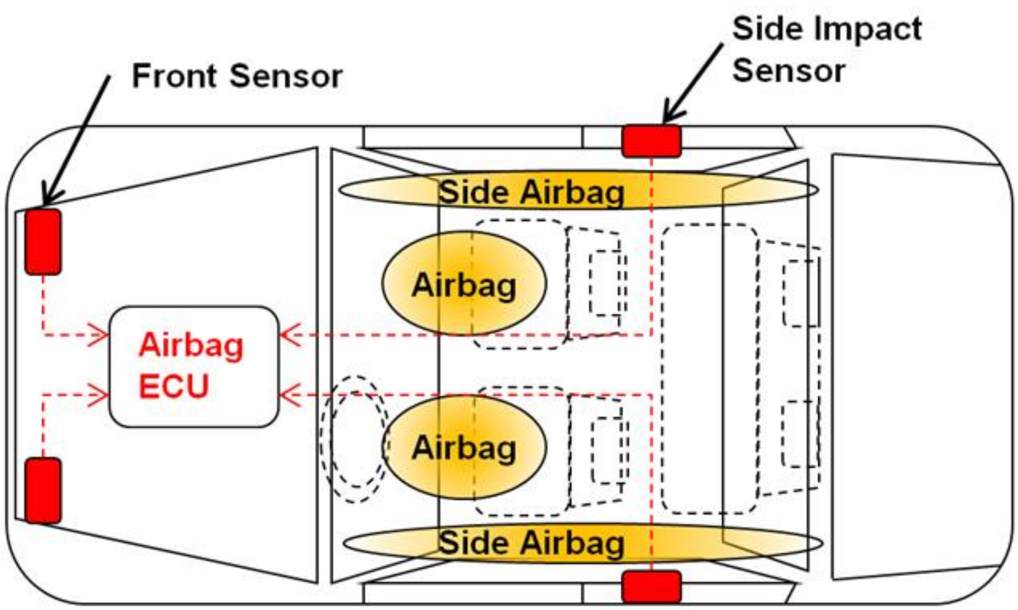


**Figure 2. Components of Typical Airbag System**

Since its introduction to passenger vehicles, the design of frontal airbags has evolved through several generations. The development of first generation frontal airbags was motivated by the low seatbelt usage in the U.S. In the early 1980s, seatbelt usage in the U.S. was estimated to be only 14%. Automakers, therefore, designed their airbag systems with the priority of protecting unrestraint drivers [12]. Although these airbag systems aimed to reduce the risk of occupant injury, field experience begin to show that the rapid deployment of airbags was causing injury to some drivers [13]. Injuries relating to airbag contact were especially common in infants in rear facing seats, children, and shorter driver who sat closer to the airbag. By the end of 1995, NHTSA's Special Crash Investigations (SCI) had identified 30 airbag related fatal injuries, including 3 infants in rear facing seats, 10 children, and 17 drivers, 10 of them 5'2" or shorter. [14].

In an effort to reduce airbag related injuries and fatalities, NHTSA issued an amendment to the Federal Motor Vehicle Safety Standard No. 208 (FMVSS 208) [15], which mandated automakers redesign the airbag system. The initial phase of the airbag redesign involved depowering the frontal airbags, and certifying the new design under the sled test, in 1998. These sled-certified, or depowered, airbags were intended to reduce the risk of injury to front seat occupants by reducing the force with which these airbags were deployed. In 2000, the final phase of the FMVSS 208 introduced the advanced airbags, sometimes referred to as Certified Advanced 208 Compliant (CAC) airbags. Advanced airbags began to be phased into the U.S. fleet in model year 2004 with complete phase in by model year 2007. A few models contained CAC-airbags as early as model year 2003. Like depowered airbags, advanced airbags sought to reduce occupant risk by employing a sophisticated system of occupant sensors and a two-stage inflator design which could tailor the force of deployment to the severity of the crash, the location of the occupant, and belt status. For example, the dual-stage inflators in advanced airbags tailor the deployment force to deploy only one of the two stages in less moderate crashes. On the other hand, severe crashes will trigger both stages to deploy simultaneously. Some manufacturers included some of the features of advanced airbags, e.g. dual inflators, in their sled-certified airbag designs.

In a study on frontal barrier crashes, using real world data from 1997-2007, Gabauer and Gabler concluded that the combination of seatbelts and airbags dramatically reduced the risk of serious injuries [16]. Likewise, Duma et al. found that airbag-induced eye injuries were reduced in vehicles equipped with depowered airbags [17]. However, other similar research using real world data have concluded adverse effects from airbags. In a study comparing the risk of abdominal injury for belted drivers involved in crashes with and without airbag deployment, Thor and Gabler found higher risk of abdominal injury associated with airbag deployment for belted drivers [18]. Similarly, Jernigan et al. compared the risk of severe upper extremity injury between full-powered airbags and depowered airbags, and showed that depowered airbags were associated with higher risk of upper extremity injuries [19].

One concern has been whether advanced airbags may be associated with higher injury risk than earlier airbag designs. Based on an analysis of Fatality Analysis Reporting System (FARS), Braver et al [20] reported that the mortality for belted drivers was higher for advanced airbag equipped vehicles than for sled-certified vehicles. One hypothesis is that drivers may be bottoming-out airbags in which only a single stage was deployed. If the airbag was bottomed-out, the driver could directly impact and deform the steering wheel assembly which underlies the airbag. The hypothesis is that steering wheel deformation would then be correlated with greater frontal crash injury risk.

## 1.2 Knee Airbags

To improve the performance of the standard driver and passenger frontal airbags, several automakers are equipping their vehicles with driver knee airbags and, in some cases, knee airbags for the right front passenger. BMW, Chrysler, Lexus, Mercedes-Benz, Kia, and Toyota have all installed knee airbags in one or more of the vehicles in either their current or previous fleets. These knee airbags are generally mounted in the compartment under the steering wheel in the driver position and under the instrument panel of the right front passenger.

Knee airbags are designed to deploy in conjunction with the frontal airbag to help protect the occupants' lower extremities in a frontal crash from impacts with the instrument panel or other components in the occupant compartment [21][22]. Specifically, knee airbags aim to reduce the resultant load and forces to the knee, thigh and hip complex due to driver knee contact to the lower instrument panel [23]. In a study using real-world crash data from the Crash Injury Research and Engineering Network (CIREN) database, Weaver et al. concluded that instances of driver pelvic fracture decreased in vehicles equipped with knee airbags [24].

Although knee airbags are designed primarily to mitigate lower extremity injuries, they may also affect occupant kinematics in a crash [22]. Knee airbags, for example, can help to position the occupant into a more upright position which can improve the interaction of the standard frontal airbag with the thorax. The results can be improved loading of the thorax and reduced injury risk.

## 1.3 Seatbelts

Seatbelts were first installed in passenger cars in the 1950s, with mandatory installation in new vehicles in 1968 [25]. Widely recognized as the most effective safety equipment in the vehicle, seatbelts serve to secure the occupant in the seat during crashes, mitigating the risk of injury by reducing the range of excursion and limiting the possibility of ejection. In 2011 alone, NHTSA estimates that seatbelts saved 11,949 lives, and an additional 3,384 fatalities could have been avoided if all passenger vehicle occupants had worn seatbelts [10]. Compared to airbags, which has an estimated 18% effectiveness at preventing fatalities for unbelted drivers, lap and should belts are estimated to be 42% effective in preventing driver fatalities [11].

Although seatbelts have been shown to mitigate serious injuries, several improvements aimed to reduce the risk of seatbelt induced injuries have been made over the years. Early studies showed that, for both belted drivers and passengers, skeletal fractures in the shoulder and chest region are largely associated with the seatbelt itself [26]. In order to address these seatbelt induced injuries, many automakers have installed load limiters at the belt anchor. In the event of a crash, load limiters plastically deform at the designed force threshold, reducing the load placed on the occupant by the seatbelt. Several studies have shown seatbelt with load limiters to be beneficial in reducing the risk of seatbelt induced thoracic injuries [27], [28], [29].

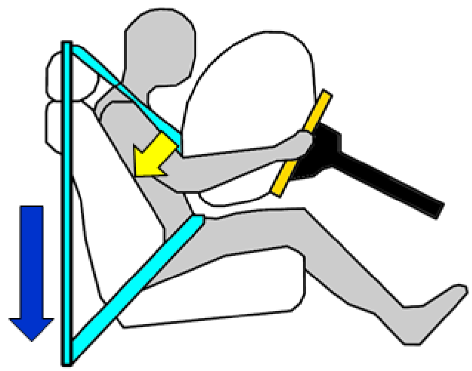

**Figure 3. Pre-tensioner Activate to Reduce Excess Slack in Seatbelt**

In modern seatbelt systems, load limiters are often coupled with pre-tensioners to reduce head and chest excursion. In order to provide comfort, conventional lap and should belts are designed to allow for the occupant to freely move about within the confines of the seat during normal operation. In the event of a crash, the gear wheel which contains the webbing locks to secure the occupant in place. However, the excess slack in the webbing still allows for a small range of motion for the occupant. Modern seatbelt pre-tensioners are typically pyrotechnical devices which work in conjunction with the accelerometers in the vehicle to retract seatbelt webbing and reduce excessive slack in the event of a crash, therefore limiting the range of motion for the drivers' head and chest. Pre-tensioners can be installed at any of the anchor points in a seatbelt system, and are classified by its location, such as retractor pre-tensioner or buckle pre-tensioner [30].

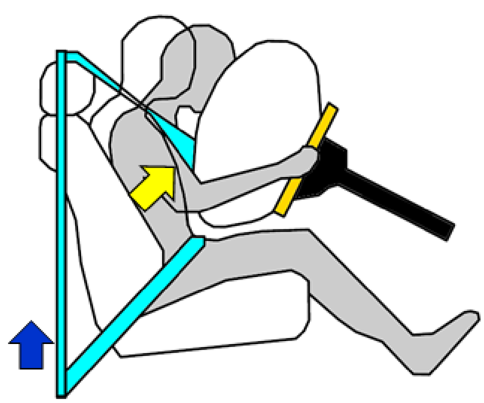

**Figure 4. Load Limiter Reduces Seatbelt Load on Occupant**

## 1.4 Research Objective

Although the combination of airbag and seatbelt is considered to be the most effective vehicle safety system, U.S. drivers involved in crashes continue to be at risk of serious thoracic injury. One hypothesis is that this risk may be due to the lack of airbag deployment or the airbag 'bottoming-out' in some cases, causing drivers to make contact with the steering wheel. The objective of this study is to determine the influence of various advanced airbags on occupant injury risk in frontal automobile crash.

# 2 APPROACH

The approach of this study was to use real world crash data, and compare the odds of frontal crash injury of occupants in a) vehicles with and without steering wheel deformation, b) vehicles with and without knee airbag, and b) vehicles equipped with advanced airbags to vehicles with depowered airbag, first generation airbag, and no airbag equipped.

## 2.1 DATA SOURCES

The study was based upon real world crashes extracted from the National Automotive Sample System's (NASS) Crashworthiness Data System (CDS). NASS is a crash data collection program established by NHTSA. Each year NASS/CDS investigates approximately 5,000 cases, selected from police reported crashes at 24 sites across the United States. In order for a crash to be included in NASS/CDS, at least one of the vehicle involved were required to be towed from the scene. After the crash, NASS crash investigators document vehicle damage, occupant impacts with the interior, and crash site evidence, such as skid marks, and damage to roadside objects. NASS/CDS uses a damage based algorithm, called WinSmash, to compute the vehicle velocity change (delta-V) during a crash based on measured vehicle deformation [31].

The nature and severity of the injuries sustained by the occupants are collected through the review of medical records and interviews with the crash victims. NASS describes the severity of occupant injuries based on the Abbreviated Injury Scale (AIS). AIS ranks injury severity on a scale of 1-6 based on its threat to the life of the occupant [32]. As shown in Table 1, AIS=1 is a minor injury, AIS=3 is a serious injury and AIS=6 is an unsurvivable injury. This analysis classified injury severity by the maximum AIS (MAIS) level injury sustained by an occupant. For drivers who were fatally injured, MAIS was set to 6 regardless of individual injury level. The injuries were further classified by body region, i.e. the head, face, neck, chest, abdomen, spine, upper extremities, and lower extremities. The injury distribution was described by computing the highest, i.e. most severe, injury sustained in each body region. In the analysis which follows, NASS sample weights were applied in order to represent the national population.

**Table 1. AIS Injury Severity Ranking**

| AIS Code | Description |
|---|---|
| 1 | Minor |
| 2 | Moderate |
| 3 | Serious |
| 4 | Severe |
| 5 | Critical |
| 6 | Maximal (currently untreatable) |

The following study is based upon cases extracted from NASS/CDS case years 1993-2011. In order to be included in the dataset, cases were required to meet the following conditions:

- Drivers age 16 and older
- Passenger car or light truck in frontal impact
- Vehicle with or without frontal airbags
- Exclude rollover cases
- Exclude cases involving driver ejection
- Known belt use

The vehicles included in the dataset were all involved in crashes where the first harmful event was frontal impact. Airbags were deployed in all airbag equipped vehicles in the dataset as a result of the crash. Moreover, the dataset also included both vehicles with and without knee airbag equipped. Rollover crashes account for an over-representative number of serious injuries and deaths from car crashes, but the injurious circumstances are often unclear. Due to the complex nature of rollovers, they were not included in this analysis.

The resulting sample included four airbag designs: 1) first generation airbags prior to model year 1998, 2) depowered airbags introduced in 1998, 3) Certified Advanced 208 Compliant (CAC) airbags, and 4) vehicles with no airbag equipped.

## 2.2 STATISTICAL ANALYSIS METHODS

The comparison between the datasets was based upon the odds of injury, as shown in Equation 1, where the probability (P) of injury for a certain body region was expressed as the percentage of injured cases in a total number of known cases, as calculated in Equation 2. Odds ratio was used to compare the odds of injury during critical event to a reference event, as shown in Equation 3. For example, in the comparison of odds of injury for crashes with and without steering wheel deformation, critical events were defined as crashes with steering wheel deformation, and reference events were defined as crashes with no steering wheel deformation. An odds ratio greater than one suggests the reference event have a smaller odds of injury, while an odds ratio less than one suggests that the reference event have a greater odds of injury. In the analysis which follows, error bars have been added to show 95% Wald confidence intervals calculated based on the odds ratio point estimate and its associated standard error. A confidence interval which included odds ratio of one indicates no statistically significant difference in the odds of injury.

In order to include the effect of several covariates, odds ratios were calculated using a logistic regression model, as shown in Equation 4, where $\beta_N$ is the coefficient estimate which describes the effect of factors, such as driver belt status, occupant weight and vehicle delta-V, upon injury odds.

$$Odds = \frac{P}{1-P}$$ **Equation 1**

$$P = \frac{Number\ of\ cases\ at\ a\ certain\ severity}{Total\ number\ of\ known\ cases}$$ **Equation 2**

$$Odds\ Ratio = \frac{Odds\ of\ Injury\ during\ critical\ Event}{Odds\ of\ Injury\ during\ reference\ Event}$$ **Equation 3**

$$Odds\ of\ Occurrence = e^{(\beta 0+\beta 1*Factor1+\beta 2*Factor2+\dots\beta N*FactorN)}$$ **Equation 4**

The cases collected in NASS/CDS are clustered into 24 primary sampling units (PSU). The cases are further separated into 10 strata based on factors which include vehicle damage and the severity of the occupant injuries. Due to the limited number of PSUs, NASS/CDS does not sample every applicable case in the U.S. Crashes with high severity and/or severe occupant injuries are oversample. Nationally representative population is provided by adjusting the sample using a weight factor to compensate for potential non-response and coverage bias. In order to account for the complex sampling scheme employed by NASS/CDS, the SAS routine SurveyLogistic was used to compute the odds ratios and their associated confidence limits in the following analysis. NASS sample weight was used in the following analysis in order to represent the national population.

## 2.3 MODEL DEVELOPMENT METHODS

The probability of an event occurrence can be estimate using a logistic regression model. Given a dependent variable, a logistic regression predicts the outcome of a categorical variable, such as steering wheel deformation (deformed or not deformed), as shown in Equation 5. Similar to the calculation of odds, $\beta_N$ shown in Equation 5 is the coefficient estimate which describes the effect of relevant covariates.

**Equation 5**

$$Probability\ of\ Occurence = \frac{1}{1 + e^{-(\beta 0 + \beta 1 * Factor1 + \beta 2 * Factor2 + \ldots \beta N * FactorN)}}$$

# 3 Incidence and Risk of Direct Steering Wheel Impact

## 3.1 Research Objective

Seatbelts and airbags are the two primary components of the safety system that helps to secure the occupant and reduce the rapid deceleration experienced by occupants in a frontal crash. However, despite the widespread availability of advanced airbags, and seatbelt usage over 85% in the United States, drivers still may contact the steering wheel in the event of a crash, and may subsequently incur serious injury as a result of steering wheel impact.

The objective of the following section is to answer the following questions:

- How frequently does steering wheel deformation occur?
- What factors influence steering wheel deformation?
- What are the injury outcomes of steering wheel deformation?

## 3.2 Approach

For the steering wheel analysis, the dataset was restricted to vehicles equipped with depowered airbags or advanced airbags in order to include only the latest safety technologies. This study considered both the effect of belt usage and the type of frontal airbags in the vehicle. The type of driver airbag was identified for each vehicle prior to the analysis using NHTSA's safety equipment list [33]. NHTSA's SaferCar database, which lists safety features of U.S. vehicles from model year 1990 to 2013, was used to identify vehicles equipped with pre-tensioner and load limiters. A list of vehicles with advanced airbags, pre-tensioners, and load limiters can be found in the Appendix.

All cases in the following study involved airbag deployment. Steering wheel deformation and driver belt status were recorded for all cases. The final dataset was then divided into those vehicles with and without steering wheel deformation. Cases with steering wheel deformation were identified with the NASS/CDS variable "rimdef", and subsequently grouped by the occupant injuries recorded by NASS/CDS.

## 3.3 Dataset Composition

Table 2 presents the composition of the belted driver dataset for both unweighted and weighted values. The dataset is organized based on the steering wheel (SW) deformation, as well as the number of drivers sustaining MAIS 2+ and MAIS 3+ injuries. Likewise, the composition of the dataset for unbelted drivers is presented in Table 3 as a function of steering wheel deformation and MAIS level. Steering wheel deformation was not recorded in 426 cases, while another 171 cases involved steering wheel deformation caused by a person or object other than the driver, e.g. rescue personnel or occupant compartment collapse. These cases were omitted from the dataset.

**Table 2. Dataset Composition by Steering Wheel Deformation for Belted Drivers**

| Injury Level | Unweighted | | |
|---|---|---|---|
| | Total | No Measurable SW Deformation | Measurable SW Deformation |
| Exposed | 10,429 | 9,604 | 825 |
| MAIS 2+ | 2,136 | 1,637 | 499 |
| MAIS 3+ | 984 | 643 | 341 |
| Injury Level | Weighted | | |
| | Total | No Measurable SW Deformation | Measurable SW Deformation |
| Exposed | 3,290,900 | 3,172,037 | 118,863 |
| MAIS 2+ | 288,036 | 244,481 | 43,555 |
| MAIS 3+ | 74,588 | 52,780 | 21,808 |

**Table 3. Dataset Composition by Steering Wheel Deformation for Unbelted Drivers**

| Injury Level | Unweighted | | |
|---|---|---|---|
| | Total | No Measurable SW Deformation | Measurable SW Deformation |
| Exposed | 2,407 | 1,705 | 702 |
| MAIS 2+ | 982 | 505 | 477 |
| MAIS 3+ | 599 | 249 | 350 |
| Injury Level | Weighted | | |
| | Total | No Measurable SW Deformation | Measurable SW Deformation |
| Exposed | 611,062 | 532,286 | 78,776 |
| MAIS 2+ | 109,695 | 69,533 | 40,162 |
| MAIS 3+ | 45,059 | 18,918 | 26,141 |

Lastly, the dataset was broken down by airbag type. Table 4 presents the unweighted and weighted values for the belted drivers. The composition of the dataset for unbelted drivers is presented as a function of airbag type in Table 5.

**Table 4. Dataset Composition by Airbag Type for Belted Drivers**

| Injury Level | Unweighted | | |
|---|---|---|---|
| | Total | Depowered Airbag Vehicles | CAC Vehicles |
| Exposed | 10,429 | 7,522 | 2,907 |
| MAIS 2+ | 2,136 | 1,618 | 518 |
| MAIS 3+ | 984 | 762 | 222 |
| Injury Level | Weighted | | |
| | Total | Depowered Airbag Vehicles | CAC Vehicles |
| Exposed | 3,290,900 | 2,550,071 | 740,829 |
| MAIS 2+ | 288,036 | 229,192 | 58,844 |
| MAIS 3+ | 74,588 | 55,522 | 19,066 |

**Table 5. Dataset Composition by Airbag Type for Unbelted Drivers**

| Injury Level | Unweighted | | |
|---|---|---|---|
| | Total | Depowered Airbag Vehicles | CAC Vehicles |
| Exposed | 2,407 | 1,855 | 522 |
| MAIS 2+ | 982 | 782 | 200 |
| MAIS 3+ | 599 | 478 | 121 |
| Injury Level | Weighted | | |
| | Total | Depowered Airbag Vehicles | CAC Vehicles |
| Exposed | 611,062 | 487,600 | 123,462 |
| MAIS 2+ | 109,695 | 86,479 | 23,217 |
| MAIS 3+ | 45,059 | 35,070 | 9,989 |

## 3.4 FREQUENCY OF STEERING WHEEL DEFORMATION

Figure 5 shows the distribution of cases with and without measurable steering wheel deformation for drivers exposed to frontal crashes, with MAIS2+ injuries and with MAIS3+ injuries. The assumption was made that the cases with unknown deformation were distributed in the same proportions to deformed and undeformed groups as the known cases.

As shown by the figure, only 4% of belted drivers were involved with a steering wheel with any measurable deformation. However, this 4% of cases was overrepresented in the injury outcomes, and was associated with 15% of MAIS2+ drivers and 29% of MAIS3+ injured drivers. Even for drivers wearing their belts with deployed airbags, steering wheel impact with measurable deformation still accounted for nearly one-third of serious to fatally injured belted drivers.

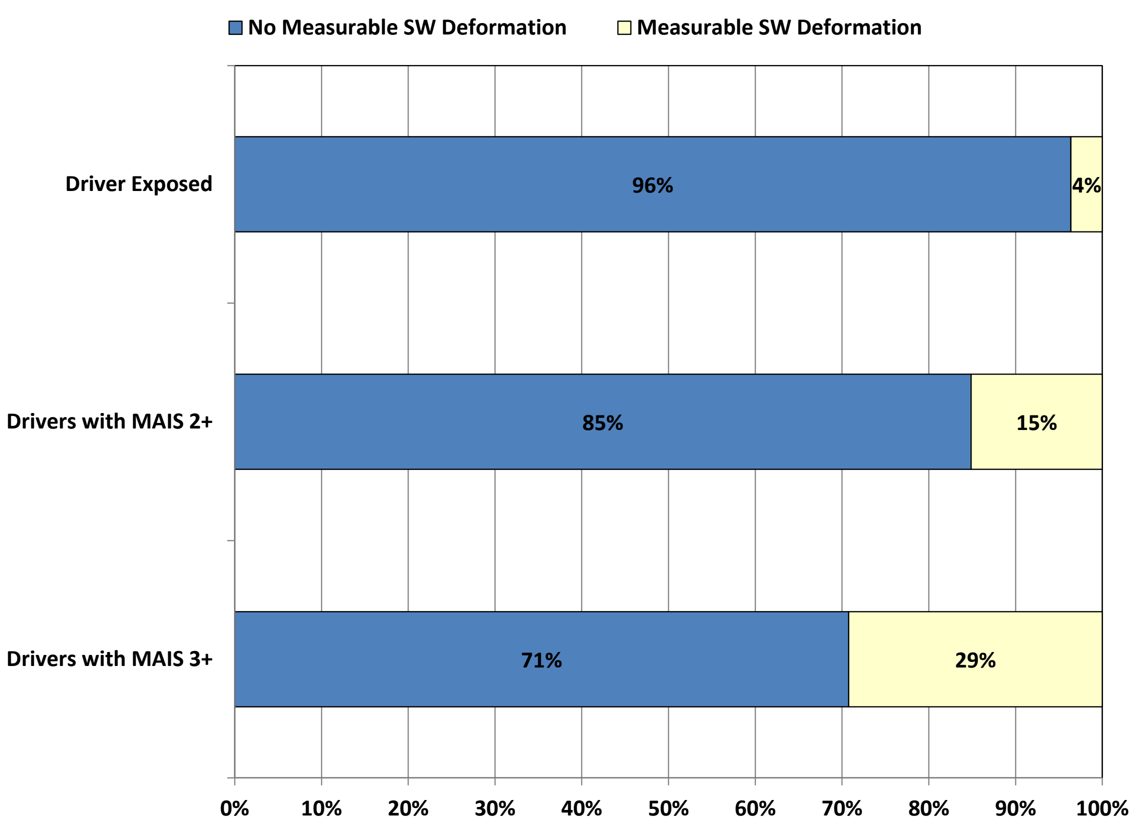


**Figure 5. Distribution of Belted Drivers With and Without Steering Wheel Deformation**

Figure 6 shows the distribution of cases with and without measurable steering wheel deformation for unbelted drivers exposed to frontal crashes, with MAIS2+ injuries and with MAIS3+ injuries. As before, cases with unknown steering wheel deformation were assumed to be distributed in the same proportions to deformed and undeformed groups as the known cases. As might be expected, unbelted drivers were more likely to cause steering wheel deformation (13%) than belted drivers (4%). In most belted cases, the three point belt keeps the driver out of the steering wheel. Although a small fraction, the 13% of drivers in vehicles with steering wheel deformation is overrepresented in the injury outcomes. This small fraction is associated with 37% of MAIS2+ drivers and well over half (58%) of MAIS3+ unbelted drivers. Clearly, failure to wear a safety belt puts unbelted drivers at a higher risk of impacting the steering wheel than belted drivers. The result was a sharply elevated risk of injury.

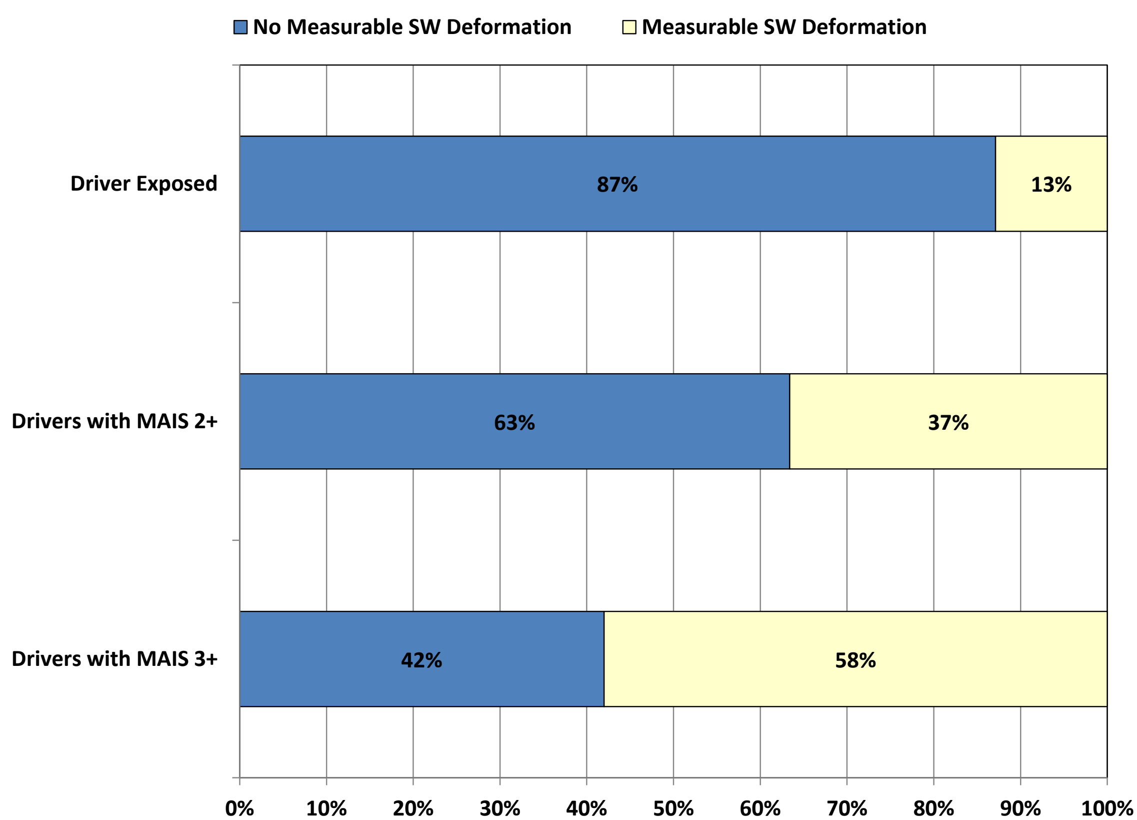


**Figure 6. Distribution of Unbelted Drivers With and Without Steering Wheel Deformation**

## 3.1 FACTORS INFLUENCING STEERING WHEEL DEFORMATION

### *3.1.1 TEST OF MODEL EFFECTS*

In order to determine the potential factors that may influence the severity of steering wheel impact, the complex interaction between the driver and the vehicle's restraint system was approximated with a simple mass-spring system. For a steering wheel with a linear spring stiffness in which an occupant of mass *m* contacts the steering wheel at velocity *v*, the steering wheel-restraint deformation x can be computed as shown in Equation 6 and Equation 7:

$$\frac{1}{2}mv^2 = \frac{1}{2}kx^2$$ **Equation 6**

$$x = \left(\sqrt{\frac{m}{k}}\right)v$$ **Equation 7**

This simple model does not, of course, account for the non-linear force-deflection of the belt-airbag-steering wheel system, but is useful to identify the factors which are likely to control steering wheel deformation. As a first approximation, this qualitative analysis indicates that steering wheel deformation is likely to be influenced by the delta-V, the mass of the occupant, and the stiffness of the belt-airbag-steering wheel system.

The effect of multiple event crashes was also considered in the analysis. In 34% of the cases the vehicle experienced multiple crash events, e.g. a crash where the vehicle strikes a guardrail, and was then redirected onto the road where it collided with another vehicle. In these multiple event crashes, specifically multiple frontal impacts, the airbag may inflate during the first event to protect the occupant, but after deflating does little to help the occupant when it is deflated during the subsequent events.

To account for the stratified sampling scheme used by NASS/CDS, the SurveyReg function in SAS 9.2 was used to test the effect of each of the independent variables in a Wald test. Magnitude of steering wheel deformation was used as the response. The weight and age of the occupant, as well as the longitudinal and lateral delta-V were included as continuous covariates. The belt status, type of airbag, and the effect of load limiters and pre-tensioners were included in the analysis as categorical covariates. Lastly, the effect of multiple frontal crashes was used as a categorical variable (1 if crash involved multiple frontal impacts, 0 if single event crash) and tested for its effect on steering wheel deformation.

As shown in Table 6, longitudinal delta-V, driver weight, and belt status were statistically significant at the alpha=0.05 level in influencing steering deformation. However, lateral delta-V, driver age, whether or not the vehicle was equipped with advanced or depowered airbag, the presence of load limiters and pre-tensioner, and the factor of multiple frontal crashes did not have a statistically significant effect on probability of steering wheel deformation.

**Table 6. Test of Model Effect Result by SAS**

| **Variable** | **P-Value** |
|---|---|
| Longitudinal Delta-V | <0.0001 |
| Lateral Delta-V | 0.2584 |
| Driver Age | 0.0731 |
| Driver Weight | <0.0001 |
| Belt Status | <0.0001 |
| Advanced airbag | 0.6490 |
| Load Limiter | 0.9817 |
| Pre-Tensioner | 0.6378 |
| Multiple-Frontal Crashes | 0.5629 |

The effect of multiple events can also be illustrated using the distribution of steering wheel deformation. Figure 7 and Figure 8 and shows that for single and multi-event crashes, there was little difference in the magnitude of steering wheel deformation for either belted or unbelted drivers.

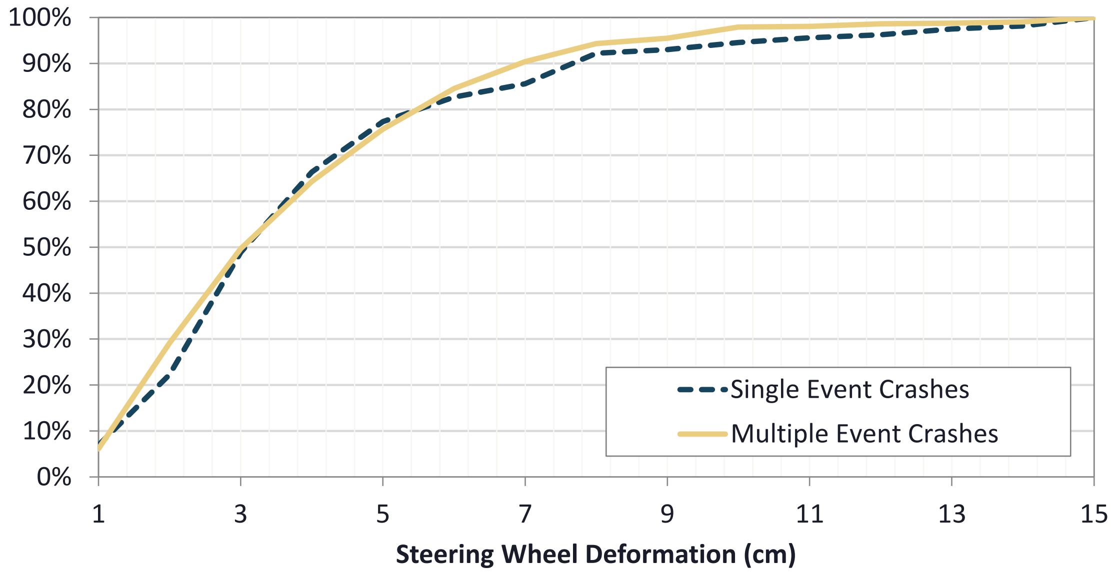


**Figure 7. Belted Driver Steering Wheel Deformation Distribution for Multiple and Single Event Crashes**

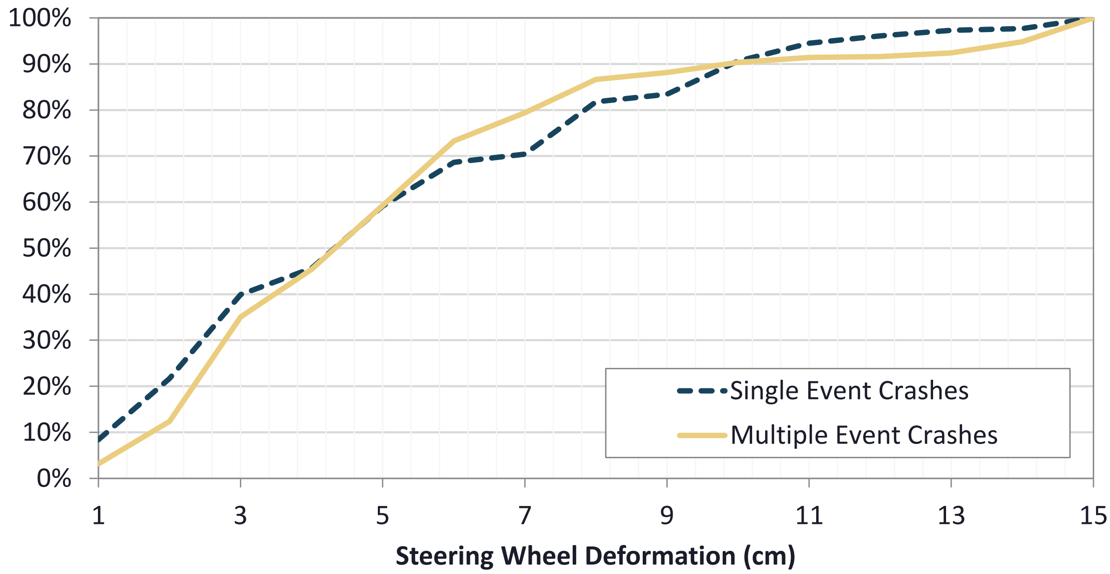


**Figure 8. Unbelted Driver Steering Wheel Deformation Distribution for Multiple and Single Event Crashes**

### 3.1.2 *PROBABILITY OF STEERING WHEEL DEFORMATION*

In addition to the factors which are significant in influencing steering wheel deformation, we are also interested in the delta-V threshold at which steering wheel deformation first becomes measurable. In this section, logistic regression was used to model the probability of steering wheel deformation as a function of longitudinal delta-V, driver weight, and belt status.

A logistic regression model was constructed using the SurveyLogistic function of SAS 9.2. The logistic model considers the stratified sampling scheme used by NASS/CDS, and contains three variables: longitudinal delta-V, driver weight, and belt status. The estimated coefficient of each variable and its respective 95% confidence interval are tabulated in Table 7.

**Table 7. Logistic Regression Parameter Estimates**

| Variable | Coefficient Estimates | 95% Confidence Limits | |
|---|---|---|---|
| Intercept | -5.6355 | -6.5615 | -4.7096 |
| Longitudinal delta-V | 0.0688 | 0.0597 | 0.0779 |
| Driver Weight | 0.0229 | 0.0151 | 0.0307 |
| Belt Status | -1.3333 | -1.7467 | -0.9198 |

Table 8 lists the result of the Chi-Square test which test against the null hypothesis that at least one of the variables' regression coefficients is equal to zero in the model. Based on the calculated Chi-Square value and the associated probability, we can reject the null hypothesis that at least one of the variables' regression coefficients is equal to zero.

**Table 8. Testing Global Null Hypothesis**

| Test | Chi-Square | DF | Pr > ChiSq |
|---|---|---|---|
| Likelihood Ratio | 175,111.9 | 3 | <0.0001 |
| Score | 234,307.3 | 3 | <0.0001 |
| Wald | 274.4 | 3 | <0.0001 |

Using the parameter estimates in Table 7 and the logarithmic regression equation shown in Equation 8, the probability of steering wheel deformation for a 70 kg belted and unbelted driver can be estimated with respect to longitudinal delta-V, as shown in Figure 9.

$$Probability\ of\ SW\ Deformation = \frac{1}{1 + e^{-(Intercept + B*DeltaV + C*Weight + D*Belt)}} \quad \textbf{Equation 8}$$

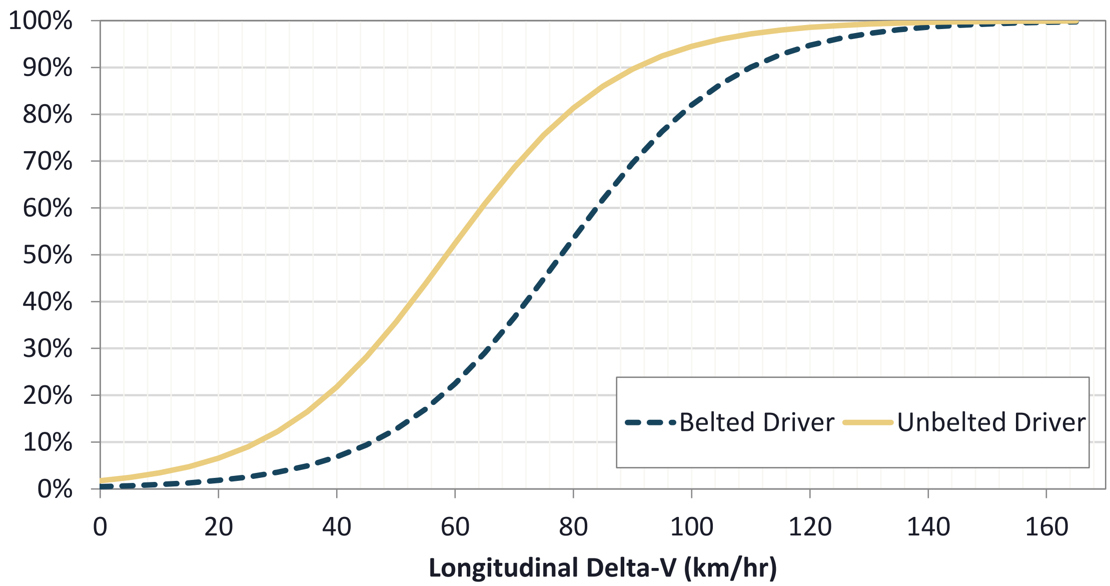


**Figure 9. Probability of Measurable Steering Wheel Deformation for Belted and Unbelted 70kg Driver**

Based on the logistic regression shown in Figure 9, the probability of steering wheel deformation is a function of delta-V, belt use, and driver weight. An unbelted 70-kg driver has a 10% probability of deforming the steering wheel at approximately 28 km/hr. By comparison, a belted driver of the same weight must be in a much more severe crash (delta-V = 48 km/hr) to have the same 10% chance of any measureable steering wheel deformation.

### 3.1.3 *INFLUENCE OF AIRBAG TYPE ON STEERING WHEEL DEFORMATION*

A separate dataset was generated in order to compare the influence of different generation of airbag on steering wheel deformation. The dataset used for the comparison was extracted from NASS/CDS case year 1993-2011, and included vehicles equipped with the four types of airbag: 1) no airbag equipped, 2) first generation airbag, 3)depowered airbag, and 4) advanced airbag. The dataset included cases with airbag deployment and non-deployment in order to compare vehicles with and without airbag equipped in crashes of similar severity. Table 9 Table 10 shows the dataset composition of airbag for belted and unbelted drivers, respectively.

**Table 9. Composition of Airbag Distribution NASS/CDS 1993-2011 – Belted Drivers**

| Deployment Level | Unweighted | | | |
|---|---|---|---|---|
| | No Airbag Equipped | First Generation Airbag | Depowered Airbag | Advanced Airbag |
| No Airbag Deployment | 4,211 | 1,644 | 4,164 | 1,571 |
| Airbag Deployed | - | 5,177 | 7,522 | 2,907 |
| Total | 4,211 | 6,821 | 11,686 | 4,478 |
| Deployment Level | Weighted | | | |
| | No Airbag Equipped | First Generation Airbag | Depowered Airbag | Advanced Airbag |
| No Airbag Deployment | 2,340,412 | 1,548,050 | 2,742,612 | 683,530 |
| Airbag Deployed | - | 2,405,771 | 2,550,071 | 740,829 |
| Total | 2,340,412 | 3,953,821 | 5,292,683 | 1,424,359 |

**Table 10. Composition of Airbag Distribution NASS/CDS 1993-2011 – Unbelted Drivers**

| Deployment Level | Unweighted | | | |
|---|---|---|---|---|
| | No Airbag Equipped | First Generation Airbag | Depowered Airbag | Advanced Airbag |
| No Airbag Deployment | 4,425 | 330 | 473 | 139 |
| Airbag Deployed | - | 1,664 | 1,855 | 522 |
| Total | 4,425 | 1,994 | 2,328 | 661 |
| Deployment Level | Weighted | | | |
| | No Airbag Equipped | First Generation Airbag | Depowered Airbag | Advanced Airbag |
| No Airbag Deployment | 1,540,647 | 254,685 | 209,091 | 41,652 |
| Airbag Deployed | - | 542,029 | 487,600 | 123,462 |
| Total | 1,540,647 | 796,714 | 696,691 | 165,114 |

Odds ratio was calculated for each of the airbag types, using advanced airbag as the reference, in order to compare the influence of each type of airbag on steering wheel deformation. Odds ratio were calculated using a logistic regression model in order to control for longitudinal delta-V, driver weight, and belt status. This method allows for the comparison of potential difference in the odds of steering wheel deformation for crashes of similar severity and driver weight.

Table 11 and Table 12 show the odds ratio of steering wheel deformation for all belted and unbelted drivers, respectively. The odds ratio calculated in the tables compares the odds of steering wheel deformation for crashes with no airbag deployment and airbag deployed cases. As shown in the table, vehicles with no airbag equipped present both the belted and unbelted drivers with greater odds of deforming the steering wheel. Specifically, compared to advanced airbags, belted drivers in vehicles with no airbag had over 3 times greater statistically significant odds of deforming the steering wheel. Similarly, unbelted drivers had over 2 times greater odds of deforming the steering wheel in vehicles with no airbag equipped. No statistically significant difference in odds of deforming the steering wheel were found between first generation, depowered, and advanced airbags.

**Table 11. Odds Ratio of Steering Wheel Deformation All Belted Drivers (Airbag Deployed and No Airbag Deployment) Adjusted for Driver Weight and Longitudinal Delta-V**

| Airbag Type | Odds Ratio | 95% Confidence Limit | |
|---|---|---|---|
| | | Lower | Upper |
| **No Airbag Equipped** | 3.789 | 2.058 | 6.976 |
| **First Generation Airbag** | 1.658 | 0.957 | 2.874 |
| **Depowered Airbag** | 1.242 | 0.707 | 2.182 |

**Reference: Advanced Airbag**

**Table 12. Odds Ratio of Steering Wheel Deformation**
**All Unbelted Drivers (Airbag Deployed and No Airbag Deployment)**
**Adjusted for Driver Weight and Longitudinal Delta-V**

| Airbag Type | Odds Ratio | 95% Confidence Limit | |
|---|---|---|---|
| | | Lower | Upper |
| **No Airbag Equipped** | 2.419 | 1.327 | 4.410 |
| **First Generation Airbag** | 1.408 | 0.736 | 2.694 |
| **Depowered Airbag** | 1.001 | 0.524 | 1.915 |

**Reference: Advanced Airbag**

Table 13 and Table 14 show the odds ratio of steering wheel deformation in crashes with airbag deployment for belted and unbelted drivers, respectively. Belted drivers in vehicles with first generation airbag had statistically significant greater odds of deforming the steering wheel as compared to drivers with advanced airbag. Specifically, the odds of deforming the steering wheel increased by a factor of 2 for drivers with first generation airbags. No statistically significant difference in the odds of steering wheel deformation were found between depowered airbag and advanced airbag. Similarly, no statistical significant difference in odds of deforming the steering wheel was found between first generation, depowered, and advanced airbag for unbelted drivers.

**Table 13. Odds Ratio of Steering Wheel Deformation – Belted Drivers With Airbag Deployment Only**
**Adjusted for Driver Weight and Longitudinal Delta-V**

| Airbag Type | Odds Ratio | 95% Confidence Limit | |
|---|---|---|---|
| | | Lower | Upper |
| **First Generation Airbag** | 1.878 | 1.029 | 3.426 |
| **Depowered Airbag** | 1.339 | 0.766 | 2.341 |

**Reference: Advanced Airbag**

**Table 14. Adjusted Odds Ratio of Steering Wheel Deformation – Unbelted Drivers With Airbag Deployment Only**
**Adjusted for Driver Weight and Longitudinal Delta-V**

| Airbag Type | Odds Ratio | 95% Confidence Limit | |
|---|---|---|---|
| | | Lower | Upper |
| **First Generation Airbag** | 1.573 | 0.751 | 3.297 |
| **Depowered Airbag** | 0.948 | 0.453 | 1.983 |

**Reference: Advanced Airbag**

## 3.2 Steering Wheel Deformation - Belted Drivers

### *3.2.1 Injury Consequences for Belted Drivers*

Figure 10 presents the distribution of total delta-V for vehicles with and without measurable steering wheel deformation. The median delta-V for crashes without measurable steering wheel deformation was 19 km/hr while the median delta-V for crashes with measurable steering wheel deformation was 30 km/hr. This figure shows that, as might be expected, steering wheel deformation is more likely to occur in higher severity crashes.

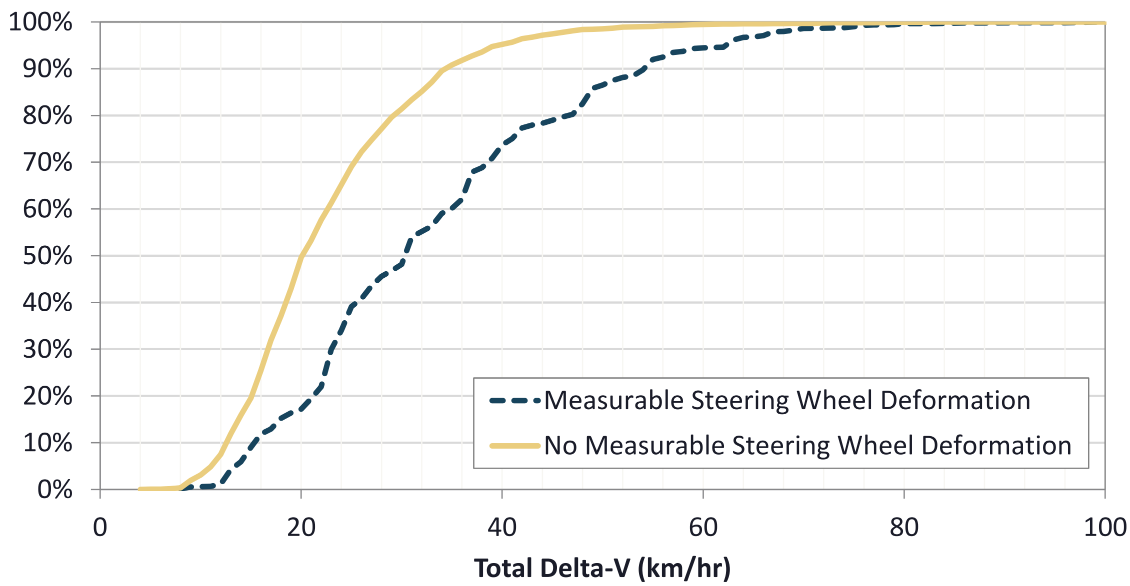


**Figure 10. Total Delta-V Distribution of Vehicles With and Without Steering Wheel Deformation (Belted Drivers)**

For belted drivers with moderate (MAIS2+) and serious (MAIS3+) injuries, Figure 11 and Figure 12 shows that crashes with steering wheel deformation were associated with crashes with higher severity.

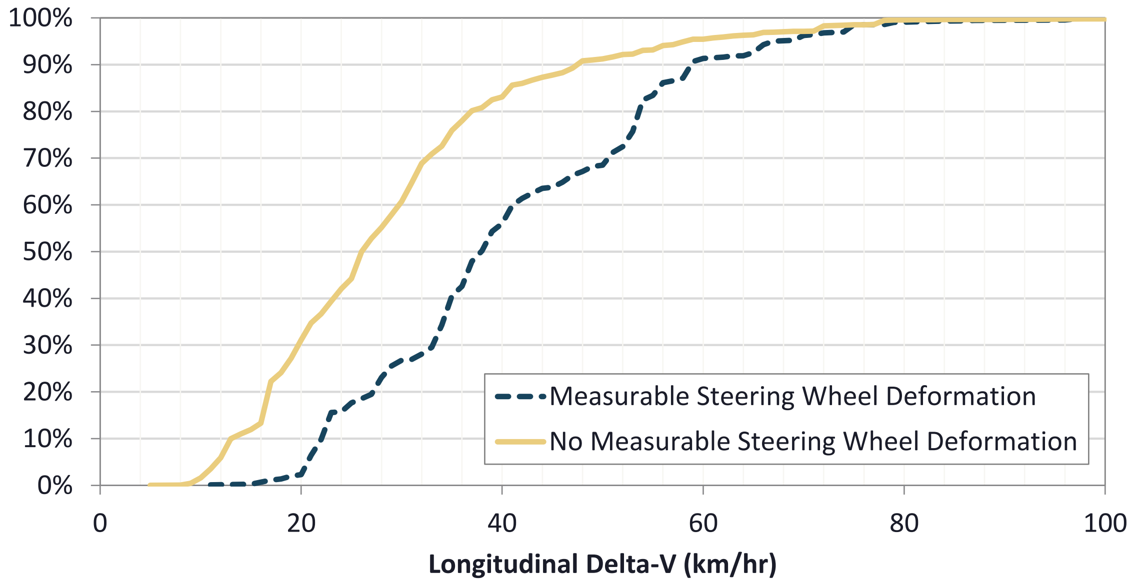


**Figure 11. Longitudinal Delta-V Distribution of Vehicles With and Without Steering Wheel Deformation (MAIS2+ Belted Drivers)**

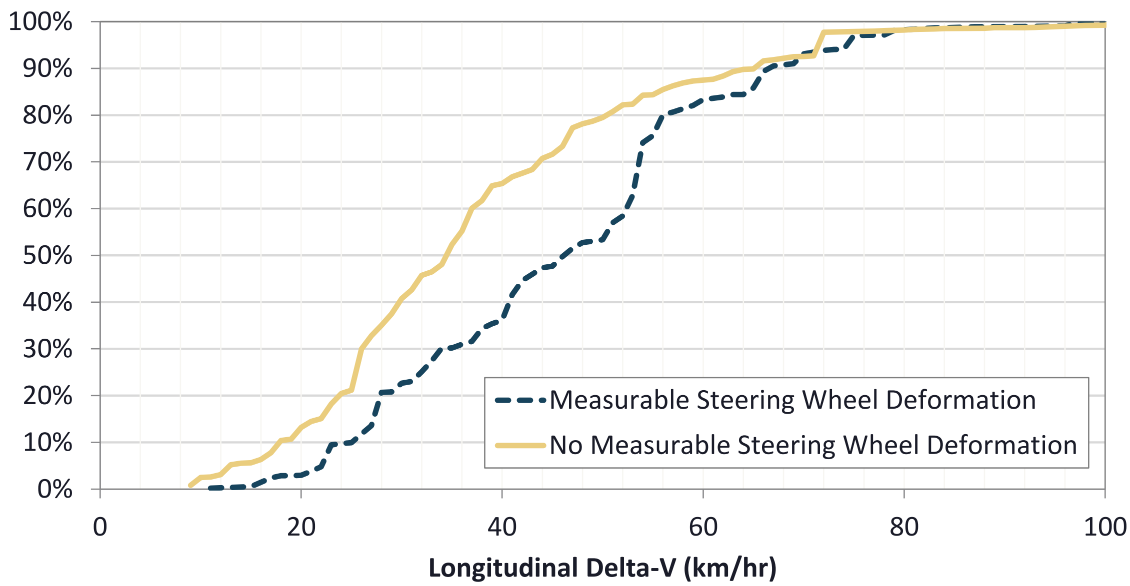


**Figure 12. Longitudinal Delta-V Distribution of Vehicles With and Without Steering Wheel Deformation (MAIS3+ Belted Drivers)**

Figure 13 shows the adjusted odds ratio of AIS2+ injuries by body region. A logistic regression model was fitted to the dataset in order to control for the effect of crash severity (delta-V) and driver weight. This model allowed a comparison of the odds of injury in crashes with and without steering wheel deformation between drivers that were of the same weight and involved in crashes with the same severity. Error bars have also been added to show 95% Wald confidence intervals. As shown in the figures, given the same longitudinal delta-V and driver weight, crashes with measurable steering wheel deformation present the driver with greater odds of AIS2+ injuries in all body regions. However, the 95% confidence intervals of the odds ratio suggest no statistically significant difference in odds of AIS2+ neck injuries, between crashes with and without measurable steering wheel deformation. A summary of the adjusted odds ratio can be found in Table 15.

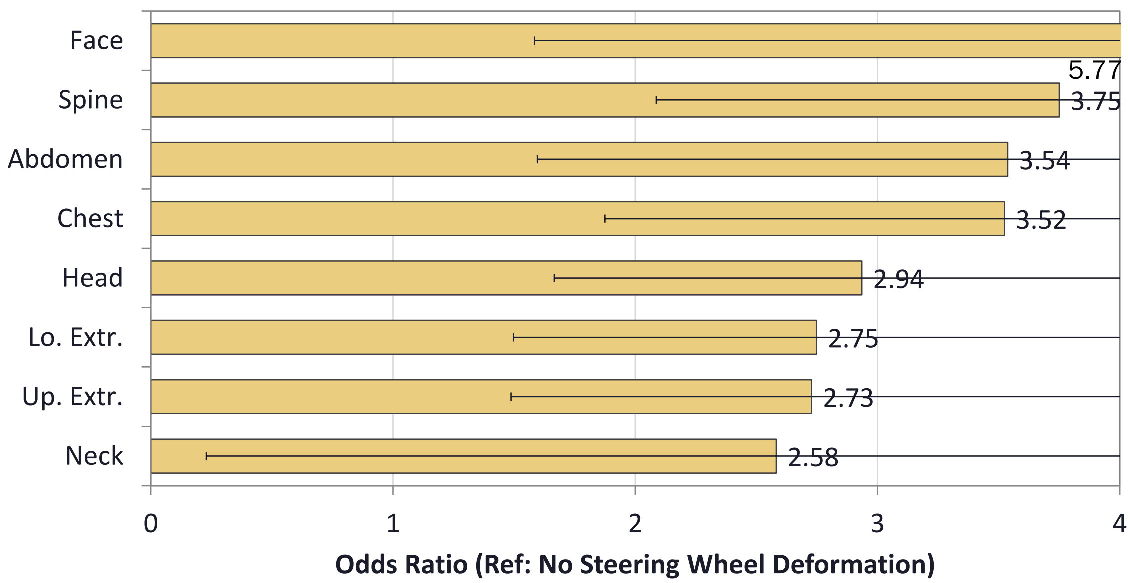


**Figure 13. Adjusted Odds Ratio of AIS2+ Injury for Belted Driver**

**Table 15. Adjusted Odds Ratio of AIS2+ Injury for Belted Drivers**

| AIS2+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | Lower | Upper |
| **Head** | 2.935 | 1.665 | 5.176 |
| **Face** | 5.767 | 1.584 | 20.998 |
| **Neck** | 2.582 | 0.229 | 29.063 |
| **Chest** | 3.524 | 1.875 | 6.623 |
| **Abdomen** | 3.538 | 1.596 | 7.843 |
| **Spine** | 3.750 | 2.087 | 6.739 |
| **Up. Extr.** | 2.728 | 1.487 | 5.005 |
| **Lo. Extr.** | 2.748 | 1.497 | 5.045 |

**Reference: No Steering Wheel Deformation**

Figure 14 present the odds ratio of AIS3+ injuries adjusted for delta-V and driver weight. Based on the confidence intervals of the adjusted odds ratio shown in Figure 14, steering wheel deformation presents statistically significant higher odds of AIS3+ injury in all body regions, except the abdomen, neck and face. A summary of the adjusted odds ratio can be found in Table 16.

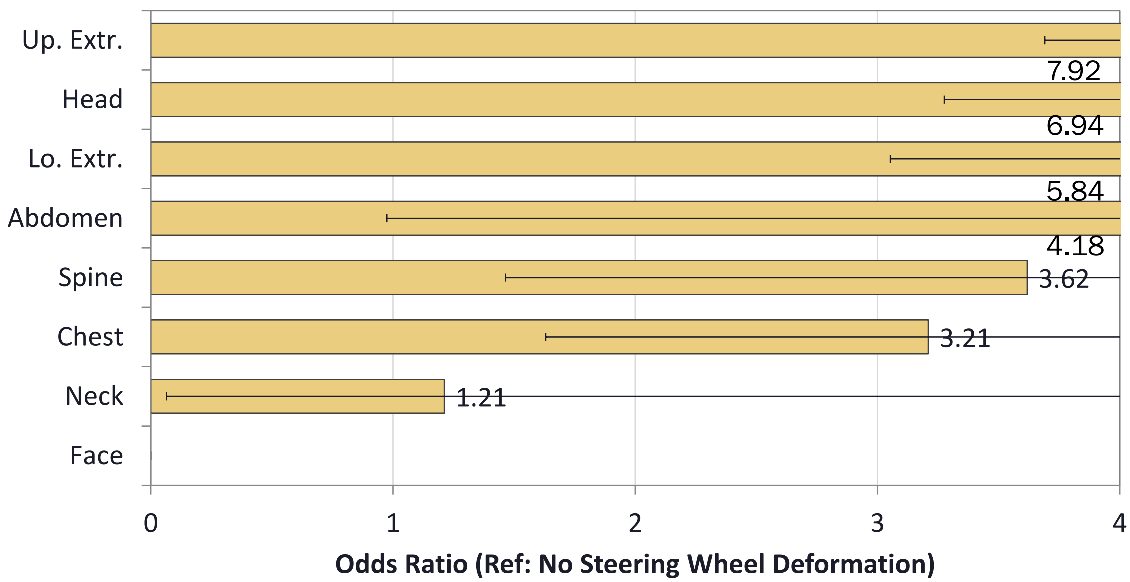


**Figure 14. Adjusted Odds Ratio of AIS3+ Injury for Belted Driver**

**Table 16. Adjusted Odds Ratio of AIS3+ Injury for Belted Drivers**

| AIS3+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | **Lower** | **Upper** |
| **Head** | 6.942 | 3.276 | 14.709 |
| **Face** | - | - | - |
| **Neck** | 1.212 | 0.065 | 22.537 |
| **Chest** | 3.210 | 1.630 | 6.319 |
| **Abdomen** | 4.184 | 0.974 | 17.968 |
| **Spine** | 3.618 | 1.464 | 8.937 |
| **Up. Extr.** | 7.923 | 3.691 | 17.006 |
| **Lo. Extr.** | 5.835 | 3.053 | 11.152 |

**Reference: No Steering Wheel Deformation**

### 3.2.2 *INJURY SOURCES FOR BELTED DRIVERS*

Figure 15 and Figure 16 show the distribution of the steering wheel deformation locations for AIS2+ and AIS 3+ injuries, respectively. The accompanying diagram in the figure shows the NASS/CDS coding scheme for steering wheel deformation. During a scene investigation, the investigators are instructed to denote the location with the most extreme downward deflection with respect to an un-deformed edge. "Complete Collapse" is selected in cases in which two half sections are deformed axially downward (toward the instrument panel) beyond the hub [34].

At both severity levels, the upper half of the steering wheel was more likely to be the deformed area than the lower half. This steering wheel deformation position may be due to occupant rotation over the top of the wheel rather than submarining under the wheel.

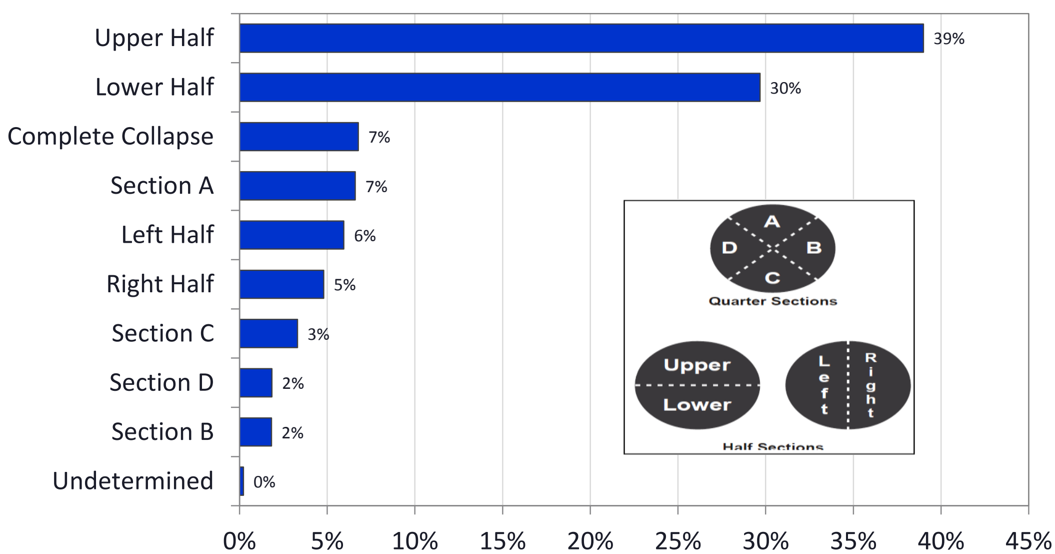


**Figure 15. Steering Wheel Deformation Location for AIS2+ Injuries**

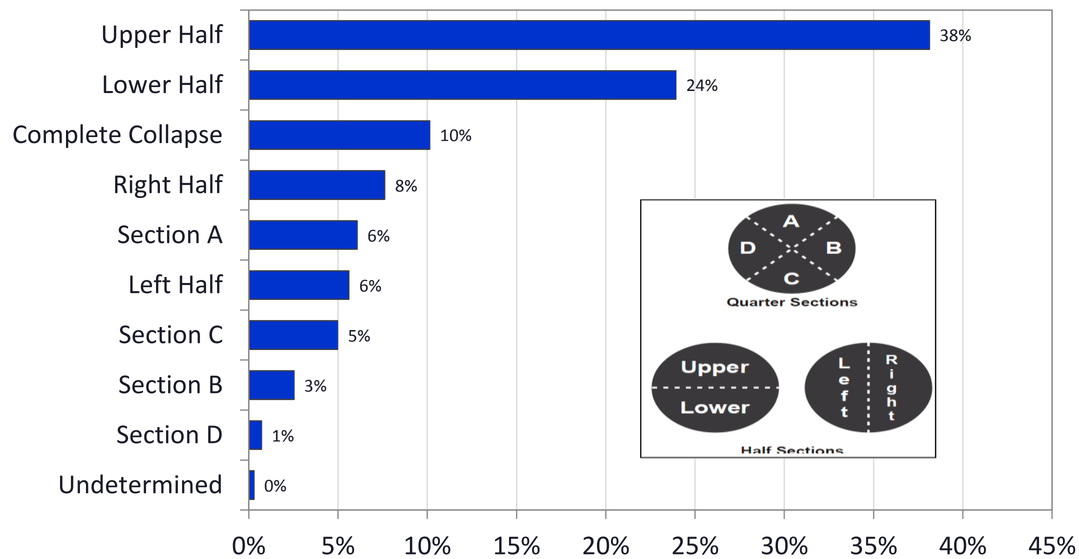


**Figure 16. Steering Wheel Deformation Location for AIS3+ Injuries**

Figure 17 shows the distribution of points at which the occupant made contact with the interior of the vehicle for all MAIS 2+ cases. Due to the large number of different contact sources, only the top 10 most frequent contact sources are shown. The remainders are grouped together under the category labeled "Other". Note that NASS investigators only coded MAIS2+ drivers as having struck the steering rim and steering combination in 11% of MAIS2+ cases. This was similar to the results of our separate analysis of steering wheel deformation which found that steering assembly deformation occurred in 15% of MAIS2+ cases.

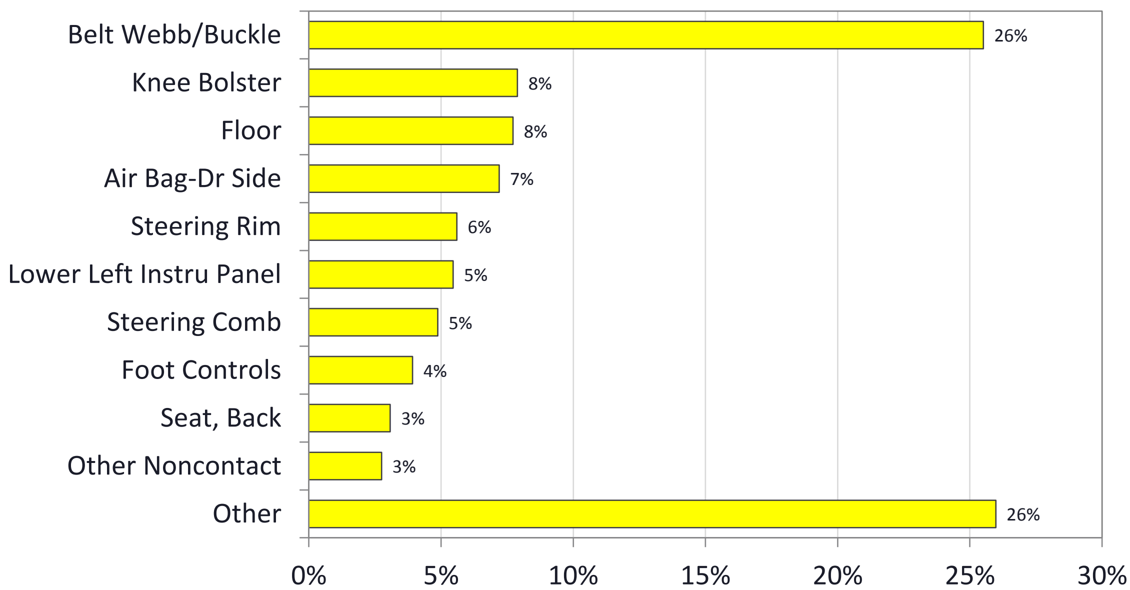


**Figure 17. Injury Contact Sources for MAIS2+ Injuries**

In addition, for belted drivers of all injury levels involved in crashes with measurable steering wheel deformation, Figure 18 shows a distribution of which components of the steering wheel assembly were contacted. In nearly two-thirds of the crashes, the injuries were caused by contact with the steering wheel rim. "Steering Combination" refers to injury caused by the combination of steering rim and steering hub.

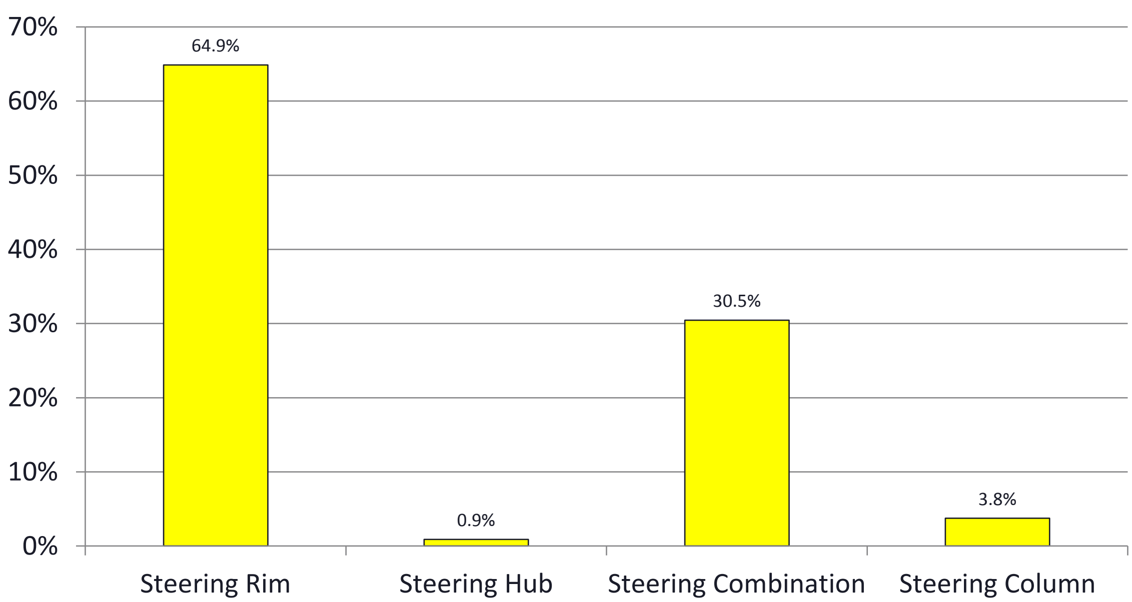


**Figure 18. Steering Wheel Contact Sources for All Belted Cases**

Figure 19 to Figure 22 show the distribution of injuries associated with each of the steering wheel components (steering rim, hub, combination, and column) for belted drivers. In crashes with belted drivers, the steering rim most frequently led to upper extremities injuries. Injuries from the steering hub were most frequently to the thorax. As expected, the upper extremities and the thorax contributed to the majority of injuries associated with the combination of steering rim and hub, as shown in Figure 21. Figure 22 shows that the steering column was associated predominantly with lower extremity injuries. This finding is consistent with results from Rastogi and Duthie, which suggests axial loading of the femur via knee impact to the steering column as a mode of injury [35]. Figure 23 shows fractures in the femur, patella, and pelvic region as the most frequent lower extremity injury types associated with steering wheel components.

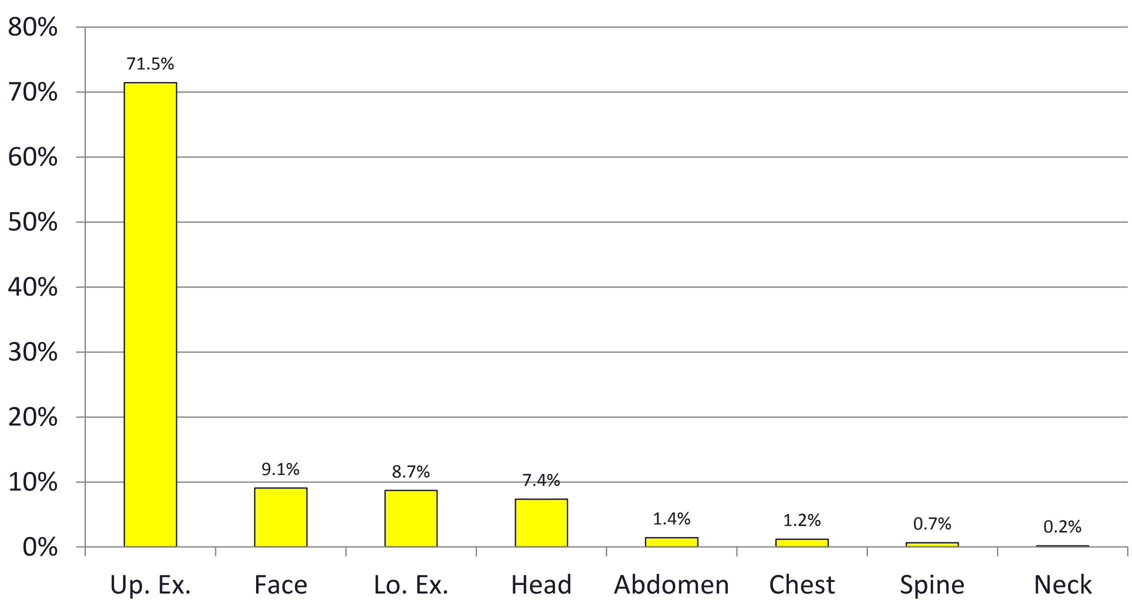


**Figure 19. Distribution of Injuries Associated With Steering Rim for All Belted Drivers**

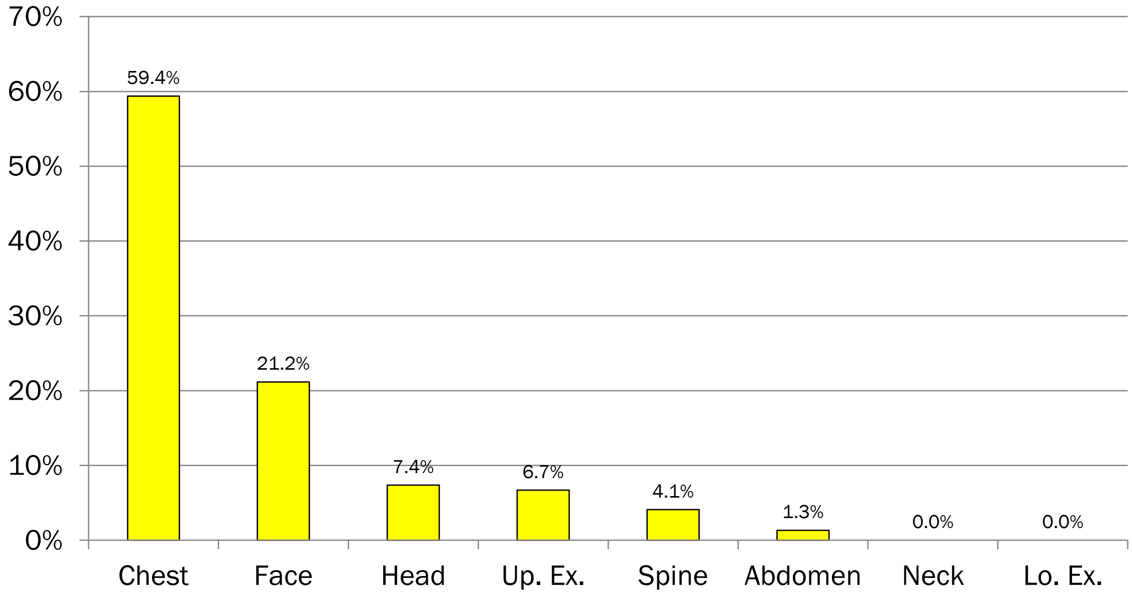


**Figure 20. Distribution of Injuries Associated With Steering Hub for All Belted Drivers**

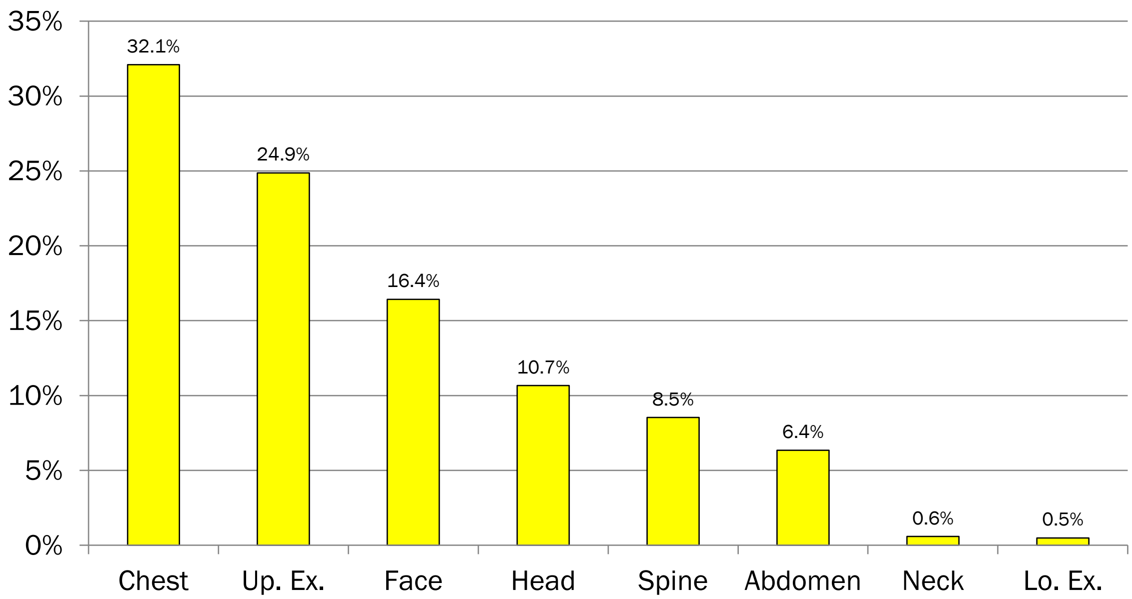


**Figure 21. Distribution of Injuries Associated With Steering Combination for All Belted Drivers**

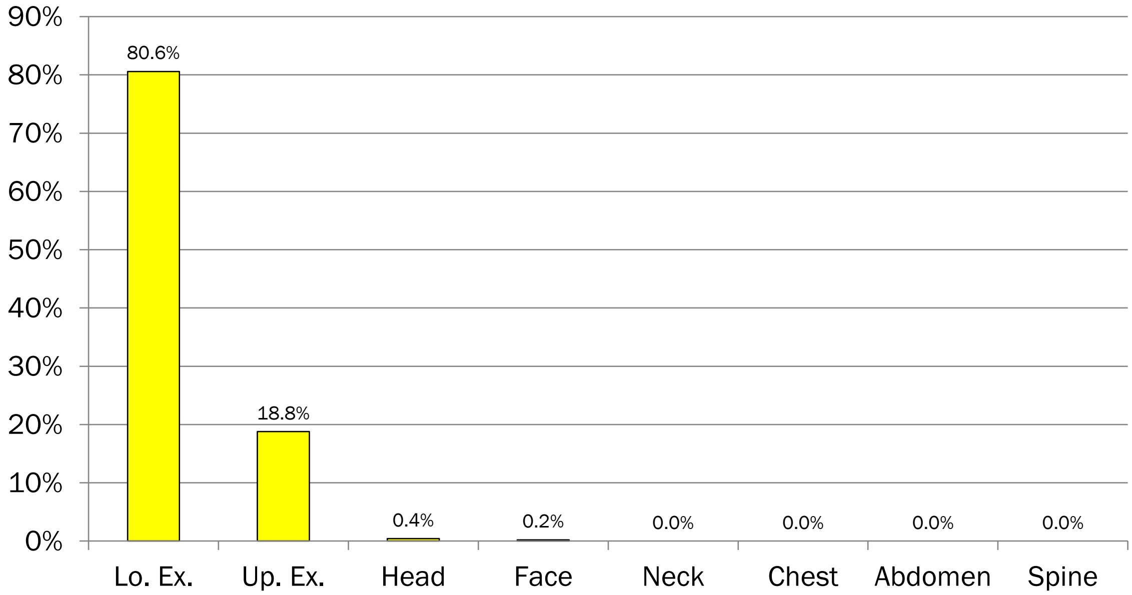


**Figure 22. Distribution of Injuries Associated With Steering Column for All Belted Drivers**

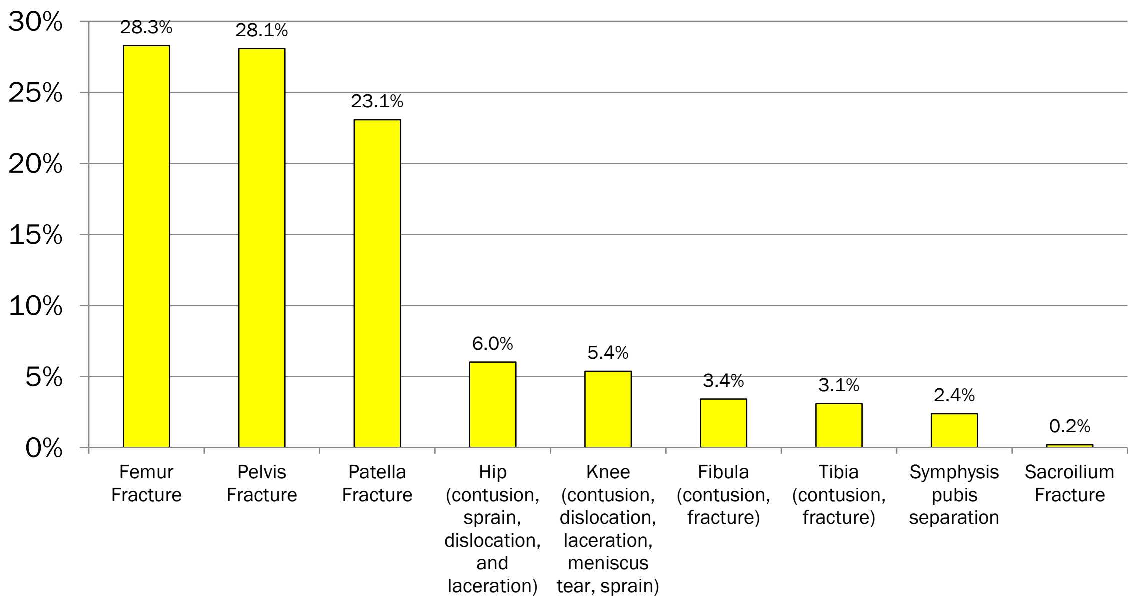


**Figure 23. Lower Extremity Injury Types Associated With Steering Wheel Components – Belted Drivers**

In severe crashes, it is possible for the driver to be injured by vehicle interior components through intrusion, rather than the occupant moving into the component. In order to identify and separate driver injury between direct contact and intrusion, Figure 24 shows the distribution of steering wheel intrusion for crashes with and without steering wheel deformation. As shown from the figure, steering wheel assembly intrusion is a rare event for both crashes with and without steering wheel deformation. Therefore, we can conclude that for belted drivers, steering wheel deformation is a result of the driver moving into the steering wheel, not through intrusion.

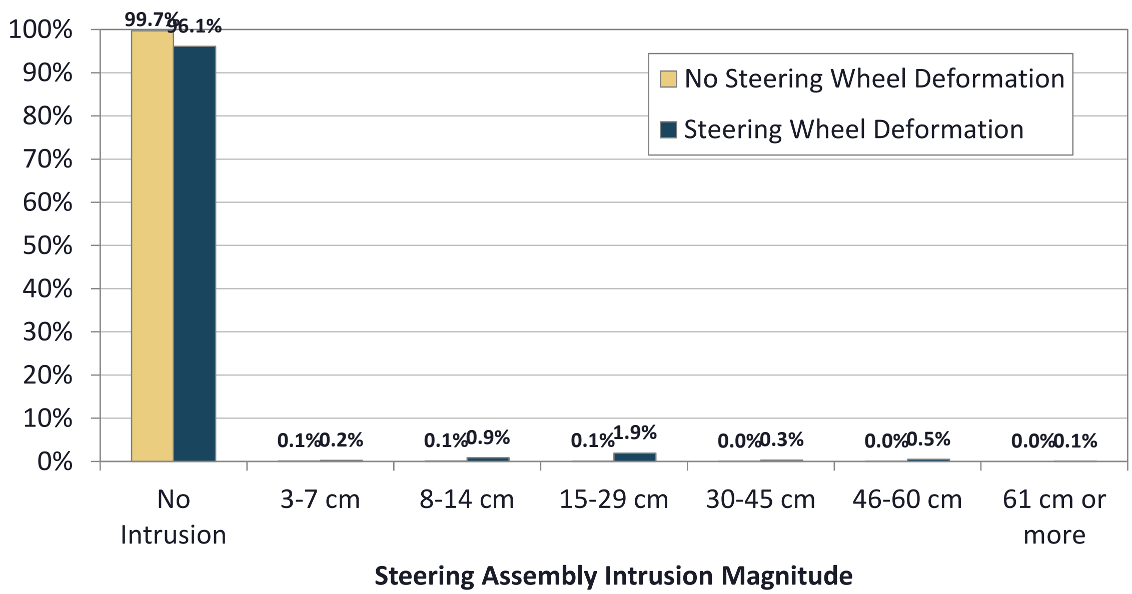


**Figure 24. Steering Wheel Assembly Intrusion Magnitude – Belted Drivers**

### *3.2.3 Discussion*

Steering wheel contact occurs at higher delta-V than crashes without steering wheel contact, as shown in Figure 10. Crashes with measurable steering wheel deformation had a median delta-V of about 30 km/hr, compared to a median delta-V of about 19 km/hr in cases without steering wheel deformation. The results shown in Figure 13 and Figure 14 indicate statistically significant greater odds of both AIS2+ and AIS3+ injuries for nearly all body regions for cases with measurable steering deformation.

These results show a large difference in the odds of injury between crashes with and without steering wheel deformation. After controlling for delta-V and weight of the driver, Figure 13 showed over five times greater odds of AIS2+ face injuries for cases with measurable steering wheel deformation, and over three times greater odds of injury in the spine, abdomen, and chest. Likewise, for AIS3+ injuries, measurable steering wheel deformation poses almost 8 times greater odds of injury for the upper extremity as well as almost 7 times greater odds for the head, as shown in Figure 14.

All cases in this section of the study involved belted drivers in vehicles equipped with airbags. However, the findings have shown that these safety devices do not prevent the driver from loading the steering wheel during a frontal crash. In the steering wheel deformation location distributions, shown in Figure 15 and Figure 16, the majority of the deformations were observed on the upper half of the steering wheel. A likely cause of these deformations could be contact with the driver's upper body. In the case of a driver that was seated closer to the steering wheel, even though the driver was belted and makes full contact with the airbag, the driver may "bottom-out" the air bag, pressing his or her chest and face onto the steering wheel as the driver rotates forward.

Figure 17 shows that the major source of injury for drivers included in this dataset was the seatbelt. Figure 18 indicates that for belted drivers, when injuries were caused by steering wheel impact, the injuries were largely associated with direct contact with the steering rim.

In the crashes where steering wheel component (steering rim, hub, or column) was identified as the contact source, Figure 19 to Figure 22 showed that the steering rim impact was associated predominantly with upper extremity, while the majority of impact with the steering hub results in thoracic injuries. Lastly, lower extremities injuries accounts for the majority of impact events with the steering column.

## 3.3 Steering Wheel Deformation – Unbelted Drivers

### *3.3.1 Injury Consequences for Unbelted Drivers*

Figure 25 presents the distribution of total delta-V for vehicles with and without measurable steering wheel deformation. The median delta-V for crashes without measurable steering wheel deformation was 22 km/hr while the median delta-V for crashes with measurable steering wheel deformation was 32 km/hr. As with belted drivers, steering wheel deformation for unbelted drivers is more likely to occur in higher severity crashes.

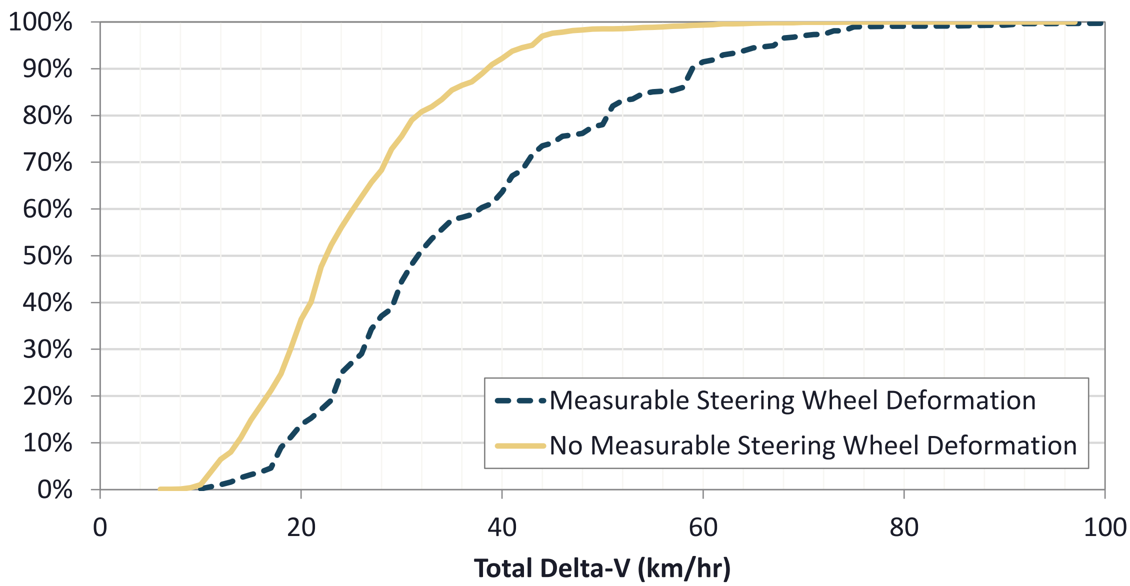


**Figure 25. Total Delta-V Distribution of Vehicles With and Without Steering Wheel Deformation (Unbelted Drivers)**

Similar to the dataset of belted drivers, Figure 26 and Figure 27 show that crashes with steering wheel deformation were associated with higher crash severity for unbelted drivers with MAIS2+ and MAIS3+ injures.

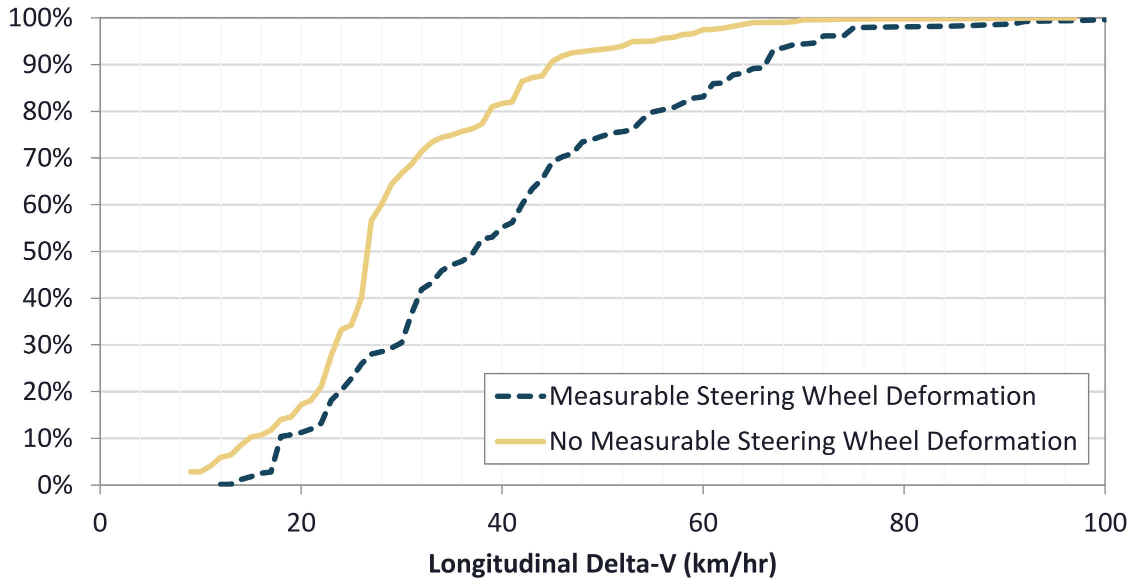


**Figure 26. Longitudinal Delta-V Distribution of Vehicles With and Without Steering Wheel Deformation (MAIS2+ Unbelted Drivers)**

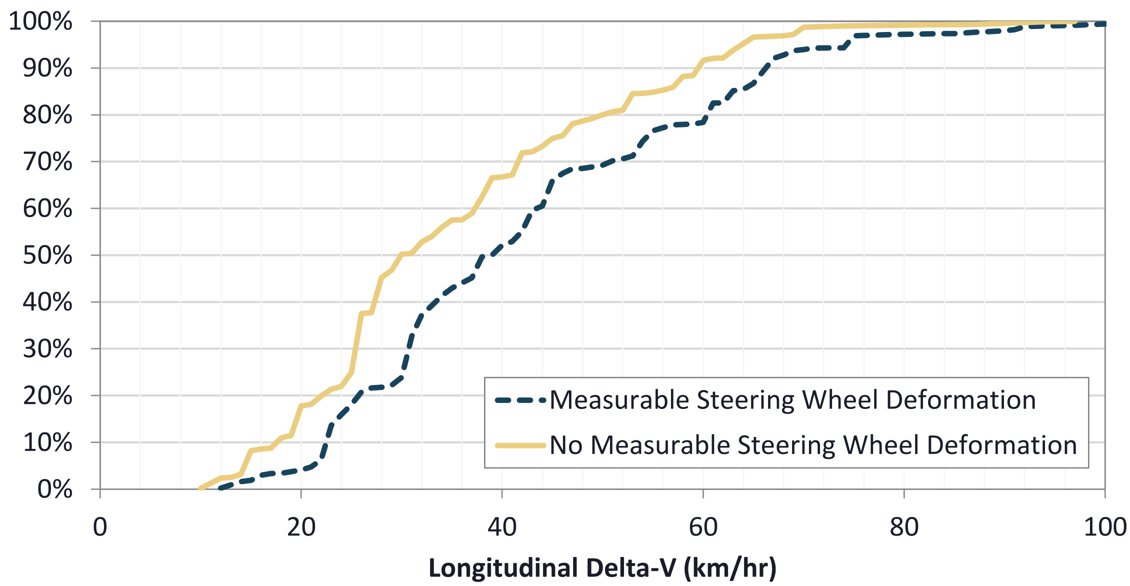


**Figure 27. Longitudinal Delta-V Distribution of Vehicles With and Without Steering Wheel Deformation (MAIS3+ Unbelted Drivers)**

Figure 28 shows the adjusted odds ratio of AIS2+ injuries by body region. A logistic regression model was fitted to the dataset in order to control for the combined non-linear effect of crash severity (delta-V) and driver weight. This model allowed a comparison of the odds of injury in crashes with and without steering wheel deformation for drivers that were of the same weight and involved in crashes with the same severity. Error bars have also been added to show 95%

Wald confidence intervals. As shown in the figures, given the same longitudinal delta-V and driver weight, crashes with measurable steering wheel deformation present unbelted driver with greater odds of AIS2+ injuries in all body regions. However, the 95% confidence intervals indicate that only the chest and lower extremities have statistically significant higher odds of AIS2+ injury in crashes with measurable steering wheel deformation. Specifically, four times greater odds of AIS2+ thoracic injuries and almost three times greater odds of AIS2+ lower extremity injuries for crashes with measurable steering wheel deformation for unbelted drivers. A summary of the adjusted odds ratio can be found in Table 17.

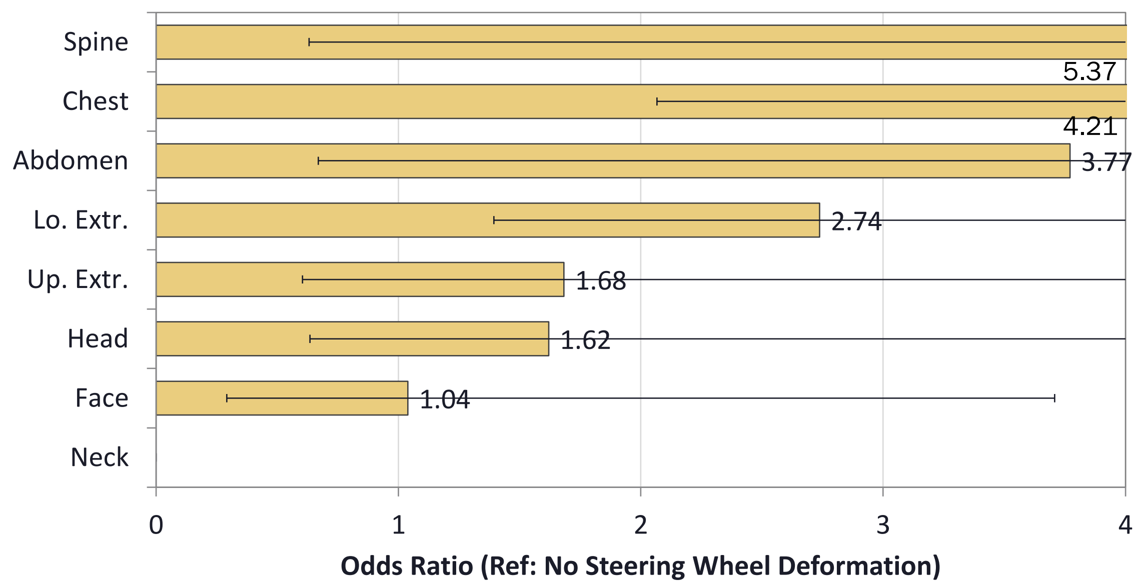


**Figure 28. Adjusted Odds Ratio of AIS2+ Injury for Unbelted Driver**

**Table 17. Adjusted Odds Ratio of AIS2+ Injury for Unbelted Drivers**

| AIS2+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | Lower | Upper |
| **Head** | 1.620 | 0.635 | 4.129 |
| **Face** | 1.039 | 0.291 | 3.708 |
| **Neck** | - | - | - |
| **Chest** | 4.206 | 2.067 | 8.558 |
| **Abdomen** | 3.771 | 0.669 | 21.267 |
| **Spine** | 5.365 | 0.631 | 45.597 |
| **Up. Extr.** | 1.683 | 0.604 | 4.687 |
| **Lo. Extr.** | 2.738 | 1.394 | 5.378 |

**Reference: No Steering Wheel Deformation**

Figure 29 presents the odds ratio of AIS3+ injuries adjusted for delta-V and driver weight for unbelted drivers. The confidence intervals shown in Figure 29 suggest crashes with measurable steering wheel deformation presents statistically higher odds of AIS3+ for unbelted drivers' abdomen, lower extremities, and chest. Specifically, for cases with measurable steering wheel deformation, the odds of AIS3+ abdomen injuries increase by a factor of 48 for unbelted drivers. A summary of the adjusted odds ratio can be found in Table 18.

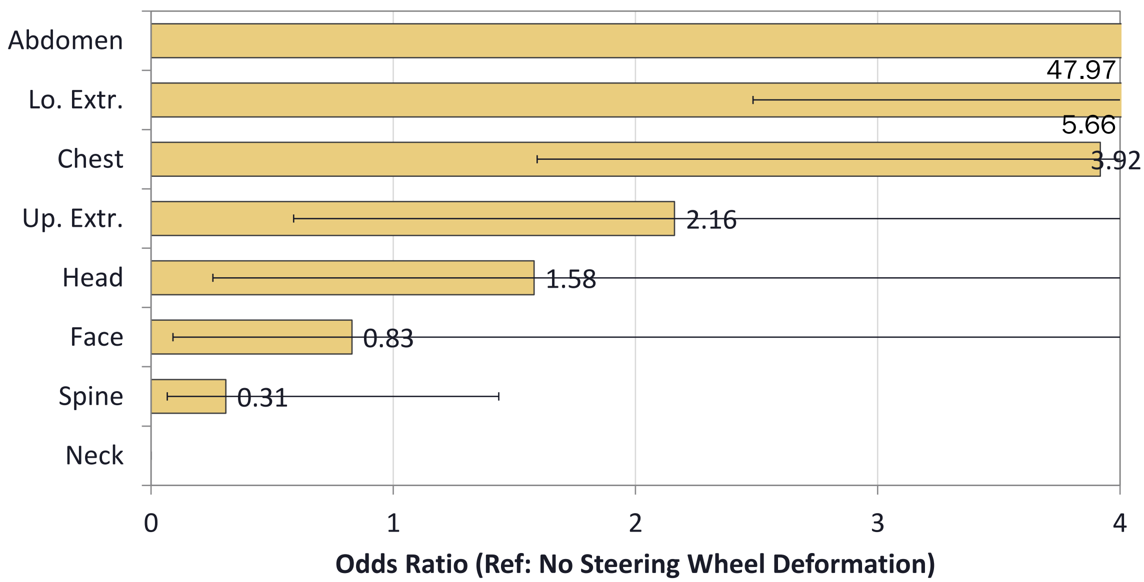


**Figure 29. Adjusted Odds Ratio of AIS3+ Injury for Unbelted Driver**

**Table 18. Adjusted Odds Ratio of AIS3+ Injury for Unbelted Drivers**

| AIS2+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | Lower | Upper |
| Head | 1.581 | 0.255 | 9.788 |
| Face | 0.829 | 0.090 | 7.617 |
| Neck | - | - | - |
| Chest | 3.919 | 1.594 | 9.632 |
| Abdomen | 47.971 | 14.012 | 164.226 |
| Spine | 0.309 | 0.067 | 1.435 |
| Up. Extr. | 2.161 | 0.588 | 7.939 |
| Lo. Extr. | 5.656 | 2.485 | 12.877 |

**Reference: No Steering Wheel Deformation**

### *3.3.2 INJURY SOURCES FOR UNBELTED DRIVERS*

Figure 30 and Figure 31 shows the distribution of the steering wheel deformation locations for AIS2+ and AIS3+ injuries, respectively. Whereas for belted drivers, upper and lower half of steering wheel deformation was roughly equal, for unbelted drivers, the deformation was overwhelmingly to the upper half of the steering wheel for both AIS2+ and AIS3+ injured drivers.

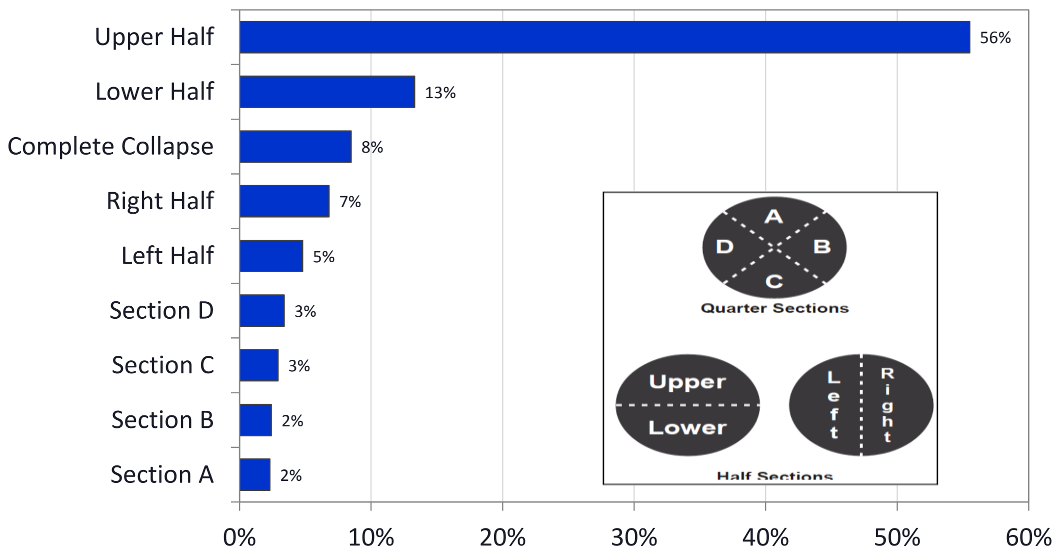


**Figure 30. Steering Wheel Deformation Location for AIS2+ Injuries for Unbelted Drivers**

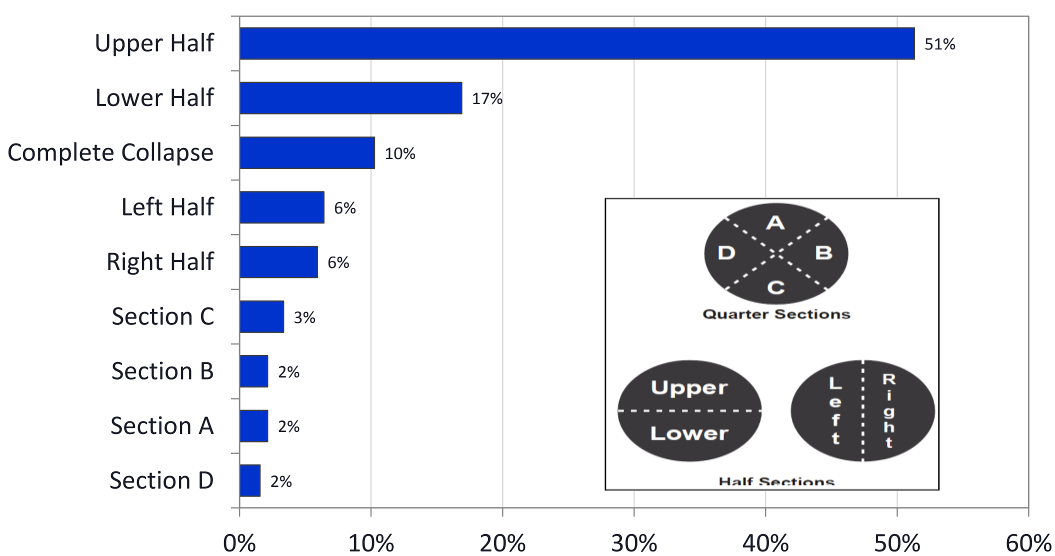


**Figure 31. Steering Wheel Deformation Location for AIS3+ Injuries for Unbelted Drivers**

Figure 32 shows the distribution of points at which the occupant made contact with the interior of the vehicle for all MAIS 2+ cases. Due to the large number of different contact sources, only the top 10 most frequent contact sources are shown, the remainders are grouped together under the row labeled "Other". Unlike belted drivers, unbelted drivers were primary injured by the combination of steering rim and steering hub. In addition, for all cases with measurable steering wheel deformation, Figure 33 shows a distribution of all contact sources relating to the steering wheel for all unbelted drivers regardless of injury level, where "Steering Combination" refers to injury caused by the combination of steering rim and steering hub

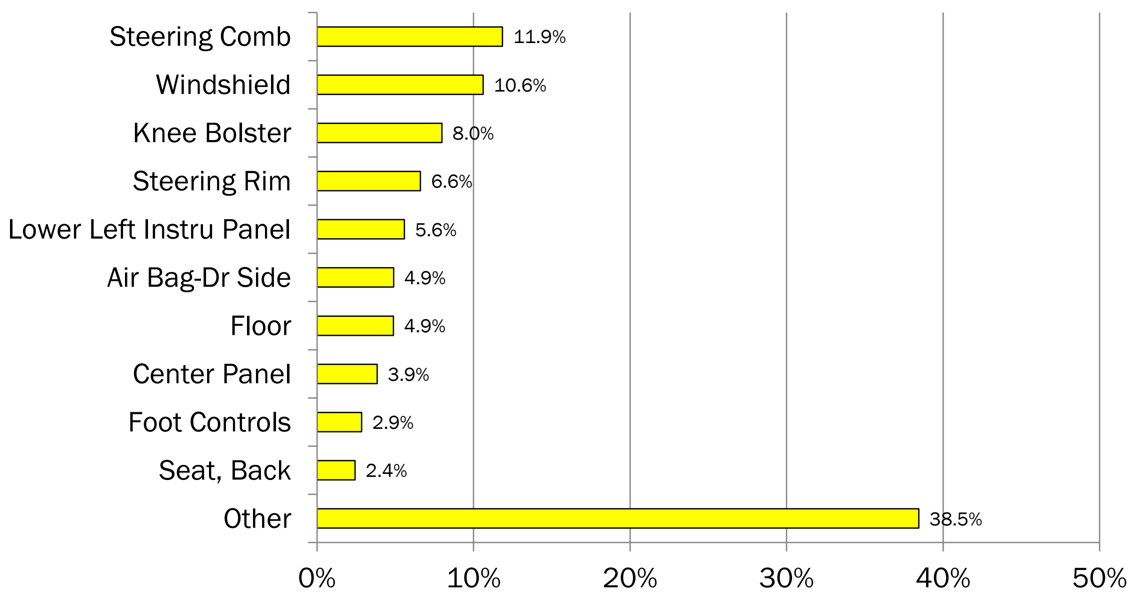


**Figure 32. Injury Contact Sources for MAIS2+ Injuries for Unbelted Drivers**

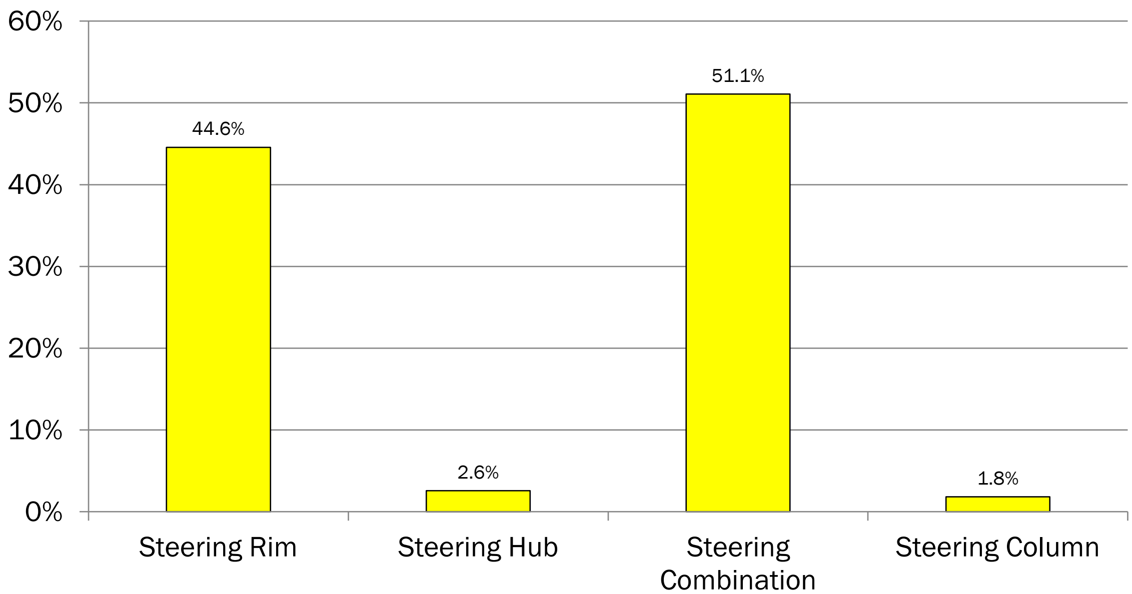


**Figure 33. Steering Wheel Contact Sources for All Unbelted Cases**

Figure 34 to Figure 37 shows the distribution of injuries associated with each of the steering wheel component (steering rim, hub, combination, and column) for unbelted drivers. For crashes involving unbelted drivers, the distribution of dominant body region associated with each of the steering wheel components was very similar to crashes with belted drivers. In lower extremity injuries associated with steering wheel component impact, femur fractures and pelvis fractures still consist of the majority of the injuries for unbelted drivers, as shown in Figure 38.

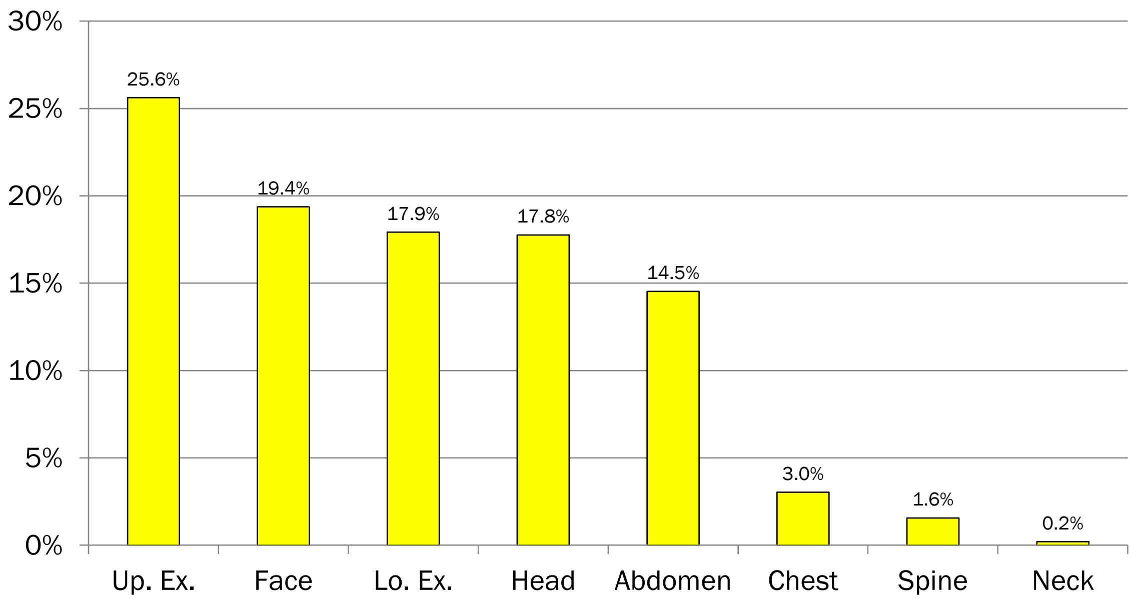


**Figure 34. Distribution of Injuries Associated With Steering Rim for All Unbelted Drivers**

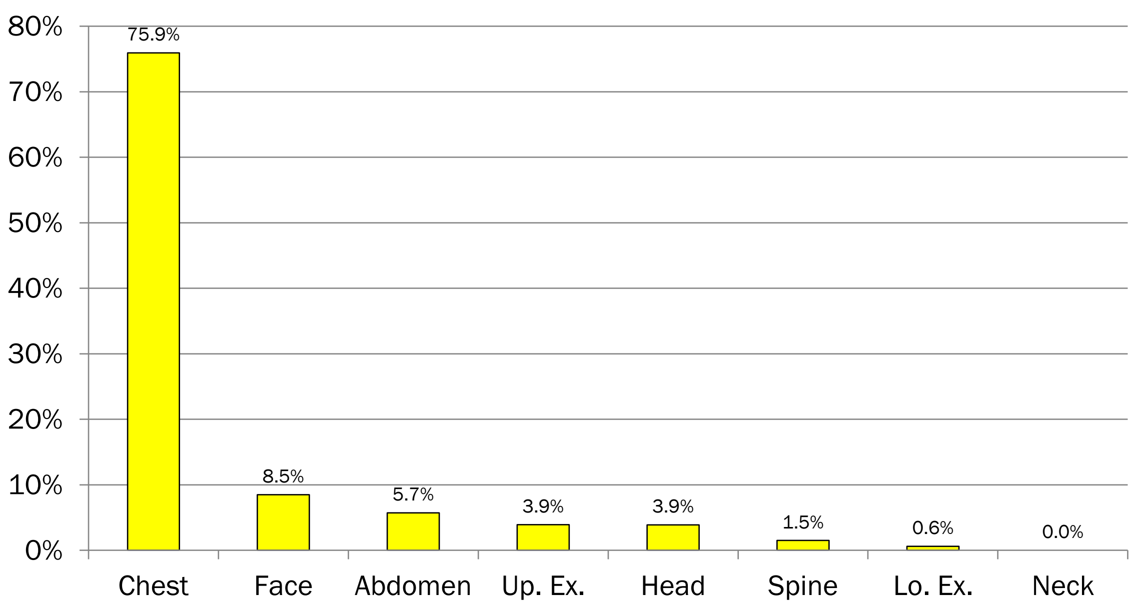


**Figure 35. Distribution of Injuries Associated With Steering Hub for All Unbelted Drivers**

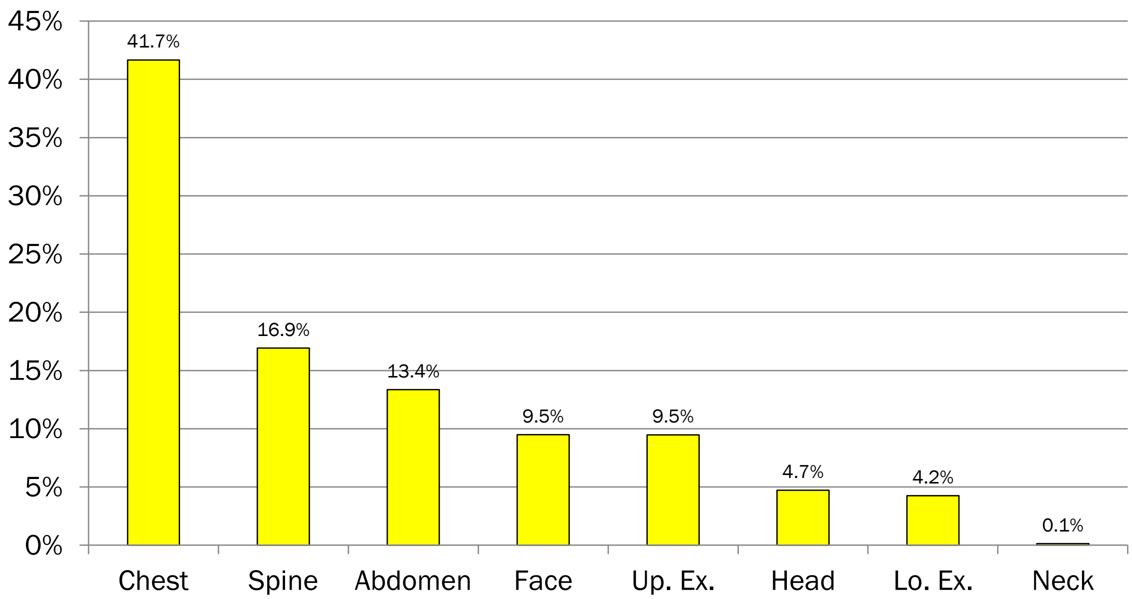


**Figure 36. Distribution of Injuries Associated With Steering Combination for All Unbelted Drivers**

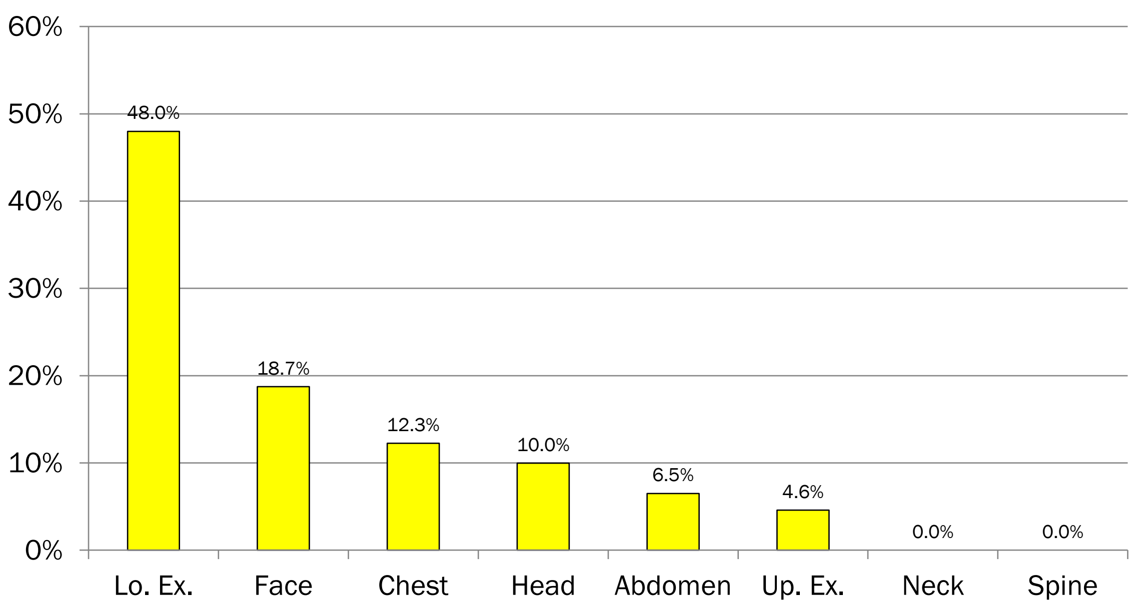


**Figure 37. Distribution of Injuries Associated With Steering Column for All Unbelted Drivers**

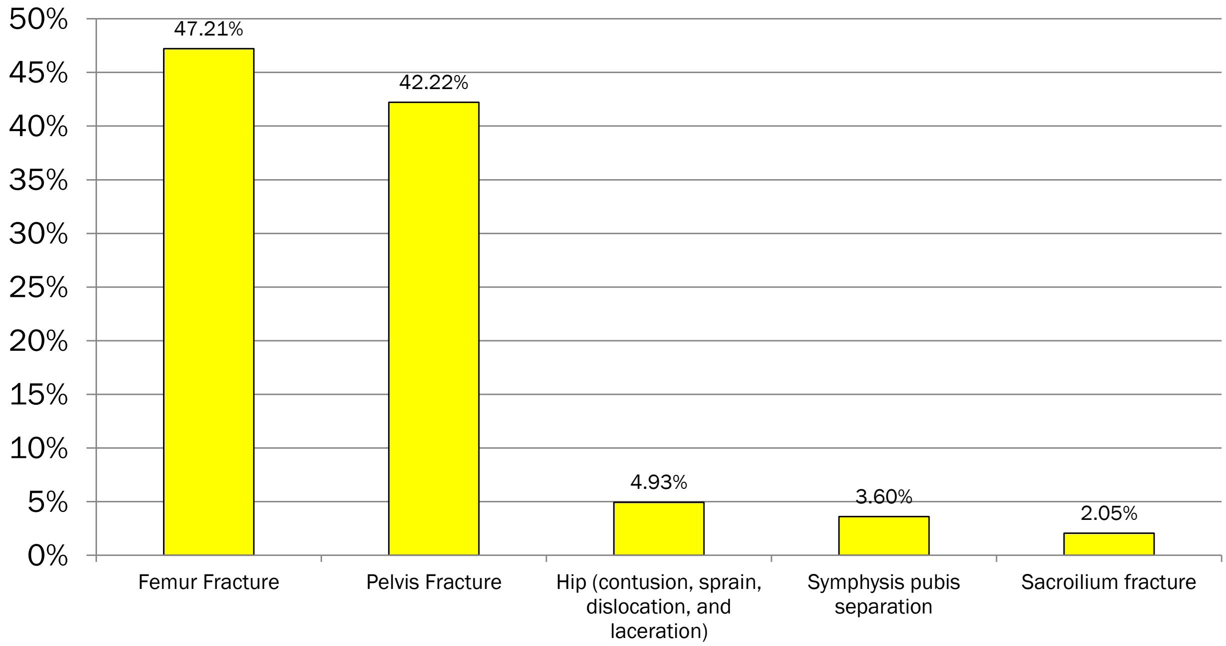


**Figure 38. Lower Extremity Injury Types Associated With Steering Wheel Components – Unbelted Drivers**

Similar to the belted dataset, Figure 39 shows the distribution of steering wheel intrusion for crashes with and without steering wheel deformation in unbelted drivers. As shown from the figure, steering wheel assembly intrusion is a rare event for both crashes with and without steering wheel deformation. Therefore, we can conclude that for unbelted drivers, steering wheel deformation is also a result of the driver moving into the steering wheel, rather than through intrusion.

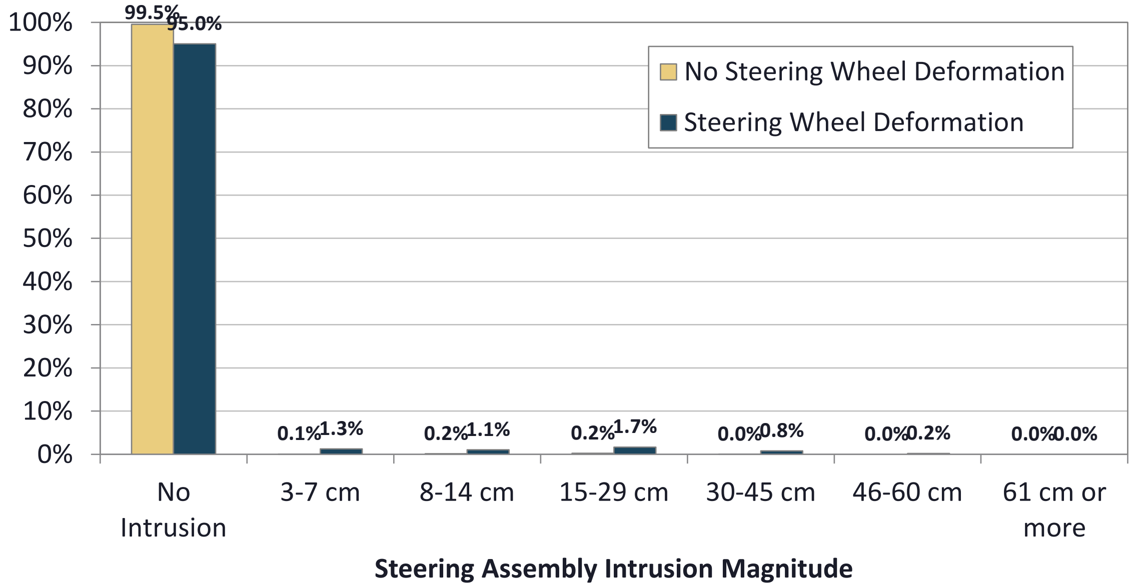


**Figure 39. Steering Wheel Assembly Intrusion Magnitude – Unbelted Drivers**

### *3.3.3 DISCUSSION*

Similar to the belted driver analysis, the incidence of steering wheel contact increases with increasing delta-V. Among unbelted drivers, crashes with measurable steering wheel deformation had a median delta-V of about 32 km/hr, compared to a median delta-V of about 22 km/hr in cases without steering wheel deformation. The odds of both AIS2+ and AIS3+ injury were greater for crashes involving steering wheel deformation than not.

All cases in this section of the study involved unbelted drivers in vehicles equipped with airbags. In our dataset, crashes with steering wheel deformation involved 13% of all unbelted drivers, but accounted for over half of all MAIS3+ injured unbelted drivers. Similar to belted drivers, unbelted drivers are at higher odds of injury in crashes with measurable steering wheel deformation, as indicated by delta-V and odds of injury distribution. Based on the adjusted odds ratios and the associated 95% confidence intervals, unbelted drivers have statistically significant higher odds of AIS2+ thoracic and lower extremity injuries in crashes with measurable steering wheel deformation. Likewise, odds of AIS3+ lower extremity and thoracic injuries increased by a factor of 5 and 3, respectively, for unbelted drivers in crashes with measurable steering wheel deformation. The findings indicate that drivers cannot rely solely on airbags to prevent them from making contact with the steering wheel during a frontal crash. When the steering wheel was deformed, the deformations in the majority of the cases occurred on the upper half of the steering wheel. In the event of a frontal crash, the unbelted driver is not restrained against vaulting over the steering wheel. Even when the airbag was deployed, the forward momentum of the driver is likely to causes the driver to pitch forward and "bottom-out" the airbag, subsequently impacting the steering wheel.

## 3.4 Conclusions

This chapter of the thesis analyzed the incidence and risk of direct steering wheel impact. The dataset included vehicles that were involved in crashes with and without steering wheel deformation. The findings of the analysis are summarized as followed.

In both belted and unbelted drivers, steering wheel deformation was found to be a rare event. Only 4% of the belted driver and 13% of the unbelted drivers in the dataset were involved in crashes with steering wheel deformation. However, this small percentage of crashes with steering wheel deformation was overrepresented in the injury outcome: 29% of serious injured belted drivers and 58% of serious injured unbelted drivers were involved in crashes with steering wheel deformation. Clearly, failure to wear a safety belt puts unbelted drivers at a higher risk of impacting the steering wheel than belted drivers. The result is a sharply elevated risk of injury.

The probability of steering wheel deformation was found to be associated with longitudinal delta-V, driver weight, and belt status. No statistically significant difference in the odds of steering wheel deformation was found between vehicles equipped with depowered and advanced airbags in crashes with airbag deployment. In the dataset of belted drivers with airbag deployment, first generation airbags were found to have statistically greater odds of deforming the steering wheel as compared to advanced airbags. Compared to advanced airbags, vehicles with no airbag equipped were found to have 3 times and 2 times greater odds of deforming the steering wheel for belted and unbelted drivers, respectively. Pre-tensioners and load limiters did not have a statistically significant effect on the probability of steering wheel deformation.

Crashes with steering wheel deformation were associated with higher odds of injury in nearly all body regions. For the dataset of belted drivers, steering wheel deformation presented the driver with almost 8 times greater odds of AIS3+ upper extremity injury as well as almost 7 times greater odds of AIS3+ head injury. In crashes with steering wheel deformation, the upper half of the steering wheel was more likely to be the deformed area, possibly a result of the driver rotating over the top of the wheel rather than submarining under the wheel. In cases with steering wheel deformation, the steering rim was found to be the most frequent contact source for belted drivers. Driver upper extremity was found to be the most frequent injury associated with the steering rim, while chest injuries were most frequently associated with the steering hub, and the lower extremities were most frequently contacted by the steering column.

The injury outcome for unbelted drivers was similar to belted drivers. Crashes with steering wheel deformation was found to have 5 times greater odds of AIS3+ lower extremity injury and almost 4 times greater odds of AIS3+ chest injury for unbelted drivers. Compared to belted drivers, steering wheel deformation location was overwhelmingly to the upper half of the steering wheel and injuries were most frequently associated with steering assembly contact. In all injuries associated with the steering rim, the injured body region was divided almost equally amongst the upper extremity, face, lower extremity, head, and abdomen. Chest injuries were still predominantly associated with the steering hub and lower extremity injuries were most frequently associated with the lower extremity.

The findings in this chapter indicate that airbag deployment and seatbelt restraint do not completely eliminate the possibility of steering wheel contact. In severe crashes, the driver is likely to pitch forward and potentially "bottom-out" the airbag and impacting the steering wheel. The result was a sharp increase in the odds of injury for both belted and unbelted drivers in crashes with steering wheel deformation.

Several limitations need to be considered in this study. This study only considered a limited number of potential factors which influence steering wheel deformation. Factors such as steering wheel design (number of spokes), and steering wheel stiffness due to difference in material and construct were not readily available in NASS/CDS. This chapter therefore assumed all steering wheels to have identical stiffness.

# 4 INFLUENCE OF KNEE AIRBAG ON FRONTAL CRASH INJURY

## 4.1 RESEARCH OBJECTIVE

Knee airbags are designed to deploy in conjunction with the frontal airbag to help protect the occupants' lower extremities in a frontal crash from impacts with the instrument panel or other components in the occupant compartment. In addition to mitigate lower extremity injuries, knee bags may also affect occupant kinematics in a crash by positioning the occupant into a more upright position which can improve the interaction of the standard frontal airbag with the thorax.

The objective of this chapter of the thesis is to determine the influence of knee airbag on driver injury in frontal crashes.

## 4.2 APPROACH

The first step in the knee airbag analysis was to generate a list of vehicles equipped with knee airbags. Several sources were used to develop a list of vehicles equipped with knee airbags. A preliminary list of vehicles equipped with knee airbags was generated using the *Holmatro's Rescuer's Guide Book to Vehicle Safety Systems* [36], a guide book listing safety equipment available in vehicles model year 1985-2008. If a vehicle model had a knee airbag in 2008 and the vehicle model generation encompassed 2008, e.g. 2005-2010, we assumed that later models, e.g. 2009-2010 in this example, also were equipped with knee airbags. This list of vehicles was further checked against NHTSA's SaferCar Database. No additional vehicles were added to the dataset from the SaferCar Database.

As a quality check, the list of vehicles was compared with NCAP crash test reports from NHTSA [37]. Each report documents the vehicle both before and after the crash test with detailed photographs showing various exterior and interior views. Our initial list of vehicles was checked against the available post-test photographs of the occupant compartment interior. An example shown in Figure 40 verifies that this particular vehicle was indeed equipped with knee airbags. A list of vehicles that were verified by NCAP test photo is presented in the appendices. A complete list of vehicles that are equipped with knee airbags can also be found in the appendices.

**Figure 40. 2012 BMW 328i – NCAP Test 7857 Post-Crash Test Photo Showing Deployed Knee Airbag**

In order to include only vehicles with the latest safety technologies, the analysis of the effectiveness of knee airbag was restricted to vehicles equipped with depowered or advanced airbag deployment. Airbag was deployed in all vehicles in this dataset as a result of the crash. The final dataset was divided into two subsequent datasets: vehicles equipped with knee airbags and vehicles that are not equipped with knee airbags.

Similar to the steering wheel impact analysis, the comparison between cases involving vehicles with and without knee airbag equipped was based upon the odds of injury. In the knee airbag odds ratio calculation, critical events were defined as crashes with knee airbag deployment and the reference events were defined as crashes involving vehicles without knee airbag deployment.

## 4.3 DATASET COMPOSITION

### *4.3.1 BELTED DRIVER*

The knee airbag analysis was based upon vehicles equipped with depowered or advanced airbags extracted from NASS/CDS case year 1997-2011. In all cases, the standard frontal airbags had deployed. Table 19 and Table 20 present the breakdown of the final dataset for belted drivers in both unweighted and weighted cases, respectively. The dataset was organized based on knee airbag status, as well as the number of drivers sustaining a MAIS greater than or equal to 2, including drivers who suffered from a fatal injury. Likewise, the table also included drivers who sustained a serious injury, or a MAIS greater than or equal to 3, and cases involving fatal injuries.

**Table 19. Knee Airbag Dataset Composition – Unweighted Belted Drivers**

| | Total | Not equipped with Knee Airbag | Equipped with Knee Airbag | Unknown |
|---|---|---|---|---|
| **Driver Exposed** | 10,779 | 10,515 | 262 | 2 |
| **Drivers With MAIS 2+** | 2,291 | 2,245 | 46 | 0 |
| **Drivers With MAIS 3+** | 1,098 | 1,073 | 25 | 0 |

**Table 20. Knee Airbag Dataset Composition – Weighted Belted Drivers**

| | Total | Not equipped with Knee Airbag | Equipped with Knee Airbag | Unknown |
|---|---|---|---|---|
| **Driver Exposed** | 3,355,507 | 3,296,848 | 58,544 | 115 |
| **Drivers With MAIS 2+** | 297,735 | 293,054 | 4,681 | 0 |
| **Drivers With MAIS 3+** | 81,053 | 79,081 | 1,972 | 0 |

A total of 10,779 cases with belted drivers were extracted from NASS/CDS for the knee airbag analysis. Of these cases, 264 cases were identified as involving a vehicle equipped with knee airbags. A manual check was performed on all 264 cases by examining the photograph of the post-crash vehicle provided by NASS to ensure that the knee airbag in the vehicle did indeed deploy. Of the 264 cases, 2 cases included photographs of the vehicle airbag after it has been repaired. The deployment of the airbag could not be confirmed and these cases were excluded from the analysis.

To check for any vehicle model year that may have not been included in Holmatro's Guide Book's 1985-2008 model year range and was not tested by NHTSA's NCAP test, photos of cases involving vehicles model year 2007 and newer were extracted from the NASS/CDS dataset for further verification. A total number of 385 unique cases were then manually checked by examining their respective NASS photographs. No additional vehicles or model years of previously listed vehicle were found within these cases.

### *4.3.2 UNBELTED DRIVER*

Table 19 and Table 20 present the breakdown of the final dataset of unbelted driver unweighted and weighted cases. The dataset was organized based on knee airbag status, as well as the number of drivers sustaining a MAIS greater than or equal to 2, including drivers who suffered from a fatal injury. Likewise, the table also included drivers who sustained a severe injury, or a MAIS greater than or equal to 3, and cases involving fatal injuries.

**Table 21. Knee Airbag Dataset Composition – Unweighted Unbelted Drivers**

| | **Total** | **Not equipped with Knee Airbag** | **Equipped with Knee Airbag** | **Unknown** |
|---|---|---|---|---|
| **Driver Exposed** | 2,553 | 2,501 | 53 | 0 |
| **Drivers With MAIS 2+** | 1,080 | 1,061 | 19 | 0 |
| **Drivers With MAIS 3+** | 674 | 662 | 12 | 0 |

**Table 22. Knee Airbag Dataset Composition – Weighted Unbelted Drivers**

| | **Total** | **Not equipped with Knee Airbag** | **Equipped with Knee Airbag** | **Unknown** |
|---|---|---|---|---|
| **Driver Exposed** | 626,600 | 617,176 | 9,424 | 0 |
| **Drivers With MAIS 2+** | 116,594 | 113,270 | 3,324 | 0 |
| **Drivers With MAIS 3+** | 50,513 | 49,623 | 890 | 0 |

A total of 2,553 cases with unbelted drivers were extracted from NASS/CDS for the knee airbag analysis. All cases listed as involving vehicles equipped with knee airbags were checked manually by examining the NASS post-crash photographs. In two of the cases the vehicles' knee airbag did not deploy. These cases were treated as vehicles that are not equipped with knee airbags. The final dataset includes 53 cases with unbelted drivers in vehicles with confirmed knee airbag deployment.

To check whether the dataset represents U.S. vehicle population, the distribution of vehicles with knee airbags extracted from NASS/CDS was compared against available U.S. market sales data. According to Automotive News report of light vehicle production in the U.S., approximately 9% of model year 2006-2011 vehicles sold in the U.S. were equipped with driver knee airbag [38]. In comparison, approximately 7% (weighted) of vehicles model year 2006-2011 extracted from NASS/CDS were equipped with knee airbag. As shown in Figure 41 and Figure 42, knee airbags were extremely rare in vehicles older than model year 2005, and virtually no crashes involving vehicles with knee airbags were available in NASS/CDS prior to case year 2007.

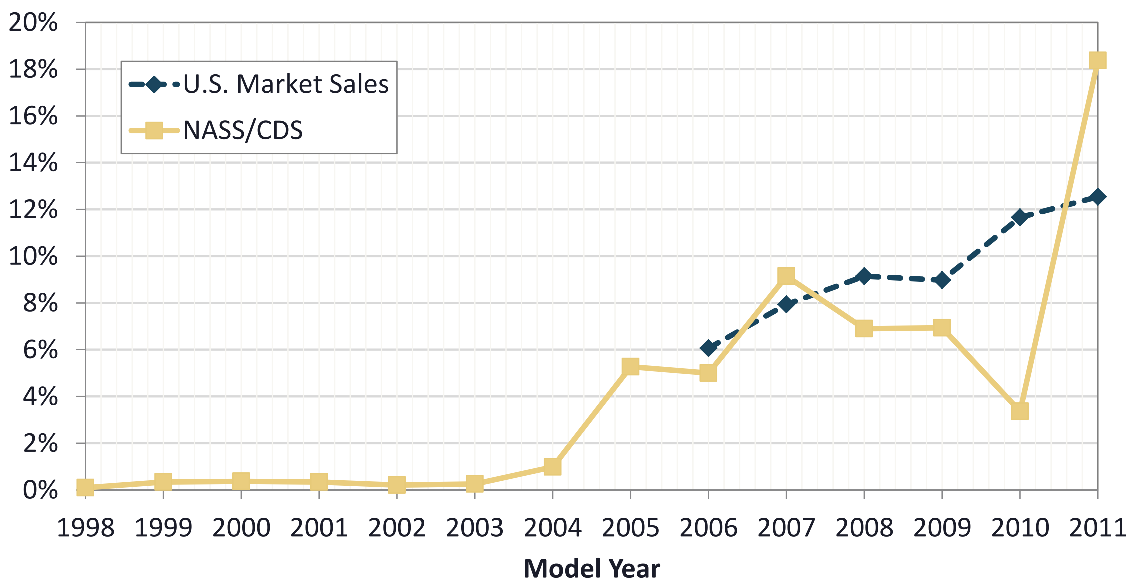


**Figure 41. Distribution of Vehicles With Knee Airbag in NASS/CDS and U.S. Market Sale by Model Year**

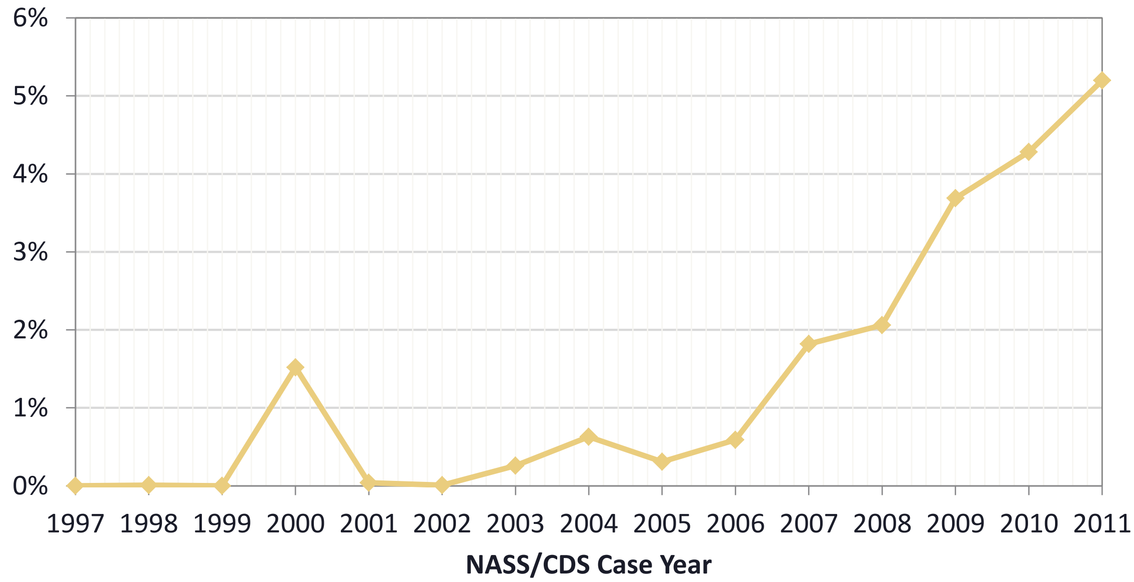


**Figure 42. Distribution of Vehicles With Knee Airbag in NASS/CDS by Case Year**

## 4.4 FACTORS INFLUENCING INJURY

The SurveyReg function in SAS 9.2 was used to test the effect of the following independent variable on the occurrence of MAIS 2+ and MAIS 3+ injury in a Wald test: longitudinal delta-V, lateral delta-V, driver belt status, type of airbag (depowered or advanced), multiple event crashes, driver weight, driver age, presence of pre-tensioner and load limiter, the presence of knee airbag, and the presence of steering wheel deformation.

As shown in Table 23 the test of effects reported by SAS suggests that longitudinal delta-V, belt status, type of airbag, multiple event crashes, driver age, pre-tensioner, and the presence of steering wheel deformation were statistically significant at the alpha=0.05 level in influencing the occurrence of MAIS2+ injury. Similarly, Table 24 shows that longitudinal delta-V, belt status, multiple event crashes, driver age, and the presence of steering wheel deformation were statistically significant factors in influencing the occurrence of MAIS3+ injury. Based on the result reported by these two tables, the type of airbags and pre-tensioners were only statistically significant factors in influencing the occurrence of MAIS2+ injury but not MAIS3+ injury.

**Table 23. Variable Effect on Occurrence of MAIS 2+ Injury**

| Variable | P-Value |
|---|---|
| Longitudinal Delta-V | <0.0001 |
| Lateral Delta-V | 0.1659 |
| Belt Status | 0.0022 |
| Advanced Airbag | 0.0147 |
| Multiple Event Crashes | 0.0005 |
| Driver Weight | 0.2989 |
| Driver Age | <0.0001 |
| Pre-tensioner | 0.0422 |
| Load Limiter | 0.1962 |
| Driver Knee Airbag | 0.1852 |
| Steering Wheel Deformation | <0.0001 |

**Table 24. Variable Effect on Occurrence of MAIS 3+ Injury**

| Variable | P-Value |
|---|---|
| Longitudinal Delta-V | <0.0001 |
| Lateral Delta-V | 0.5770 |
| Belt Status | <0.0001 |
| Advanced Airbag | 0.8699 |
| Multiple Event Crashes | <0.0001 |
| Driver Weight | 0.0615 |
| Driver Age | <0.0001 |
| Pre-tensioner | 0.6228 |
| Load Limiter | 0.3116 |
| Driver Knee Airbag | 0.9316 |
| Steering Wheel Deformation | <0.0001 |

## 4.5 Effect of Knee Airbags on Belted Driver Crash Injury

### *4.5.1 Injury Risk for Belted Drivers*

Using delta-V, or the vehicles' change in velocity, we compared the crash severity between vehicles with and without knee airbag equipped. In NASS/CDS cases, delta-V is estimated based on the vehicle deformation and stiffness characteristics. Figure 43 shows that the distribution of total delta-V are very similar for vehicles equipped with knee airbags and vehicles that are not equipped with knee airbags.

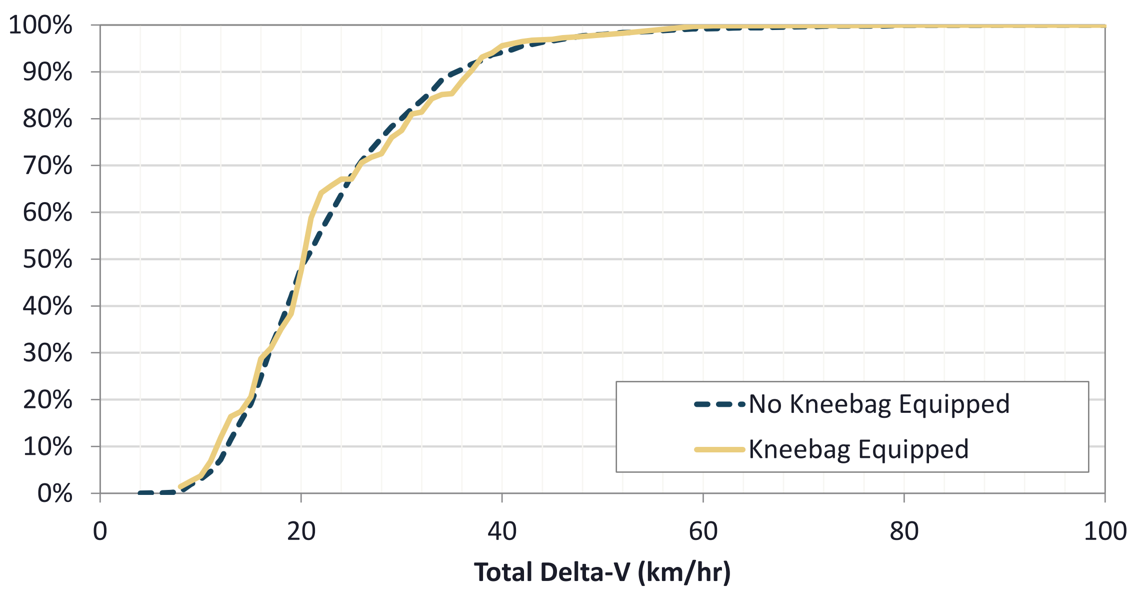


**Figure 43. Total Delta-V Distribution of Vehicles With and Without Knee Airbags**

As shown in Figure 44, fewer than 2% of vehicles in our sample had driver knee airbags. Similarly, only 1.6% of driver MAIS2+ injuries and 2.5% of MAIS3+ injuries were incurred by drivers with knee airbag vehicles.

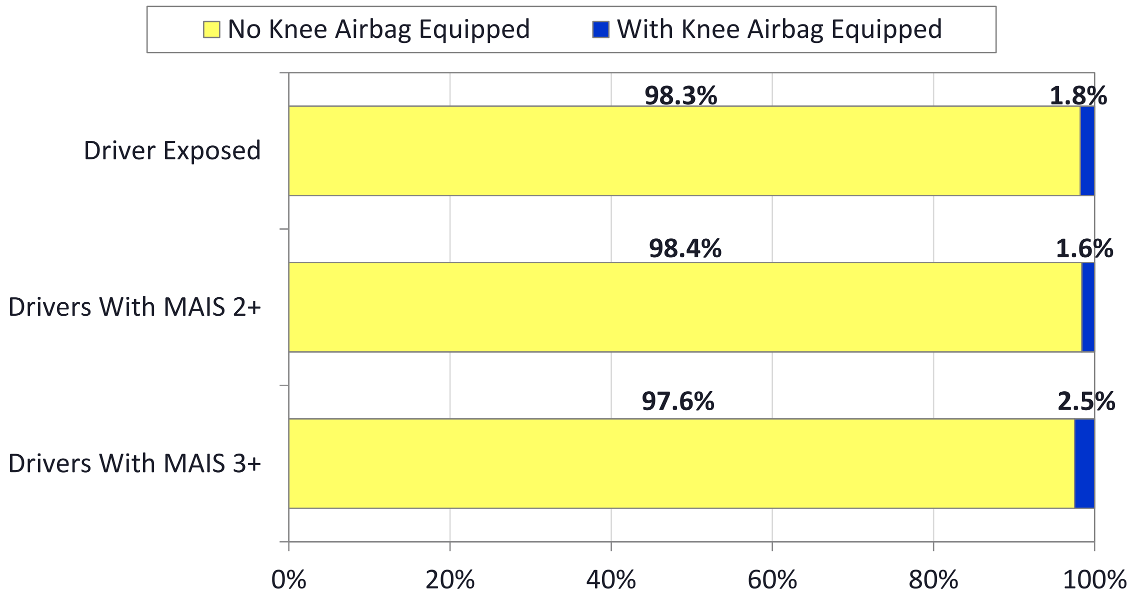


**Figure 44. Weighted Distribution of Knee Airbag Equipped Vehicles – Belted Drivers**

Figure 45 shows the adjusted odds ratio of AIS2+ injuries by body region. A logistic regression model was fitted to the dataset in order to control for delta-V, driver age, steering wheel deformation, and number of events. This model allowed a comparison of the odds of injury in crashes involving vehicles with and without knee airbag between drivers that were of the same age and involved in crashes with the similar type and severity. Error bars have been added to show 95% Wald confidence intervals calculated based on the odds ratio point estimate and its associated standard error. Crashes involving vehicles with no knee airbag equipped were used as the reference. Confidence intervals which included odds ratio of one indicates no statistically significant difference in the odds of injury between crashes in vehicles with and without knee airbag equipped. On the other hand, an odds ratio greater than one indicates crashes in vehicles with knee airbag equipped presents a greater odds of injury for the particular body region.

As shown in the figures, given the same total delta-V and driver age, crashes involving vehicles equipped with knee airbags present the driver with statistically significant greater odds of

AIS2+ injuries in the lower extremity, head, and spine. Vehicles equipped with knee airbag had statistically significant lower odds of AIS2+ upper extremity, chest, and abdomen injury. The 95% confidence intervals of the odds ratio suggest no statistically significant difference in odds of AIS2+ injury in the head, spine, and lower extremity. A summary of the adjusted odds ratio can be found in Table 25.

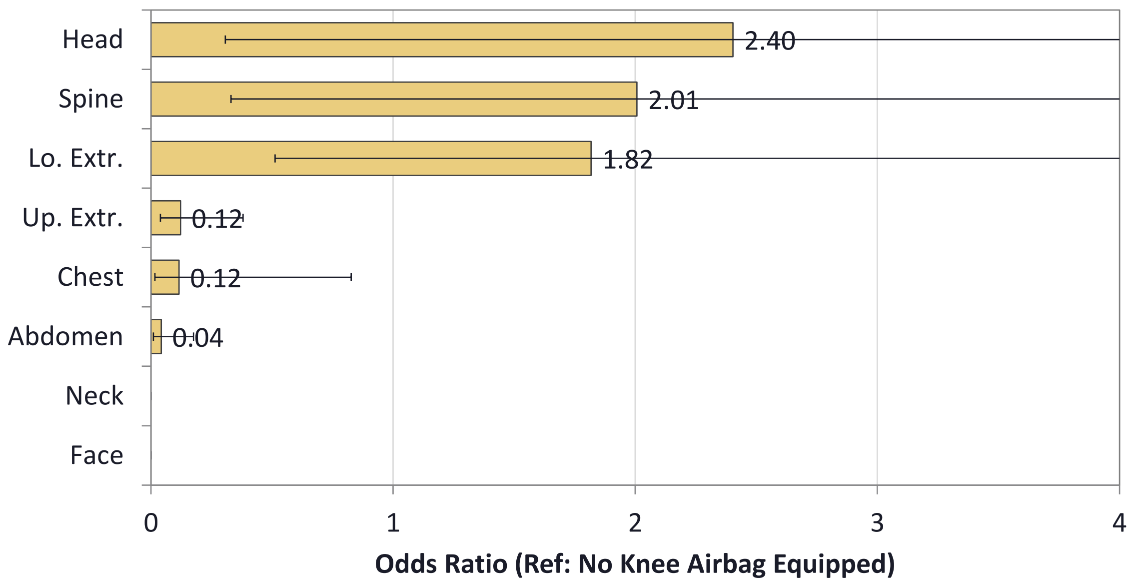


**Figure 45. Odds Ratio of AIS2+ Injuries for Crashes With and Without Knee Airbag Deployment for Belted Drivers (Controlled for Delta-V, Driver Age, and Number of Events)**

**Table 25. Adjusted Odds Ratio of AIS2+ Injury for Belted Drivers**

| AIS2+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | Lower | Upper |
| **Head** | 2.404 | 0.307 | 18.837 |
| **Face** | - | - | - |
| **Neck** | - | - | - |
| **Chest** | 0.116 | 0.016 | 0.827 |
| **Abdomen** | 0.042 | 0.010 | 0.175 |
| **Spine** | 2.007 | 0.330 | 12.198 |
| **Up. Extr.** | 0.122 | 0.039 | 0.380 |
| **Lo. Extr.** | 1.818 | 0.512 | 6.454 |

**Reference: Vehicles with No Knee Airbag Equipped**

Figure 46 present the odds ratio of AIS3+ injuries adjusted for delta-V, driver age, steering wheel deformation, and number of events. Vehicles equipped with knee airbags present the driver with statistically significant lower odds of AIS3+ abdomen injury. There was no statistically significant difference in the odds of AIS3+ injury in any other body region. A summary of the adjusted odds ratio can be found in Table 26.

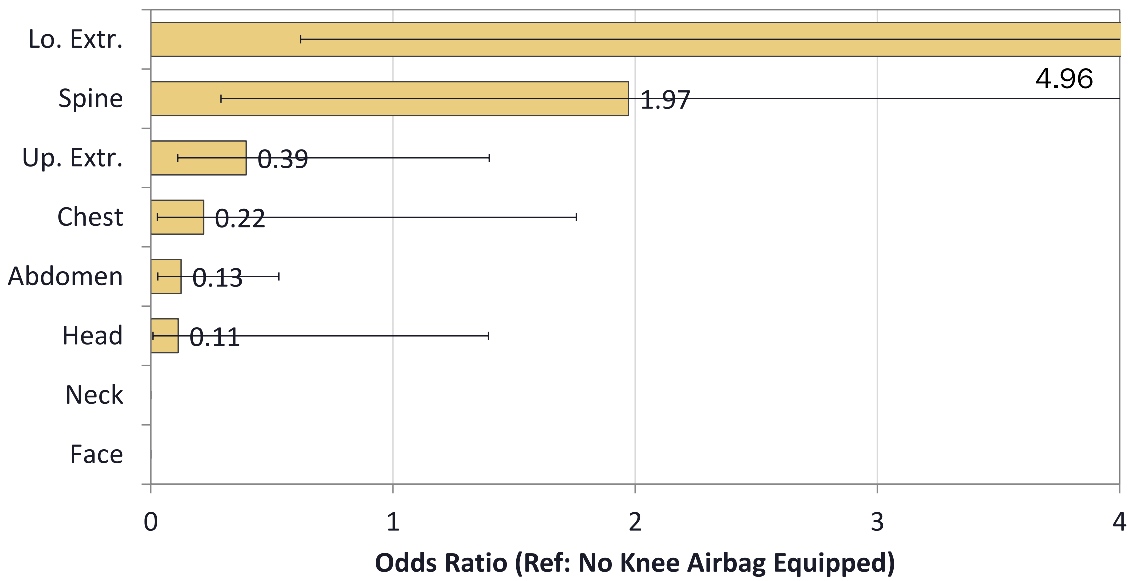


**Figure 46. Odds Ratio of AIS3+ Injuries for Crashes With and Without Knee Airbag Deployment for Belted Drivers (Controlled for Delta-V, Driver Age, and Number of Events)**

**Table 26. Adjusted Odds Ratio of AIS3+ Injury for Belted Drivers**

| AIS2+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | Lower | Upper |
| **Head** | 0.113 | 0.009 | 1.394 |
| **Face** | - | - | - |
| **Neck** | - | - | - |
| **Chest** | 0.218 | 0.027 | 1.757 |
| **Abdomen** | 0.125 | 0.029 | 0.529 |
| **Spine** | 1.972 | 0.290 | 13.433 |
| **Up. Extr.** | 0.394 | 0.111 | 1.397 |
| **Lo. Extr.** | 4.961 | 0.618 | 39.814 |

**Reference: Vehicles with No Knee Airbag Equipped**

### *4.5.2 INJURY SOURCE FOR BELTED DRIVERS*

To further investigate the influence of knee airbags on the drivers' lower extremity, Figure 47 shows the distribution of AIS2+ lower extremity injuries for belted drivers in vehicles equipped with knee airbag. As shown in the figure, injuries to the knee and fibula accounts for almost 75% of all AIS2+ injuries for belted drivers in vehicles equipped with knee airbag.

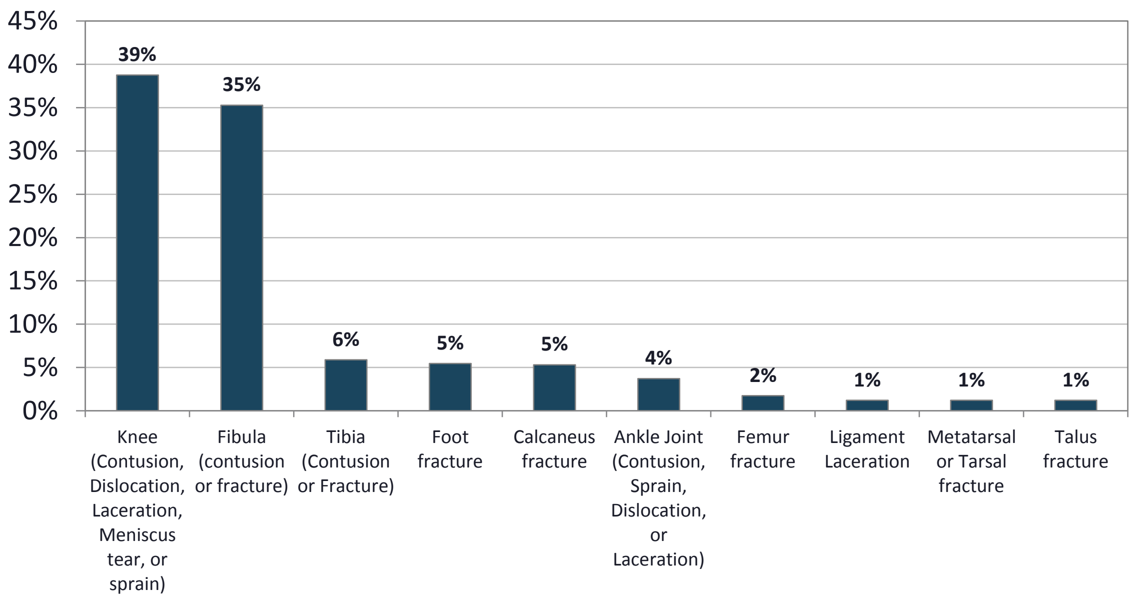


**Figure 47. AIS2+ Lower Extremity Injury – Belted Drivers in Vehicles With Knee Airbag**

Figure 48 shows the distribution of AIS2+ lower extremity injury for the dataset of belted drivers in vehicles with no knee airbag equipped. Due to the large number of lower extremity injuries, only the top 10 most frequent AIS2+ lower extremity injuries are shown in the figure. In the absence of knee airbag, the majority of the AIS2+ lower extremity injuries for belted drivers were roughly evenly distributed amongst tibia, fibula, talus, and knee.

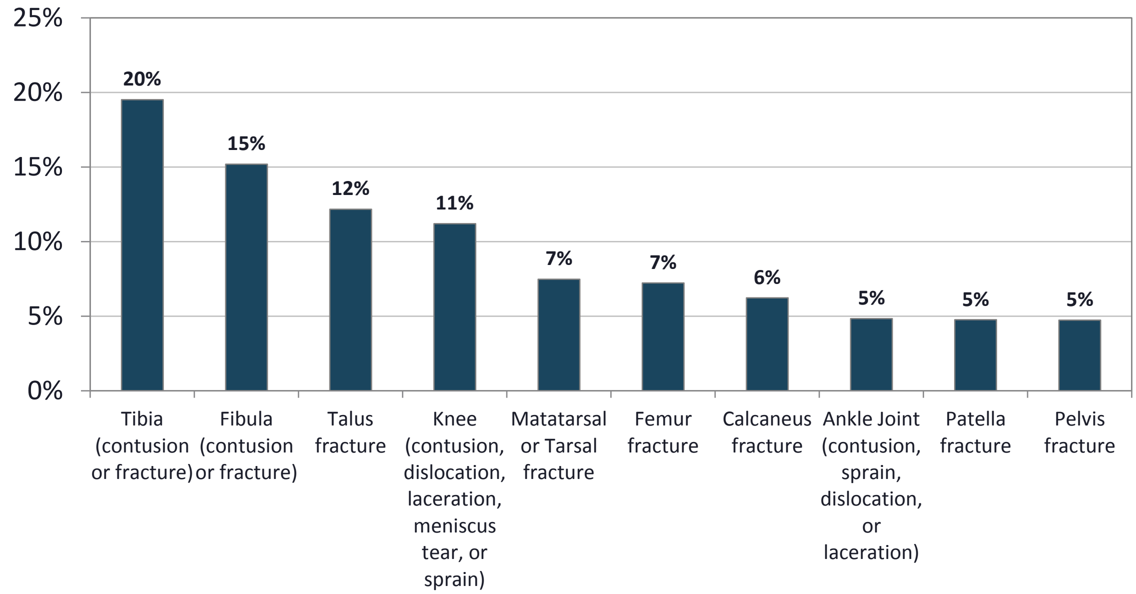


**Figure 48. AIS2+ Lower Extremity Injury – Belted Drivers in Vehicles With No Knee Airbag**

### *4.5.3 DISCUSSION*

The results in Figure 45 and Figure 46 indicate several body regions with relative risk lower than 1. Specifically, vehicles equipped with knee airbag had statistically significant lower odds of AIS2+ upper extremity, chest, and abdomen injuries for the belted driver. Similarly, belted drivers in vehicles equipped with knee airbag also had statistically significant lower odds of AIS3+ abdomen injury. The decrease in risk in these body regions may be attributed to the upright seating position provided by the knee airbag, enabling the driver to make contact with the steering wheel airbag at a safer angle.

Comparing lower extremity injury source between vehicles with and without knee airbag equipped, Figure 47 and Figure 48 shows that injuries to the knee are more common in vehicles with knee airbags. One potential reason for the increase incidence of knee injuries may be the close proximity of knee airbags to the drivers' knee during deployment.

There are several limitations that need to be considered. This analysis is based on a very small sample of knee airbag cases. The dataset composition, illustrated in Figure 44, shows a large disparity between the number of vehicles equipped with knee airbags and the number of vehicles without knee airbags. The small set of available cases with knee bag equipped vehicle creates a large uncertainty in the potential risk and benefits of knee airbags. We cannot conclude with absolute certainty, a cause and effect relationship on the effect of knee airbags and injury risk. This study should be viewed as only a preliminary indication of what might be observed if a large data set were available. The findings of this study should be revisited when a larger dataset of knee airbag cases become available.

## 4.6 Effect of Knee Airbags on Unbelted Driver Crash Injury

### *4.6.1 Injury Risk for Unbelted Drivers*

Figure 49 shows the frequency of drivers with knee airbag deployments and associated MAIS 2+ and MAIS 3+ injuries. Similar to belted cases, less than 2% of vehicles in our sample involving frontal crashes with unbelted drivers and deployed airbags have a knee airbag. Similarly, approximately 3% of all crashes with MAIS2+ and 2% of all crashes with MAIS3+ injured unbelted drivers have a knee airbag.

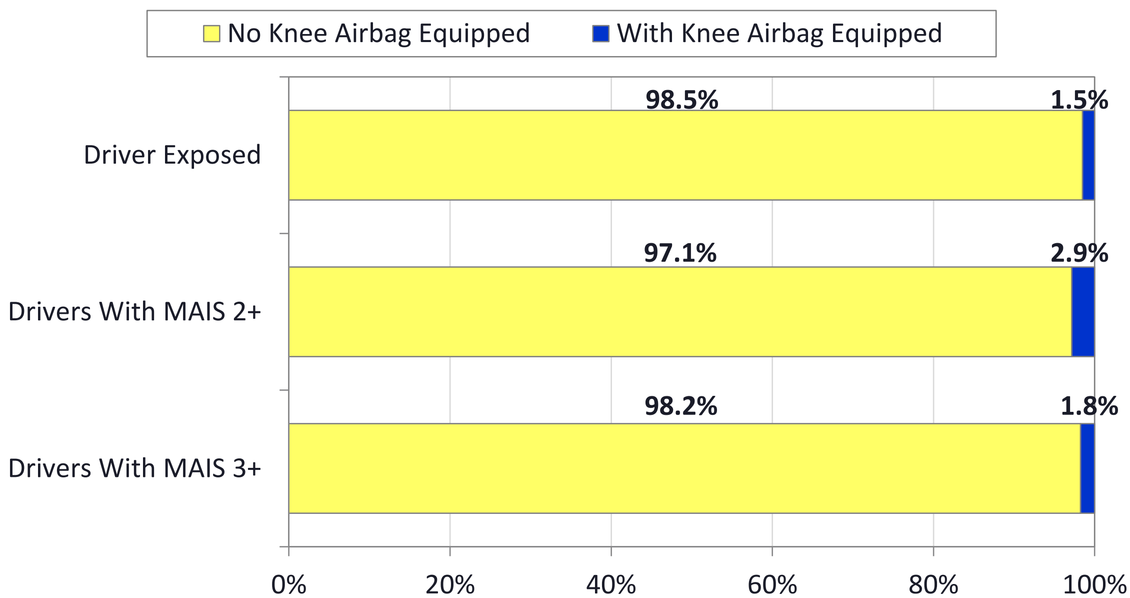


**Figure 49. Weighted Distribution of Knee Airbag Equipped Vehicles – Unbelted Drivers**

To check if there was any difference between the crash severity experienced by drivers in the two groups, we compared the total delta-V between vehicles with and without knee airbag equipped. Figure 50 shows the distribution of total delta-V for vehicles equipped with knee airbags and vehicles that are not equipped with knee airbags. Both types of vehicles appear to have very similar median delta-V.

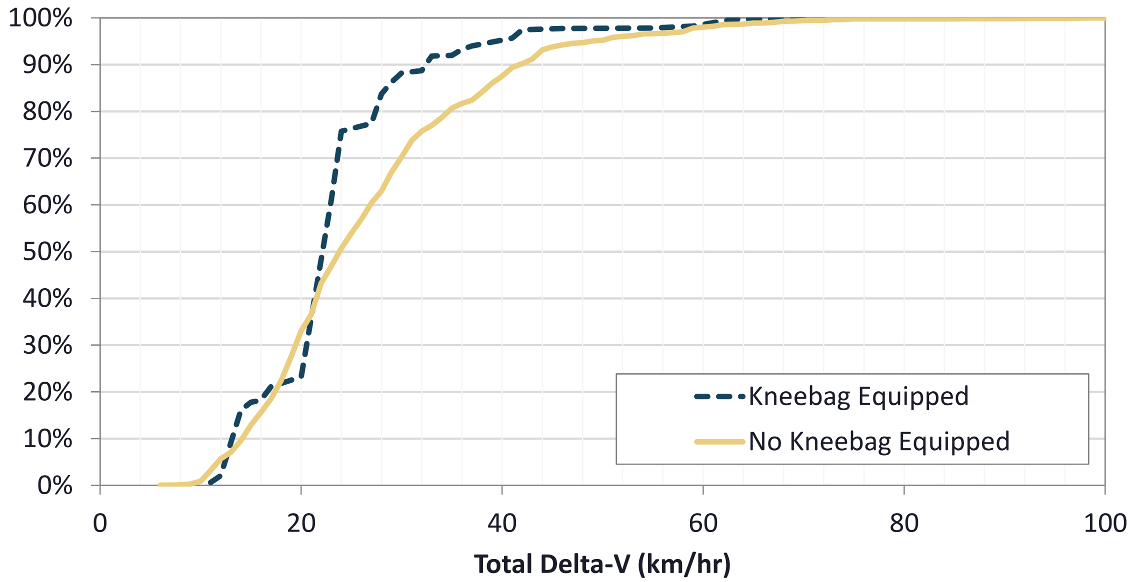


**Figure 50. Total Delta-V Distribution of Vehicles With and Without Knee Airbags (Unbelted Drivers)**

Figure 51 shows the adjusted odds ratio of AIS2+ injuries by body region. A logistic regression model was fitted to the dataset in order to control for delta-V, driver age, number of events, and steering wheel deformation. This model allowed a comparison of the odds of injury in crashes involving vehicles with and without knee airbag between drivers that were of the same age and involved in crashes with the similar type and severity. Cases involving vehicles which were not equipped with driver knee airbag were used as the reference. The error bars show 95% Wald confidence intervals calculated based on the estimated odds of injury and the associated standard error. Confidence intervals which included odds ratio of one indicates no statistically significant difference in the odds of injury between crashes in vehicles with and without knee airbag equipped. On the other hand, an odds ratio less than one indicate the deployment of knee airbag provided potential benefits to the driver during the crash.

The head was the only body region which showed statistically significant greater odds of AIS2+ injury in vehicles equipped with driver knee airbag. Vehicles equipped with knee airbag also showed statistically significant lower odds of AIS2+ chest injury for the unbelted driver. A summary of the adjusted odds ratio can be found in Table 27.

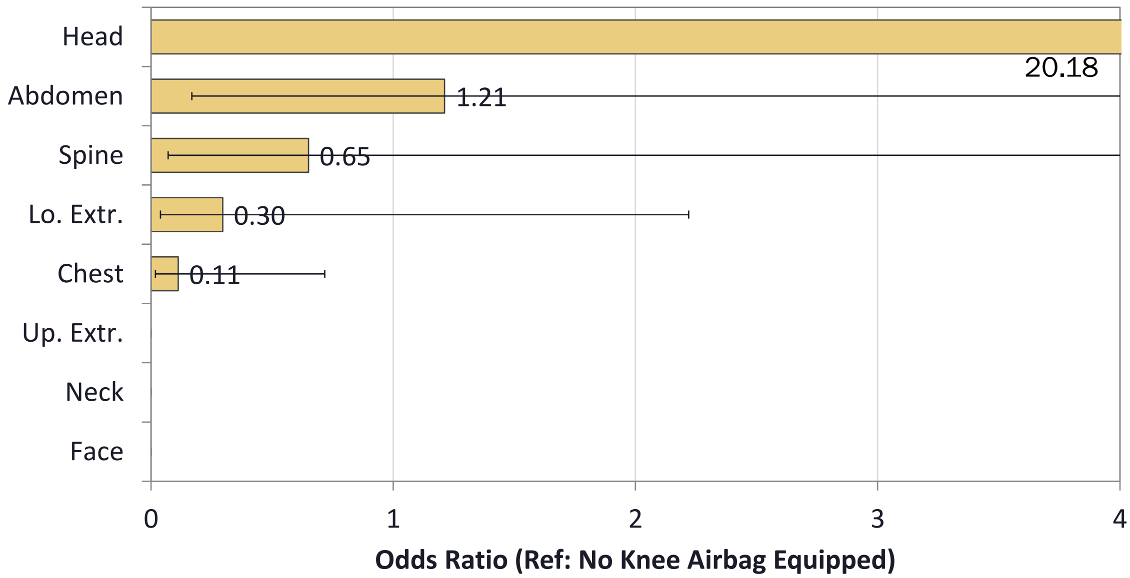


**Figure 51. Odds Ratio of AIS2+ Injuries for Crashes With and Without Knee Airbag Deployment for Unbelted Drivers (Controlled for Delta-V, Driver Age, and Number of Events)**

**Table 27. Adjusted Odds Ratio of AIS2+ Injury for Unbelted Drivers**

| AIS2+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | Lower | Upper |
| **Head** | 20.183 | 4.393 | 92.721 |
| **Face** | - | - | - |
| **Neck** | - | - | - |
| **Chest** | 0.112 | 0.018 | 0.717 |
| **Abdomen** | 1.212 | 0.168 | 8.732 |
| **Spine** | 0.650 | 0.070 | 6.053 |
| **Up. Extr.** | - | - | - |
| **Lo. Extr.** | 0.296 | 0.039 | 2.220 |

**Reference: No Knee Airbag Equipped**

Figure 52 and Table 28 present the odds ratio of AIS3+ injuries adjusted for delta-V and driver weight. No body region had statistically significant difference in the odds of AIS3+ injury between vehicles with and without driver knee airbag. The only exception is the lower extremity, which showed statistically significant smaller odds of injury for unbelted drivers.

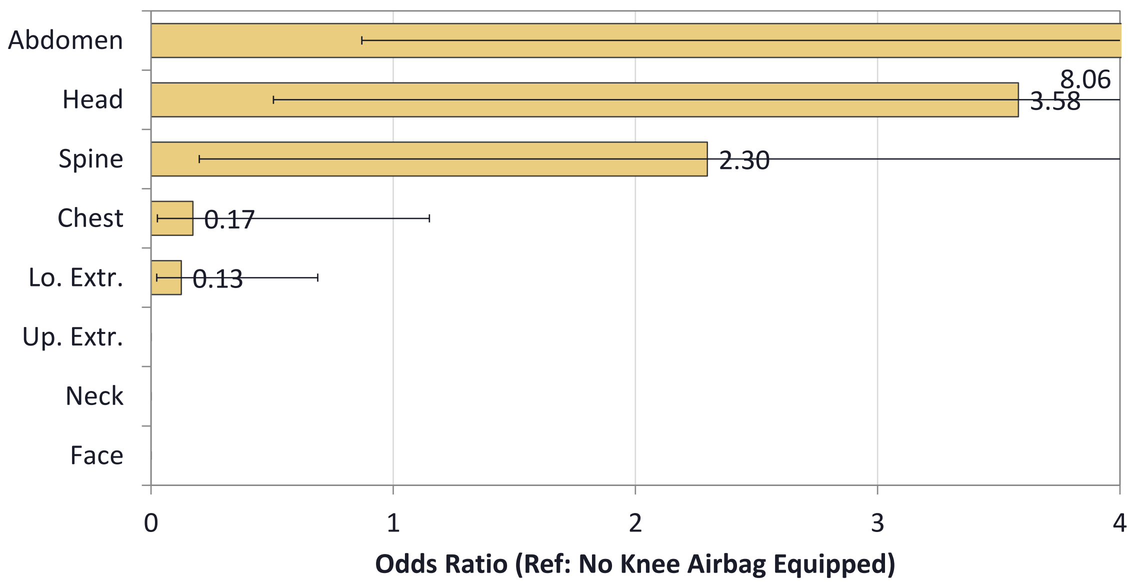


**Figure 52. Odds Ratio of AIS3+ Injuries for Crashes With and Without Knee Airbag Deployment for Unbelted Drivers (Controlled for Delta-V, Driver Age, and Number of Events)**

**Table 28. Adjusted Odds Ratio of AIS3+ Injury for Unbelted Drivers**

| AIS3+ | Odds Ratio | 95% Confidence Limits | |
|---|---|---|---|
| | | Lower | Upper |
| **Head** | 3.581 | 0.505 | 25.374 |
| **Face** | - | - | - |
| **Neck** | - | - | - |
| **Chest** | 0.173 | 0.026 | 1.149 |
| **Abdomen** | 8.063 | 0.870 | 74.713 |
| **Spine** | 2.297 | 0.199 | 26.545 |
| **Up. Extr.** | - | - | - |
| **Lo. Extr.** | 0.125 | 0.023 | 0.688 |

**Reference: No Knee Airbag Equipped**

### *4.6.2 INJURY SOURCE FOR UNBELTED DRIVERS*

Figure 53 and Figure 54 show the distribution of AIS2+ lower extremity injuries for unbelted drivers in vehicles with and without knee airbag equipped. Compare to the dataset of unbelted drivers in vehicles with no knee airbag equipped, drivers in vehicles with knee airbag showed lower frequency of femur and pelvic fractures.

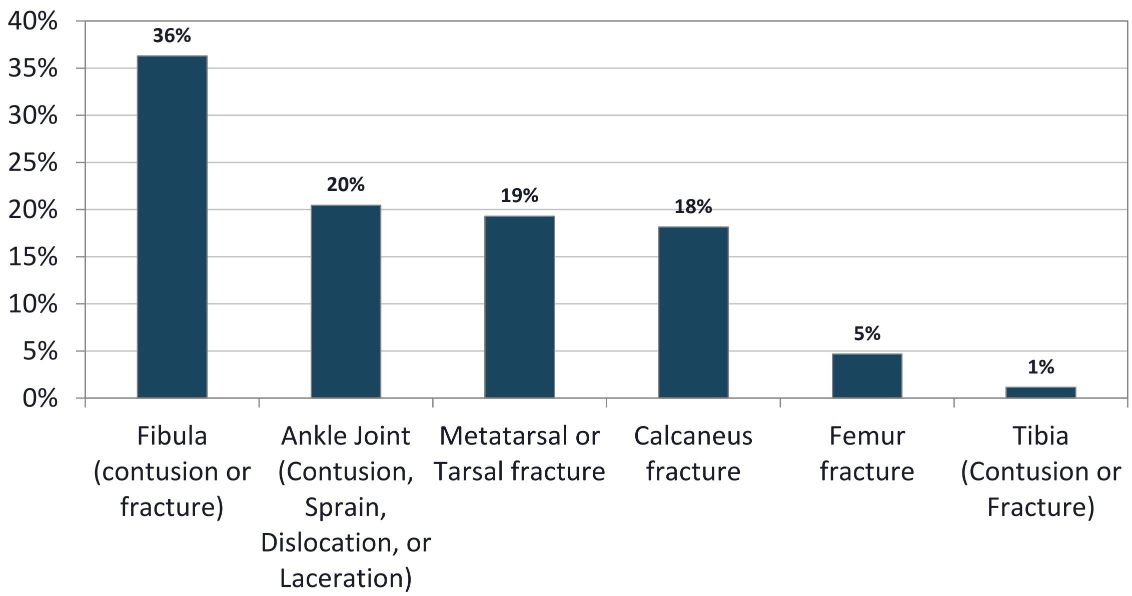


**Figure 53. AIS2+ Lower Extremity Injury – Unbelted Drivers in Vehicles With Knee Airbag**

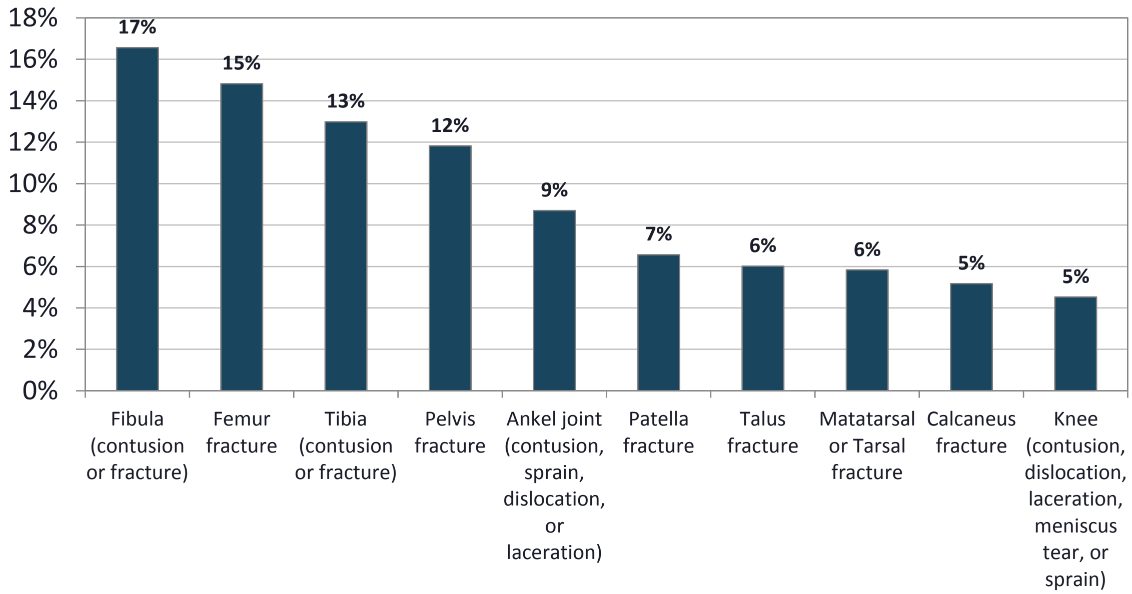


**Figure 54. AIS2+ Lower Extremity Injury – Unbelted Drivers in Vehicles With No Knee Airbag**

### *4.6.3 Discussion*

The analysis of the effectiveness of knee airbags in unbelted drivers was similar to belted drivers. The odds of injuries of driver in vehicles equipped with knee airbags was compared against the odds of injuries for drivers in vehicles that are not equipped with knee airbags.

The point estimates of the adjusted odds ratio presented in Figure 51 suggests the deployment of knee airbags may reduce the odds of AIS2+ injuries in the spine, lower extremities, and chest. Likewise, Figure 52 suggests that the deployment of knee airbags may be an effective countermeasure for AIS3+ chest and lower extremity injuries. The confidence limits associated with the odds ratio estimates suggested statistically significant greater odds of AIS2+ head injury, as well as statistically significant lower odds of AIS2+ chest injury and AIS3+ lower extremity injury for vehicles equipped with knee airbags.

In addition, unbelted drivers in vehicles with knee airbags were found to have lower frequency of femur and pelvic fractures. This is consistent with similar studies, which have cited potential benefit of knee airbag in reducing the axial compressive load on the femur and decrease pelvic fractures [22], [24].

Similar to the belted driver analysis, the confidence limits for the odds ratio estimates were exceptionally wide. We believe that these wide confidence limits were due to the small dataset available for analysis of knee airbag deployments. We caution the reader from using these findings to draw any firm conclusions about the effectiveness of knee airbags, and recommend that this analysis be revisited with additional years of NASS/CDS, when these datasets become available, to seek improved insight into the effectiveness of knee airbags.

## 4.7 Conclusions

This chapter of the thesis analyzed the influence of knee airbags on driver injury in frontal crash. The dataset consisted of vehicles equipped with depowered or advanced airbag which deployed as a result of a frontal crash. Odds of driver injury were compared between vehicles equipped with and without knee airbags. The findings of the analysis are as followed.

In the dataset of belted drivers, vehicles equipped with knee airbags were found to have statistically significant lower odds of AIS2+ injury to the upper extremity, chest, and abdomen. Likewise, vehicles equipped with knee airbags were found to have statistically significant lower odds of AIS3+ abdomen injury for belted drivers. One hypothesis for the lower odds of injury in these body regions is that the knee airbag helped position the driver in an upright seating position, allowing the driver to contact the frontal airbag at a safer angle.

A similar analysis was conducted for the dataset of unbelted drivers. The odds of injuries of unbelted driver in vehicles equipped with knee airbags was compared against the odds of injuries for drivers in vehicles that are not equipped with knee airbags. The result of the analysis on the unbelted driver dataset suggest that knee airbag have a statistically significant lower odds of AIS2+

chest injury and AIS3+ lower extremity injury. Specifically, femur and pelvic fractures were found to be less frequent for unbelted drivers in vehicles equipped with knee airbag. On the other hand, vehicles equipped with knee airbags were found to have statistically significant greater odds of AIS2+ head injury for the unbelted driver.

A major limitation that should be considered for this analysis is that the study is based on a very small sample of knee airbag cases. Less than 2% of the belted drivers in our sample were in vehicles equipped with knee airbags, and only 1.5% of all vehicles in the unbelted driver dataset were equipped with knee airbags. Due to the resultant large uncertainty, the cause and effect relationship on the effect of knee airbag cannot be determined with absolute certainty. As a result, this study should be revisited in the future when larger datasets of knee airbags are available.

# 5 CONCLUSION

Advances in airbag and seatbelt technologies have emerged over the years in response to the consumer's need for safer vehicles. Modern advanced airbag systems are now mandatory in all passenger vehicles and include sophisticated sensor system to tailor the deployment to the driver position and crash severity. Moreover, with the increase in seatbelt usage to about 85% in the United States, the combination of airbags and seatbelts has become perhaps the most effective safety system in a vehicle.

However, despite the advancement in airbag and the record high seatbelt usage rate, drivers in the United States continue to suffer serious injuries in automobile crashes. One major contributor of injury is the steering wheel deformation, in which drivers make direct contact with the steering wheel despite airbag deployment and belt usage. This thesis is based upon real world data extracted from the National Automotive Sampling System Crashworthiness Data System (NASS/CDS) database, and analyzed the influence of advanced airbags on injury risk during frontal crashes. The conclusions from the two major sections are summarized as followed.

## 5.1 INCIDENCE AND RISK OF DIRECT STEERING WHEEL IMPACT

For both belted and unbelted drivers, crashes with steering wheel deformation were rare events associated with high crash severity. Only 4% of the belted drivers were involved in crashes with measurable steering wheel deformation, however, this 4% of cases was overrepresented in the injury outcomes, accounting for 15% of MAIS2+ and 29% of MAIS3+ injured drivers. Unbelted drivers were more likely to be associated with steering wheel deformation (13%) than belted drivers (4%). In most belted cases, the three point belt keeps the driver out of the steering wheel. Although a small fraction, the 13% of unbelted drivers in vehicles with steering wheel deformation is overrepresented in the injury outcomes. This small fraction was associated with 37% of MAIS2+ drivers and well over half (58%) of MAIS3+ unbelted drivers.

The incidence of steering wheel contact also increases as higher delta-V increases. The result also showed that crash severity, driver weight, and belt usage were statistically significant factors in influencing the occurrence of steering wheel deformation. Belted drivers were found to have 3 times greater odds of deforming the steering wheel in vehicles with no airbag equipped than vehicles equipped with advanced airbags. Similarly, unbelted drivers were twice as likely to deforming the steering wheel in vehicles with no airbag equipped. No statistically significant difference in steering wheel deformation was found between vehicles with depowered and advanced airbags. Compared to advanced airbags, vehicles with no airbag equipped were found to have 3 times and 2 times greater odds of deforming the steering wheel for belted and unbelted drivers, respectively. Moreover, seatbelt pre-tensioners and load limiters were not statistically significant factors in influencing steering wheel deformation.

After controlling for crash severity and driver weight, the analysis showed that drivers involved in crashes with steering wheel deformation had statistically significant greater odds of injury in almost all body regions. Notably, steering wheel deformation presents the belted driver with 5 times greater odds of AIS2+ face injuries, as well as almost 7 times greater odds of AIS3+ head and upper extremity injuries. Similar to belted drivers, unbelted drivers had higher odds of injury in crashes with measurable steering wheel deformation, as indicated by delta-V and odds of injury distribution. Unbelted drivers had statistically significant higher odds of AIS2+ thoracic and lower extremity injuries in crashes with measurable steering wheel deformation. Likewise, odds of AIS3+ lower extremity and thoracic injuries increased by a factor of 5 and 3, respectively, for unbelted drivers in crashes with measurable steering wheel deformation.

Our conclusion is that drivers cannot rely solely on airbags to prevent them from making contact with the steering wheel during a frontal crash. Even for belted drivers, airbags and seatbelts do not prevent the driver from loading the steering wheel during a frontal crash.

## 5.2 INFLUENCE OF KNEE AIRBAG ON FRONTAL CRASH INJURY

This chapter of the thesis sought to investigate the effectiveness of knee airbags in reducing injury in the event of a frontal crash. A list of vehicles equipped with knee airbags was generated from several sources. Using this list of knee airbag equipped vehicles, a dataset of NASS cases was extracted for a comparison between the odds of injury of vehicles equipped with knee airbags in a frontal crash and vehicles without knee airbags.

In the dataset of belted drivers, the point estimates and the associated confidence interval of the adjusted odds ratio suggest that the deployment of knee airbags is an effective countermeasure for several body regions. Specifically, AIS2+ injuries in the thorax region, abdomen and upper extremity may be mitigated through knee airbags. In addition, drivers in vehicles equipped with knee airbag have statistically significant lower odds of AIS3+ abdomen injuries.

The analysis of the effectiveness of knee airbags in unbelted drivers was similar to belted drivers. The point estimates of the adjusted odds ratio suggests that vehicle equipped with knee airbags have statistically significant lower odds of AIS2+ chest injury and AIS3+ lower extremity injury for the unbelted driver. However, drivers in vehicles equipped with knee airbags were also found to have statistically significant greater odds of AIS2+ head injury.

The confidence limits for these estimates were exceptionally wide. We believe that these wide confidence limits were due to the small dataset available for analysis of knee airbag deployments. We caution the reader from using these findings to draw any firm conclusions about the effectiveness of knee airbags, and recommend that this analysis be revisited with additional years of NASS/CDS, when these datasets become available, to seek improved insight into the effectiveness of knee airbags.

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# 7 APPENDIX

**Table 29. List of Available NCAP Test Used to Verify Knee Airbag.**

| Model Year | Make | Model | NCAP Test No. |
|---|---|---|---|
| 2012 | BMW | 328i | 7857 |
| 2011 | BMW | 535i | 7024 |
| 2003 | BMW | Z4 | 4444 |
| 2011 | Chevrolet | Cruze | 7258 |
| 2013 | Chevrolet | Malibu | 7856 |
| 2012 | Chevrolet | Sonic | 7564 |
| 2011 | Chevrolet | Volt | 7393 |
| 2012 | Chrysler | 300 | 7587 |
| 2004 | Chrysler | Pacifica | 4572 |
| 2002 | Chrysler | PT Cruiser | 4230 |
| 2005 | Chrysler | Town and Country | 4936 |
| 2012 | Chrysler | Town and Country | 7460 |
| 2007 | Dodge | Caliber | 5661 |
| 2008 | Dodge | Caliber | 6530 |
| 2011 | Dodge | Caliber | 7189 |
| 2005 | Dodge | Caravan | 5761 |
| 2012 | Dodge | Charger | 7606 |
| 2005 | Dodge | Grand Caravan | 5842 |
| 2012 | Dodge | Journey | 7471 |
| 2012 | Fiat | 500 | 7505 |
| 2013 | Ford | Escape | 7941 |
| 2011 | Ford | Fiesta | 6996 |
| 2010 | Ford | Fusion | 6755 |
| 2007 | Kia | Sorento | 5899 |
| 1997 | Kia | Sportage | 2637 |
| 2007 | Lexus | ES 350 | 5757 |
| 2012 | Lexus | ES 350 | 7618 |
| 2013 | Lexus | ES 350 | 8038 |
| 2010 | Lexus | HS 250h | 6812 |
| 2008 | Lexus | IS 250 | 6213 |
| 2013 | Lexus | IS 250 | 8055 |
| 2004 | Lexus | RX 330 | 4718 |
| 2008 | Lexus | RX 350 | 6183 |
| 2010 | Lexus | RX 350 | 6642 |
| 2011 | Lexus | RX 350 | 7148 |
| 2013 | Lexus | RX 350 | 7873 |
| 2011 | Mercedes-Benz | C300 | 7182 |
| 2010 | Mercedes-Benz | E350 | 6822 |
| 2008 | Mitsubishi | Lancer | 6001 |

| Model Year | Make | Model | NCAP Test No. |
|---|---|---|---|
| 2012 | Mitsubishi | Lancer | 7720 |
| 2012 | Scion | iQ | 7729 |
| 2011 | Scion | tC | 7362 |
| 2010 | Toyota | 4Runner | 6860 |
| 2012 | Toyota | 4Runner | 7755 |
| 2005 | Toyota | Avalon | 5370 |
| 2007 | Toyota | Camry | 5675 |
| 2010 | Toyota | Camry | 6750 |
| 2012 | Toyota | Camry | 7520 |
| 2008 | Toyota | Highlander | 6193 |
| 2011 | Toyota | Highlander | 7183 |
| 2010 | Toyota | Prius | 6763 |
| 2011 | Toyota | Prius | 7358 |
| 2012 | Toyota | Prius | 7876 |
| 2010 | Toyota | Tundra | 6784 |
| 2012 | Toyota | Tundra | 7585 |
| 2009 | Toyota | Venza | 6601 |
| 2011 | Toyota | Venza | 7179 |
| 2013 | Toyota | Venza | 7969 |

**Table 30. List of Vehicles Equipped With Driver Knee Airbags.**

| Make | Model | First Model Year in Generation | Last Model Year in Generation | First Model Year Equipped with Knee Airbag | Last Model Year Equipped with Knee Airbag |
|---|---|---|---|---|---|
| Audi | A8 | 2004 | 2010 | 2004 | 2010 |
| Audi | S8 | 2004 | 2010 | 2007 | 2010 |
| BMW | 3 Series | 2006 | 2013 | 2012 | 2013 |
| BMW | 5 Series | 2011 | 2012 | 2011 | 2012 |
| BMW | 6 Series | 2004 | 2010 | 2004 | 2010 |
| BMW | 7 Series | 2002 | 2008 | 2002 | 2008 |
| BMW | Z4 | 2003 | 2008 | 2003 | 2008 |
| Chevrolet | Cruze | 2011 | 2013 | 2011 | 2013 |
| Chevrolet | Malibu | 2013 | 2013 | 2013 | 2013 |
| Chevrolet | Sonic | 2012 | 2013 | 2012 | 2013 |
| Chevrolet | Volt | 2011 | 2013 | 2011 | 2013 |
| Chrysler | 300 | 2012 | 2013 | 2012 | 2013 |
| Chrysler | Pacifica | 2004 | 2008 | 2004 | 2008 |
| Chrysler | PT Cruiser | 2001 | 2009 | 2006 | 2009 |
| Chrysler | Town and Country | 2001 | 2007 | 2005 | 2007 |
| Chrysler | Town and Country | 2008 | 2013 | 2008 | 2013 |
| Dodge | Caliber | 2007 | 2012 | 2007 | 2012 |
| Dodge | Caravan | 2001 | 2007 | 2005 | 2007 |
| Dodge | Charger | 2006 | 2013 | 2012 | 2013 |
| Dodge | Grand Caravan | 2001 | 2007 | 2005 | 2007 |
| Dodge | Journey | 2009 | 2013 | 2012 | 2013 |
| Fiat | 500 | 2011 | 2013 | 2012 | 2013 |
| Ford | Escape | 2013 | 2013 | 2013 | 2013 |
| Ford | Fiesta | 2011 | 2013 | 2011 | 2013 |
| Jaguar | X Type | 2002 | 2008 | 2004 | 2008 |
| Kia | Sorento | 2003 | 2009 | 2007 | 2009 |
| Kia | Sportage | 1995 | 2002 | 1996 | 2002 |
| Land Rover | Range Rover | 2003 | 2012 | 2007 | 2012 |
| Lexus | ES 350 | 2007 | 2012 | 2007 | 2012 |
| Lexus | GS 300 | 2006 | 2006 | 2006 | 2006 |
| Lexus | GS 350 | 2007 | 2011 | 2007 | 2011 |
| Lexus | GS 430 | 2006 | 2007 | 2006 | 2007 |
| Lexus | GS 450h | 2007 | 2011 | 2007 | 2011 |
| Lexus | HS 250h | 2010 | 2012 | 2010 | 2012 |
| Lexus | IS 250 | 2006 | 2013 | 2006 | 2013 |
| Lexus | IS 350 | 2006 | 2013 | 2006 | 2013 |
| Lexus | LS 430 | 2001 | 2006 | 2004 | 2006 |

| Make | Model | First Model Year in Generation | Last Model Year in Generation | First Model Year Equipped with Knee Airbag | Last Model Year Equipped with Knee Airbag |
|---|---|---|---|---|---|
| Lexus | LS 460 | 2007 | 2012 | 2007 | 2012 |
| Lexus | LS 600h | 2008 | 2012 | 2008 | 2012 |
| Lexus | RX 330 | 2004 | 2006 | 2004 | 2006 |
| Lexus | RX 350 | 2007 | 2009 | 2007 | 2009 |
| Lexus | RX 350 | 2010 | 2012 | 2010 | 2012 |
| Lexus | RX 350 | 2013 | 2013 | 2013 | 2013 |
| Lexus | RX 400h | 2006 | 2009 | 2006 | 2009 |
| Lexus | SC 430 | 2002 | 2010 | 2007 | 2010 |
| Mercedes-Benz | C Class | 2008 | 2013 | 2010 | 2013 |
| Mercedes-Ben | CLS Class | 2006 | 2011 | 2006 | 2011 |
| Mercedes-Benz | E Class | 2010 | 2013 | 2010 | 2013 |
| Mercedes-Benz | SL Class | 2003 | 2012 | 2003 | 2012 |
| Mercedes-Benz | SLK Class | 2005 | 2011 | 2005 | 2011 |
| Mitsubishi | Lancer | 2008 | 2013 | 2008 | 2013 |
| Scion | iQ | 2011 | 2013 | 2012 | 2013 |
| Scion | tC | 2005 | 2010 | 2005 | 2010 |
| Scion | tC | 2011 | 2013 | 2011 | 2013 |
| Toyota | 4Runner | 2010 | 2013 | 2010 | 2013 |
| Toyota | Avalon | 2005 | 2012 | 2005 | 2012 |
| Toyota | Camry | 2007 | 2011 | 2007 | 2011 |
| Toyota | Camry | 2012 | 2013 | 2012 | 2013 |
| Toyota | Highlander | 2008 | 2013 | 2008 | 2013 |
| Toyota | Prius | 2010 | 2013 | 2010 | 2013 |
| Toyota | Tundra | 2007 | 2013 | 2010 | 2013 |
| Toyota | Venza | 2009 | 2013 | 2009 | 2013 |

**Table 31. List of Vehicles Equipped With Advanced Airbag During Phase-in Period**

| Make | Model | First Model Year Equipped with Advanced Airbag |
|---|---|---|
| Acura | MDX | 2003 |
| Acura | RL | 2005 |
| Acura | TL | 2005 |
| Audi | A4 | 2005 |
| Audi | A6 | 2005 |
| BMW | 3-Series | 2005 |
| BMW | 5-Series | 2004 |
| BMW | 6-Series | 2004 |
| BMW | 7-Series | 2004 |
| BMW | X3 | 2004 |
| BMW | Z4 | 2004 |
| Buick | Lacrosse | 2005 |
| Buick | Rainier | 2005 |
| Buick | Rendezvous | 2005 |
| Buick | Terraza | 2005 |
| Cadillac | CTS | 2005 |
| Cadillac | Escalade | 2003 |
| Cadillac | Escalade | 2003 |
| Cadillac | STS | 2005 |
| Chevrolet | Fullsize | 2003 |
| Chevrolet | Uplander | 2005 |
| Chevrolet | Suburban | 2003 |
| Chevrolet | C/K-Series Pickup | 2003 |
| Chevrolet | Avalanche | 2003 |
| GMC | Jimmy | 2003 |
| GMC | C,K,R,V-Series | 2003 |
| Buick | Lacrosse | 2005 |
| Buick | Rendezvous | 2005 |
| Buick | Rainier | 2005 |
| Buick | Terraza | 2005 |
| Cadillac | CTS | 2005 |
| Cadillac | STS | 2005 |
| Cadillac | Escalade EXT | 2005 |
| Chevrolet | Trail Blazer | 2005 |
| Chevrolet | Uplander | 2005 |
| Chrysler | 300 | 2005 |
| Chrysler | Pacifica | 2005 |
| Chrylser | Town And Country | 2005 |
| Dodge | Dakota | 2005 |

| | | |
|---|---|---|
| Dodge | Durango | 2004 |
| Dodge | Grand Caravan | 2005 |
| Dodge | Magnum | 2005 |
| Ford | Taurus | 2004 |
| Ford | F-Series | 2004 |
| Ford | Mustang | 2005 |
| Ford | Crown Victoria | 2005 |
| Ford | Five Hundred | 2005 |
| Ford | Freestyle | 2005 |
| Ford | Focus | 2005 |
| Ford | Escape | 2005 |
| Ford | Freestar | 2005 |
| Ford | Freestyle | 2005 |
| Gmc | Jimmy/S-15 | 2005 |
| GMC | Sierra | 2003 |
| GMC | Yukon | 2003 |
| Honda | Accord | 2004 |
| Honda | CR-V | 2005 |
| Honda | Odyssey | 2003 |
| Honda | Pilot | 2005 |
| Hummer | H3 | 2005 |
| Hyundai | Elantra | 2004 |
| Hyundai | Santa Fe | 2005 |
| Hyundai | Tucson | 2005 |
| Infiniti | G35 | 2005 |
| Infiniti | M45 | 2006 |
| Infiniti | Qx56 | 2004 |
| Isuzu | Ascender | 2005 |
| Jaguar | S Type | 2005 |
| Jaguar | X Type | 2005 |
| Jaguar | XJ | 2005 |
| Jaguar | XJ-S Coupe | 2005 |
| Jeep | Grand Cherokee | 2005 |
| Jeep | Liberty | 2004 |
| Kia | Amanti | 2005 |
| Kia | Sorento | 2005 |
| Kia | Spectra | 2004 |
| Kia | Sportage | 2005 |
| Land | Rover | 2005 |
| Lexus | ES 330 | 2004 |
| Lexus | GX 470 | 2005 |
| Lexus | RX 330 | 2004 |
| Lexus | RX 400H | 2005 |

| | | |
|---|---|---|
| Lincoln | Town Car | 2005 |
| Mazda | Mazda3 | 2004 |
| Mazda | Mazda6 | 2005 |
| Mazda | MPV | 2004 |
| Mazda | Tribute | 2005 |
| Mercury | Marquis | 2005 |
| Mercury | Mariner | 2005 |
| Mercury | Montego | 2005 |
| Mercedes | C Class | 2005 |
| Mercedes | E Class | 2005 |
| Mercedes | CLK Class | 2005 |
| Mini | Cooper S | 2005 |
| Mitsubishi | Endeavor | 2005 |
| Mitsubishi | Galant | 2004 |
| Mitsubishi | Outlander | 2005 |
| Nissan | Altima | 2005 |
| Nissan | Armada | 2005 |
| Nissan | Frontier | 2005 |
| Nissan | Maxima | 2005 |
| Nissan | Pathfinder | 2004 |
| Nissan | Quest | 2004 |
| Nissan | Titan | 2004 |
| Nissan | Xterra | 2005 |
| Pontiac | Vibe | 2005 |
| Pontiac | Solstice | 2006 |
| Pontiac | Trans | 2005 |
| Saab | 9-7X | 2005 |
| Saturn | Relay | 2005 |
| Subaru | Legacy | 2005 |
| Subaru | Outback | 2005 |
| Suzuki | Aerio Gx | 2005 |
| Suzuki | Forenza | 2005 |
| Suzuki | Grand Vitara | 2004 |
| Suzuki | Reno | 2005 |
| Suzuki | Verona | 2005 |
| Toyota | Camry | 2004 |
| Toyota | Corolla | 2005 |
| Toyota | Solara | 2005 |
| Toyota | Highlander | 2004 |
| Toyota | Matrix | 2005 |
| Toyota | Sequoia | 2005 |
| Toyota | Sienna | 2005 |
| Toyota | Tacoma | 2005 |

| | | |
|---|---|---|
| Toyota | Tundra | 2005 |
| VW | Beetle | 2004 |
| VW | Jetta | 2005 |
| VW | Phaeton | 2005 |
| VW | Touareg | 2005 |
| Volvo | S40 | 2005 |
| Volvo | V50 | 2005 |
| Volvo | V70 | 2005 |
| Volvo | XC90 | 2005 |

**Table 32. List of Vehicles Equipped With Pre-tensioner**

| Make | Model | First Model Year Equipped with Pre-Tensioner | Last Model Year Equipped with Pre-Tensioner |
|---|---|---|---|
| Acura | CL | 2002 | 2003 |
| Acura | MDX | 2002 | 2012 |
| Acura | NSX-T | 2002 | 2005 |
| Acura | RDX | 2007 | 2012 |
| Acura | RL | 2001 | 2012 |
| Acura | RSX | 2002 | 2006 |
| Acura | TL | 2002 | 2012 |
| Acura | TSX | 2004 | 2012 |
| Acura | ZDX | 2010 | 2012 |
| Audi | A3 | 2006 | 2012 |
| Audi | A4 | 2002 | 2012 |
| Audi | A4 Avant | 2002 | 2004 |
| Audi | A4 Avant | 2002 | 2012 |
| Audi | A4 Cabriolet | 2003 | 2004 |
| Audi | A4 Cabriolet | 2008 | 2009 |
| Audi | A4/S4/S4 Avant | 2007 | 2007 |
| Audi | A4/S4 Cabriolet | 2005 | 2005 |
| Audi | A4/S4 Cabriolet | 2007 | 2007 |
| Audi | A5 | 2008 | 2012 |
| Audi | A5 Cabriolet | 2010 | 2012 |
| Audi | A6 | 2002 | 2012 |
| Audi | A6 Avant | 2004 | 2004 |
| Audi | A6 Avant | 2007 | 2012 |
| Audi | A6 Avant/S6 Avant | 2002 | 2003 |
| Audi | A6 Sedan | 2005 | 2005 |
| Audi | A6/S6 | 2007 | 2007 |
| Audi | A8 | 2001 | 2012 |
| Audi | A8L | 2004 | 2004 |
| Audi | Allroad | 2002 | 2005 |
| Audi | Q5 | 2009 | 2012 |
| Audi | Q7 | 2007 | 2012 |
| Audi | R8 | 2008 | 2012 |
| Audi | RS4 | 2008 | 2008 |
| Audi | RS6 | 2003 | 2003 |
| Audi | S4 | 2002 | 2012 |
| Audi | S4 Avant | 2002 | 2004 |
| Audi | S4 Avant | 2008 | 2012 |
| Audi | S4 Cabriolet | 2008 | 2009 |

| | | | |
|---|---|---|---|
| Audi | S5 Cabriolet | 2010 | 2012 |
| Audi | S6 | 2008 | 2012 |
| Audi | S8 | 2002 | 2003 |
| Audi | S8 | 2008 | 2009 |
| Audi | TT | 2001 | 2012 |
| Audi | TTS | 2009 | 2012 |
| Bentley | Arnage Black Label | 2002 | 2003 |
| Bentley | Arnage R | 2004 | 2006 |
| Bentley | Arnage Red Label/LWB | 2002 | 2003 |
| Bentley | Arnage RL | 2004 | 2009 |
| Bentley | Arnage T | 2004 | 2006 |
| Bentley | Arnage T/R | 2007 | 2009 |
| Bentley | Azure | 2002 | 2003 |
| Bentley | Continental | 2002 | 2003 |
| Bentley | Continental Flying Spur | 2007 | 2009 |
| Bentley | Continental GT | 2005 | 2009 |
| Bentley | Continental GTC | 2007 | 2009 |
| Bentley | Continental T | 2004 | 2004 |
| BMW | 128i/135i | 2008 | 2012 |
| BMW | 3 Series | 2002 | 2012 |
| BMW | 3 Series Wagon | 2010 | 2012 |
| BMW | 5 Series | 2004 | 2012 |
| BMW | 5 Series GT | 2010 | 2012 |
| BMW | 5 Series Wagon | 2002 | 2003 |
| BMW | 5 Series Wagon | 2010 | 2012 |
| BMW | 6 Series | 2004 | 2012 |
| BMW | 7 Series | 2002 | 2012 |
| BMW | Alpina Roadster | 2003 | 2003 |
| BMW | M3 | 2005 | 2006 |
| BMW | M3 Convertible | 2002 | 2004 |
| BMW | M3 Coupe | 2002 | 2004 |
| BMW | M5 | 2002 | 2003 |
| BMW | M5 | 2006 | 2006 |
| BMW | M6 | 2006 | 2006 |
| BMW | X3 | 2004 | 2012 |
| BMW | X5 | 2002 | 2012 |
| BMW | X6 | 2010 | 2012 |
| BMW | Z3 roadster/coupe | 2002 | 2002 |
| BMW | Z4 | 2003 | 2012 |
| BMW | Z8 roadster | 2002 | 2002 |
| Buick | Enclave | 2008 | 2012 |

| | | | |
|---|---|---|---|
| Buick | LaCrosse | 2005 | 2012 |
| Buick | Lucerne | 2006 | 2012 |
| Buick | Rainier | 2005 | 2007 |
| Buick | Rendezvous | 2004 | 2007 |
| Buick | Terraza | 2005 | 2007 |
| Cadillac | CTS | 2003 | 2012 |
| Cadillac | CTS - V | 2009 | 2012 |
| Cadillac | DTS | 2006 | 2012 |
| Cadillac | Escalade | 2007 | 2012 |
| Cadillac | Escalade ESV | 2007 | 2012 |
| Cadillac | Escalade EXT | 2007 | 2012 |
| Cadillac | Seville | 2003 | 2003 |
| Cadillac | SRX | 2004 | 2012 |
| Cadillac | STS | 2005 | 2012 |
| Cadillac | XLR | 2004 | 2009 |
| Chevrolet | Avalanche | 2007 | 2012 |
| Chevrolet | Aveo | 2004 | 2012 |
| Chevrolet | Camaro | 2010 | 2012 |
| Chevrolet | Cobalt | 2006 | 2012 |
| Chevrolet | Colorado | 2004 | 2009 |
| Chevrolet | Colorado Crew Cab | 2010 | 2012 |
| Chevrolet | Colorado Extended Cab | 2010 | 2012 |
| Chevrolet | Colorado Regular Cab | 2010 | 2012 |
| Chevrolet | Corvette | 2005 | 2012 |
| Chevrolet | Corvette Z06 | 2006 | 2012 |
| Chevrolet | Corvette ZR1 | 2009 | 2012 |
| Chevrolet | Equinox | 2005 | 2012 |
| Chevrolet | Express | 2006 | 2007 |
| Chevrolet | Express 1500 Cargo | 2008 | 2012 |
| Chevrolet | Express 1500 Passenger | 2008 | 2012 |
| Chevrolet | Express 3500 15 Passenger | 2006 | 2006 |
| Chevrolet | Express 3500 15 Passenger | 2008 | 2008 |
| Chevrolet | HHR | 2006 | 2012 |
| Chevrolet | Impala | 2001 | 2012 |
| Chevrolet | Malibu | 2004 | 2012 |
| Chevrolet | Malibu Classic | 2008 | 2008 |
| Chevrolet | Malibu Hybrid | 2008 | 2009 |
| Chevrolet | Malibu Maxx | 2006 | 2007 |
| Chevrolet | Monte Carlo | 2006 | 2007 |

| | | | |
|---|---|---|---|
| Chevrolet | Prizm | 2001 | 2002 |
| Chevrolet | Silverado | 2007 | 2008 |
| Chevrolet | Silverado 1500 | 2009 | 2009 |
| Chevrolet | Silverado 1500 Crew Cab | 2010 | 2012 |
| Chevrolet | Silverado 1500 Extended Cab | 2010 | 2012 |
| Chevrolet | Silverado 1500 Hybrid | 2009 | 2012 |
| Chevrolet | Silverado 1500 Regular Cab | 2010 | 2012 |
| Chevrolet | Silverado 2500 | 2009 | 2009 |
| Chevrolet | Silverado 2500 Crew Cab | 2010 | 2012 |
| Chevrolet | Silverado 2500 Extended Cab | 2010 | 2012 |
| Chevrolet | Silverado 2500 Regular Cab | 2010 | 2012 |
| Chevrolet | Silverado 3500 | 2009 | 2009 |
| Chevrolet | Silverado 3500 Crew Cab | 2010 | 2012 |
| Chevrolet | Silverado 3500 Extended Cab | 2010 | 2012 |
| Chevrolet | Silverado 3500 Regular Cab | 2010 | 2012 |
| Chevrolet | SSR | 2004 | 2004 |
| Chevrolet | SSR | 2006 | 2006 |
| Chevrolet | Suburban | 2004 | 2004 |
| Chevrolet | Suburban | 2007 | 2009 |
| Chevrolet | Suburban 1500 | 2010 | 2012 |
| Chevrolet | Tahoe | 2007 | 2012 |
| Chevrolet | Tahoe Hybrid | 2008 | 2012 |
| Chevrolet | Tracker | 2003 | 2003 |
| Chevrolet | Trailblazer | 2005 | 2009 |
| Chevrolet | Trailblazer EXT | 2002 | 2006 |
| Chevrolet | Traverse | 2009 | 2012 |
| Chevrolet | Uplander | 2005 | 2008 |
| Chevrolet | Venture | 2001 | 2005 |
| Chrysler | 300 | 2005 | 2012 |
| Chrysler | Aspen | 2007 | 2009 |
| Chrysler | Crossfire | 2004 | 2008 |
| Chrysler | Crossfire Roadster | 2005 | 2008 |
| Chrysler | Pacifica | 2004 | 2008 |
| Chrysler | PT Cruiser | 2001 | 2012 |
| Chrysler | PT Cruiser w/SAB | 2002 | 2005 |

| | | | |
|---|---|---|---|
| Chrysler | Sebring | 2001 | 2012 |
| Chrysler | Town & Country | 2001 | 2012 |
| Chrysler | Voyager | 2001 | 2003 |
| Daewoo | Lanos | 2002 | 2002 |
| Daewoo | Leganza | 2001 | 2002 |
| Daewoo | Nubira | 2002 | 2002 |
| Dodge | Avenger | 2008 | 2012 |
| Dodge | Caliber | 2007 | 2012 |
| Dodge | Caravan | 2001 | 2007 |
| Dodge | Challenger | 2009 | 2012 |
| Dodge | Charger | 2006 | 2012 |
| Dodge | Dakota | 2002 | 2009 |
| Dodge | Dakota Crew/Extended Cab | 2010 | 2012 |
| Dodge | Durango | 2001 | 2009 |
| Dodge | Grand Caravan | 2001 | 2012 |
| Dodge | Grand Caravan Cargo | 2010 | 2012 |
| Dodge | Journey | 2009 | 2012 |
| Dodge | Magnum | 2005 | 2008 |
| Dodge | Nitro | 2007 | 2012 |
| Dodge | Ram | 2002 | 2004 |
| Dodge | Ram 1500 | 2005 | 2009 |
| Dodge | Ram 1500 Crew/Quad Cab | 2010 | 2012 |
| Dodge | Ram 1500 Regular Cab | 2010 | 2012 |
| Dodge | Ram Van | 2001 | 2003 |
| Dodge | Ram Wagon | 2002 | 2003 |
| Dodge | Sprinter | 2007 | 2009 |
| Dodge | Stratus | 2001 | 2006 |
| Dodge | Viper | 2003 | 2003 |
| Dodge | Viper | 2006 | 2006 |
| Dodge | Viper | 2008 | 2012 |
| Dodge | Viper Roadster | 2008 | 2012 |
| Dodge | Viper SRT-10 | 2005 | 2005 |
| Ferrari | 360 Modena | 2002 | 2003 |
| Ferrari | 360 Spider | 2002 | 2003 |
| Ferrari | 575 MM | 2002 | 2003 |
| Ford | Club Wagon | 2001 | 2001 |
| Ford | Crown Victoria | 2001 | 2012 |
| Ford | E-150 | 2005 | 2009 |
| Ford | E-150 (Wagon) | 2010 | 2012 |
| Ford | E-350 12 Passenger | 2008 | 2012 |
| Ford | E-350 15 Passenger | 2006 | 2012 |

| | | | |
|---|---|---|---|
| Ford | Econoline | 2001 | 2004 |
| Ford | Edge | 2007 | 2012 |
| Ford | Escape | 2001 | 2012 |
| Ford | Escape Hybrid | 2005 | 2012 |
| Ford | EV Ranger | 2001 | 2002 |
| Ford | Excursion | 2002 | 2003 |
| Ford | Expedition | 2001 | 2012 |
| Ford | Expedition Extended | 2010 | 2012 |
| Ford | Explorer | 2002 | 2012 |
| Ford | Explorer Sport | 2002 | 2003 |
| Ford | Explorer Sport Trac | 2002 | 2012 |
| Ford | F-150 | 2001 | 2009 |
| Ford | F-150 Extended Cab | 2010 | 2012 |
| Ford | F-150 Heritage | 2004 | 2004 |
| Ford | F-150 Regular Cab | 2010 | 2012 |
| Ford | F-150 Supercab | 2010 | 2012 |
| Ford | F-250 | 2008 | 2009 |
| Ford | F-250 Regular Cab | 2010 | 2012 |
| Ford | F-250 Supercab | 2010 | 2012 |
| Ford | F-250 Supercrew | 2010 | 2012 |
| Ford | F-350 | 2008 | 2009 |
| Ford | F-350 Regular Cab | 2010 | 2012 |
| Ford | F-350 Supercab | 2010 | 2012 |
| Ford | F-350 Supercrew | 2010 | 2012 |
| Ford | Five Hundred | 2005 | 2007 |
| Ford | Flex | 2009 | 2012 |
| Ford | Focus | 2001 | 2012 |
| Ford | Freestar | 2004 | 2007 |
| Ford | Freestyle | 2005 | 2007 |
| Ford | Fusion | 2006 | 2012 |
| Ford | Fusion Hybrid | 2010 | 2012 |
| Ford | GT | 2005 | 2006 |
| Ford | Mustang | 2005 | 2012 |
| Ford | Ranger | 2001 | 2009 |
| Ford | Ranger Regular | 2010 | 2012 |
| Ford | Ranger Supercab | 2010 | 2012 |
| Ford | Ranger Supercab | 2010 | 2012 |
| Ford | Taurus | 2001 | 2012 |
| Ford | Taurus X | 2008 | 2009 |
| Ford | Thunderbird | 2002 | 2005 |
| Ford | Transit Connect Van | 2010 | 2012 |
| Ford | Transit Connect Wagon | 2010 | 2012 |

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|---|---|---|---|
| Ford | Windstar | 2001 | 2003 |
| Ford | ZX2 | 2002 | 2003 |
| Freightliner | Sprinter | 2010 | 2012 |
| GMC | Acadia | 2007 | 2012 |
| GMC | Canyon | 2004 | 2009 |
| GMC | Canyon Crew Cab | 2010 | 2012 |
| GMC | Canyon Extended Cab | 2010 | 2012 |
| GMC | Canyon Regular Cab | 2010 | 2012 |
| GMC | Envoy | 2005 | 2009 |
| GMC | Envoy XL | 2005 | 2006 |
| GMC | Envoy XUV | 2005 | 2005 |
| GMC | Savana | 2006 | 2007 |
| GMC | Savana 1500 Cargo | 2010 | 2012 |
| GMC | Savana 1500 Passenger | 2010 | 2012 |
| GMC | Savana 3500 15 Passenger | 2006 | 2006 |
| GMC | Savana 3500 15 Passenger | 2008 | 2008 |
| GMC | Savana Cargo 1500 | 2008 | 2009 |
| GMC | Savana Passenger 1500 | 2008 | 2009 |
| GMC | Sierra | 2007 | 2008 |
| GMC | Sierra 1500 | 2009 | 2009 |
| GMC | Sierra 1500 Crew/Extended Cab | 2010 | 2012 |
| GMC | Sierra 1500 Hybrid | 2010 | 2012 |
| GMC | Sierra 1500 Regular Cab | 2010 | 2012 |
| GMC | Sierra 2500 | 2009 | 2009 |
| GMC | Sierra 2500 Crew/Extended Cab | 2010 | 2012 |
| GMC | Sierra 2500 Regular Cab | 2010 | 2012 |
| GMC | Sierra 3500 | 2009 | 2009 |
| GMC | Sierra 3500 Crew/Extended Cab | 2010 | 2012 |
| GMC | Sierra 3500 Regular Cab | 2010 | 2012 |
| GMC | Sierra Hybrid | 2009 | 2009 |
| GMC | Terrain | 2010 | 2012 |
| GMC | Yukon | 2007 | 2012 |
| GMC | Yukon Hybrid | 2008 | 2012 |
| GMC | Yukon XL | 2008 | 2009 |
| GMC | Yukon XL 1500 | 2010 | 2012 |

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|---|---|---|---|
| GMC | Yukon XL 2500 | 2010 | 2012 |
| Honda | Accord | 2001 | 2012 |
| Honda | Accord Crosstour | 2010 | 2012 |
| Honda | Accord Hybrid | 2005 | 2007 |
| Honda | Civic | 2001 | 2012 |
| Honda | Civic CNG | 2010 | 2012 |
| Honda | Civic Hybrid | 2006 | 2012 |
| Honda | CR-V | 2001 | 2012 |
| Honda | Element | 2003 | 2012 |
| Honda | FCX | 2004 | 2012 |
| Honda | Fit | 2007 | 2012 |
| Honda | Insight | 2001 | 2006 |
| Honda | Insight | 2010 | 2012 |
| Honda | Odyssey | 2001 | 2012 |
| Honda | Pilot | 2003 | 2012 |
| Honda | Ridgeline | 2006 | 2012 |
| Honda | S2000 | 2001 | 2009 |
| Hummer | H2 | 2008 | 2009 |
| Hummer | H2 Pickup | 2010 | 2012 |
| Hummer | H2 SUV | 2010 | 2012 |
| Hummer | H3 | 2005 | 2012 |
| Hummer | H3T | 2009 | 2012 |
| Hyundai | Accent | 2001 | 2012 |
| Hyundai | Accent Hatchback | 2009 | 2012 |
| Hyundai | Azera | 2006 | 2012 |
| Hyundai | Elantra | 2001 | 2012 |
| Hyundai | Elantra Touring | 2009 | 2012 |
| Hyundai | Entourage | 2007 | 2012 |
| Hyundai | Genesis | 2009 | 2012 |
| Hyundai | Genesis Coupe | 2010 | 2012 |
| Hyundai | Santa Fe | 2002 | 2012 |
| Hyundai | Sonata | 2001 | 2012 |
| Hyundai | Tiburon | 2002 | 2008 |
| Hyundai | Tucson | 2005 | 2012 |
| Hyundai | Veracruz | 2007 | 2012 |
| Hyundai | XG 350 | 2002 | 2005 |
| Infiniti | EX35 | 2008 | 2009 |
| Infiniti | EX35 Wagon | 2010 | 2012 |
| Infiniti | FX35/45 | 2004 | 2008 |
| Infiniti | FX35/50 | 2009 | 2012 |
| Infiniti | FX45 | 2003 | 2003 |
| Infiniti | G20 | 2002 | 2002 |
| Infiniti | G35/Coupe/Sedan | 2003 | 2008 |

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|---|---|---|---|
| Infiniti | G37 | 2008 | 2012 |
| Infiniti | I30 | 2001 | 2001 |
| Infiniti | I35 | 2002 | 2004 |
| Infiniti | M35/45 | 2006 | 2012 |
| Infiniti | M45 | 2003 | 2004 |
| Infiniti | Q45 | 2002 | 2006 |
| Infiniti | QX4 | 2001 | 2003 |
| Infiniti | QX56 | 2005 | 2012 |
| Isuzu | Ascender 5 | 2005 | 2008 |
| Isuzu | Ascender 7 | 2005 | 2007 |
| Isuzu | I-280 | 2006 | 2006 |
| Isuzu | I-290 | 2007 | 2008 |
| Isuzu | I-350 | 2006 | 2006 |
| Isuzu | I-370 | 2007 | 2008 |
| Jaguar | New X-Type | 2006 | 2006 |
| Jaguar | S-Type | 2002 | 2008 |
| Jaguar | VDP/Super V8 | 2002 | 2003 |
| Jaguar | XF | 2008 | 2012 |
| Jaguar | XJ | 2005 | 2012 |
| Jaguar | XJ Series | 2002 | 2004 |
| Jaguar | XK | 2006 | 2012 |
| Jaguar | XK Series | 2002 | 2003 |
| Jaguar | XK8 | 2005 | 2005 |
| Jaguar | XKR | 2005 | 2005 |
| Jaguar | X-Type | 2002 | 2008 |
| Jaguar | X-Type Wagon | 2007 | 2008 |
| Jeep | Commander | 2006 | 2012 |
| Jeep | Compass | 2007 | 2012 |
| Jeep | Grand Cherokee | 2004 | 2012 |
| Jeep | Liberty | 2002 | 2012 |
| Jeep | Patriot | 2007 | 2012 |
| Jeep | Wrangler | 2007 | 2012 |
| Jeep | Wrangler Unlimited | 2009 | 2012 |
| Kia | Amanti | 2004 | 2009 |
| Kia | Borrego | 2009 | 2012 |
| Kia | Forte | 2010 | 2012 |
| Kia | Optima | 2002 | 2012 |
| Kia | Rio | 2001 | 2012 |
| Kia | Rondo | 2007 | 2012 |
| Kia | Sedona | 2002 | 2004 |
| Kia | Sedona | 2006 | 2012 |
| Kia | Sephia | 2001 | 2001 |
| Kia | Sorento | 2003 | 2004 |

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|---|---|---|---|
| Kia | Sorento | 2006 | 2009 |
| Kia | Soul | 2010 | 2012 |
| Kia | Spectra | 2002 | 2009 |
| Kia | Sportage | 2005 | 2012 |
| Land Rover | Discovery Series II | 2002 | 2004 |
| Land Rover | Freelander | 2002 | 2005 |
| Land Rover | LR2 | 2007 | 2012 |
| Land Rover | LR3 | 2005 | 2009 |
| Land Rover | LR4 | 2010 | 2012 |
| Land Rover | Range Rover | 2002 | 2012 |
| Land Rover | Range Rover Sport | 2006 | 2012 |
| Lexus | ES300 | 2001 | 2003 |
| Lexus | ES330 | 2004 | 2006 |
| Lexus | ES350 | 2007 | 2012 |
| Lexus | GS300 | 2002 | 2004 |
| Lexus | GS300/430 | 2005 | 2006 |
| Lexus | GS350/430 | 2007 | 2007 |
| Lexus | GS350/460 | 2008 | 2012 |
| Lexus | GS450h | 2007 | 2008 |
| Lexus | GS450h Hybrid | 2009 | 2012 |
| Lexus | GX460 | 2010 | 2012 |
| Lexus | GX470 | 2003 | 2009 |
| Lexus | HS250h Hybrid | 2010 | 2012 |
| Lexus | IS F | 2008 | 2012 |
| Lexus | IS250/350 | 2006 | 2012 |
| Lexus | IS250C/350C | 2010 | 2012 |
| Lexus | IS300 | 2001 | 2005 |
| Lexus | IS300 Sportcross | 2004 | 2005 |
| Lexus | LS430 | 2002 | 2006 |
| Lexus | LS460/460L | 2007 | 2012 |
| Lexus | LS600hL | 2008 | 2008 |
| Lexus | LS600hL Hybrid | 2009 | 2012 |
| Lexus | LX470 | 2002 | 2007 |
| Lexus | LX570 | 2008 | 2012 |
| Lexus | RX300 | 2001 | 2003 |
| Lexus | RX330 | 2004 | 2006 |
| Lexus | RX350 | 2007 | 2012 |
| Lexus | RX400h | 2005 | 2008 |
| Lexus | RX450h Hybrid | 2010 | 2012 |
| Lexus | SC430 | 2002 | 2012 |
| Lincoln | Aviator | 2003 | 2005 |
| Lincoln | Blackwood | 2002 | 2003 |
| Lincoln | LS | 2001 | 2006 |

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|---|---|---|---|
| Lincoln | Mark LT | 2006 | 2008 |
| Lincoln | MKS | 2009 | 2012 |
| Lincoln | MKT | 2010 | 2012 |
| Lincoln | MKX | 2007 | 2012 |
| Lincoln | MKZ | 2007 | 2012 |
| Lincoln | Navigator | 2001 | 2012 |
| Lincoln | Navigator Extended | 2010 | 2012 |
| Lincoln | Town Car | 2001 | 2012 |
| Lincoln | Zephyr | 2006 | 2006 |
| Mazda | B-Series | 2001 | 2009 |
| Mazda | CX-7 | 2007 | 2012 |
| Mazda | CX-9 | 2007 | 2012 |
| Mazda | Mazda3 | 2004 | 2012 |
| Mazda | Mazda5 | 2006 | 2012 |
| Mazda | Mazda6 | 2004 | 2012 |
| Mazda | Miata | 2001 | 2001 |
| Mazda | Miata MX-5 | 2002 | 2005 |
| Mazda | MPV | 2002 | 2006 |
| Mazda | MX-5/ Miata | 2006 | 2012 |
| Mazda | Protege | 2001 | 2003 |
| Mazda | RX-8 | 2004 | 2012 |
| Mazda | Tribute | 2001 | 2012 |
| Mazda | Tribute Hybrid | 2008 | 2012 |
| Mercedes-Benz | C230 | 2002 | 2003 |
| Mercedes-Benz | C-Class | 2002 | 2012 |
| Mercedes-Benz | CL-Class | 2002 | 2012 |
| Mercedes-Benz | CLK-Class | 2002 | 2009 |
| Mercedes-Benz | CLS-Class | 2006 | 2012 |
| Mercedes-Benz | E-Class | 2002 | 2012 |
| Mercedes-Benz | G500 | 2002 | 2003 |
| Mercedes-Benz | G-Class | 2004 | 2005 |
| Mercedes-Benz | G-Class | 2008 | 2012 |
| Mercedes-Benz | GL-Class | 2007 | 2012 |
| Mercedes-Benz | GLK-Class | 2010 | 2012 |
| Mercedes- | Maybach | 2006 | 2006 |

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|---|---|---|---|
| Benz | | | |
| Mercedes-Benz | Maybach | 2008 | 2008 |
| Mercedes-Benz | Maybach | 2010 | 2012 |
| Mercedes-Benz | Maybach 57, 62 | 2005 | 2005 |
| Mercedes-Benz | Maybach 57, 62 | 2009 | 2009 |
| Mercedes-Benz | ML-Class | 2002 | 2012 |
| Mercedes-Benz | ML-Class Hybrid | 2010 | 2012 |
| Mercedes-Benz | R-Class | 2006 | 2012 |
| Mercedes-Benz | S-Class | 2002 | 2012 |
| Mercedes-Benz | SL-Class | 2002 | 2003 |
| Mercedes-Benz | SL-Class | 2005 | 2012 |
| Mercedes-Benz | SLK | 2002 | 2004 |
| Mercedes-Benz | SLK-Class | 2005 | 2012 |
| Mercedes-Benz | SLR-Class | 2005 | 2006 |
| Mercedes-Benz | SLR-Class | 2008 | 2009 |
| Mercury | Cougar | 2002 | 2002 |
| Mercury | Grand Marquis | 2001 | 2012 |
| Mercury | Marauder | 2004 | 2004 |
| Mercury | Mariner | 2006 | 2012 |
| Mercury | Mariner Hybrid | 2006 | 2012 |
| Mercury | Milan | 2006 | 2012 |
| Mercury | Milan Hybrid | 2010 | 2012 |
| Mercury | Montego | 2006 | 2007 |
| Mercury | Monterey | 2004 | 2007 |
| Mercury | Mountaineer | 2002 | 2012 |
| Mercury | Sable | 2001 | 2009 |
| Mercury | Villager | 2001 | 2002 |
| MINI | Clubman | 2008 | 2012 |
| MINI | Clubman S | 2008 | 2012 |
| MINI | Clubman S John Cooper Works | 2010 | 2012 |
| MINI | Cooper | 2002 | 2012 |

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|---|---|---|---|
| MINI | Cooper S | 2004 | 2012 |
| MINI | John Cooper Works | 2009 | 2012 |
| Mitsubishi | Diamante | 2002 | 2004 |
| Mitsubishi | Eclipse | 2006 | 2008 |
| Mitsubishi | Eclipse Hatchback | 2009 | 2012 |
| Mitsubishi | Eclipse Spyder | 2006 | 2012 |
| Mitsubishi | Endeavor | 2004 | 2012 |
| Mitsubishi | Galant | 2004 | 2012 |
| Mitsubishi | Lancer | 2002 | 2012 |
| Mitsubishi | Lancer Evolution | 2004 | 2012 |
| Mitsubishi | Lancer Sportback | 2004 | 2004 |
| Mitsubishi | Lancer Sportback Hatchback | 2009 | 2012 |
| Mitsubishi | Mirage | 2002 | 2002 |
| Mitsubishi | Montero | 2002 | 2006 |
| Mitsubishi | Montero Sport | 2001 | 2004 |
| Mitsubishi | Outlander | 2003 | 2012 |
| Mitsubishi | Raider Club | 2007 | 2012 |
| Mitsubishi | Raider Quad | 2007 | 2012 |
| Nissan | 350Z | 2003 | 2008 |
| Nissan | 350Z Roadster | 2007 | 2009 |
| Nissan | 370Z | 2009 | 2012 |
| Nissan | 370Z Roadster | 2010 | 2012 |
| Nissan | Altima | 2001 | 2012 |
| Nissan | Altima Hybrid | 2008 | 2012 |
| Nissan | Armada | 2004 | 2012 |
| Nissan | Cube | 2009 | 2012 |
| Nissan | Cube Cargo | 2009 | 2012 |
| Nissan | Frontier | 2001 | 2004 |
| Nissan | Frontier Crew Cab | 2005 | 2012 |
| Nissan | Frontier King Cab | 2005 | 2012 |
| Nissan | GT-R | 2009 | 2012 |
| Nissan | Maxima | 2001 | 2012 |
| Nissan | Murano | 2003 | 2007 |
| Nissan | Murano | 2009 | 2012 |
| Nissan | Pathfinder | 2001 | 2012 |
| Nissan | Quest | 2001 | 2009 |
| Nissan | Rogue | 2008 | 2012 |
| Nissan | Sentra | 2001 | 2012 |
| Nissan | Titan | 2004 | 2009 |
| Nissan | Titan Crew Cab | 2010 | 2012 |
| Nissan | Titan King Cab | 2010 | 2012 |
| Nissan | Versa | 2007 | 2012 |

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|---|---|---|---|
| Nissan | Versa Hatchback | 2008 | 2012 |
| Nissan | Xterra | 2001 | 2012 |
| Oldsmobile | Silhouette | 2001 | 2004 |
| Pontiac | Aztek | 2001 | 2001 |
| Pontiac | G3 | 2009 | 2009 |
| Pontiac | G5 | 2007 | 2009 |
| Pontiac | G6 | 2005 | 2012 |
| Pontiac | G8 | 2008 | 2009 |
| Pontiac | Grand Prix | 2004 | 2008 |
| Pontiac | GTO | 2004 | 2006 |
| Pontiac | Montana | 2001 | 2005 |
| Pontiac | Montana SV6 | 2005 | 2006 |
| Pontiac | Solstice | 2006 | 2009 |
| Pontiac | Torrent | 2006 | 2009 |
| Pontiac | Vibe | 2003 | 2012 |
| Porsche | 911 | 2007 | 2007 |
| Porsche | 911 Carrera | 2004 | 2012 |
| Porsche | 911 Carrera 4 | 2006 | 2012 |
| Porsche | 911 Carrera 4 Cabriolet | 2008 | 2003 |
| Porsche | 911 Carrera 4S/Carrera 4 Cabriolet | 2004 | 2004 |
| Porsche | 911 Carrera 4S/Carrera 4 Cabrio | 2002 | 2004 |
| Porsche | 911 Carrera Cabriolet | 2005 | 2012 |
| Porsche | 911 Carrera/Carrera Cabrio | 2002 | 2003 |
| Porsche | 911 Convertible | 2007 | 2007 |
| Porsche | 911 GT | 2005 | 2005 |
| Porsche | 911 GT | 2008 | 2008 |
| Porsche | 911 GT2/Targa/Turbo | 2002 | 2003 |
| Porsche | 911 GT3 | 2010 | 2012 |
| Porsche | 911 GT3/Targa/Turbo | 2004 | 2004 |
| Porsche | 911 Targa | 2008 | 2012 |
| Porsche | 911 Turbo | 2008 | 2012 |
| Porsche | 911 Turbo Cabriolet | 2005 | 2005 |
| Porsche | 911 Turbo Cabriolet | 2008 | 2012 |
| Porsche | Boxster | 2002 | 2012 |
| Porsche | Boxster S | 2002 | 2002 |
| Porsche | Boxster S | 2004 | 2004 |
| Porsche | Cayenne | 2004 | 2006 |

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|---|---|---|---|
| Porsche | Cayenne | 2008 | 2012 |
| Porsche | Cayenne Turbo | 2005 | 2005 |
| Porsche | Cayman | 2007 | 2012 |
| Porsche | Cayman S | 2006 | 2006 |
| Porsche | Panamera | 2010 | 2012 |
| Rolls Royce | Corniche | 2002 | 2002 |
| Rolls Royce | Park Ward | 2002 | 2002 |
| Rolls Royce | Phantom | 2005 | 2008 |
| Rolls Royce | Phantom EWB | 2008 | 2008 |
| Rolls Royce | Silver Seraph | 2002 | 2002 |
| Saab | 9-2X | 2005 | 2006 |
| Saab | 9-3 | 2002 | 2012 |
| Saab | 9-3 Wagon | 2007 | 2012 |
| Saab | 9-5 | 2002 | 2012 |
| Saab | 9-5 Wagon | 2004 | 2009 |
| Saab | 9-7X | 2005 | 2009 |
| Saturn | Astra | 2008 | 2009 |
| Saturn | Aura | 2007 | 2012 |
| Saturn | Aura Hybrid | 2008 | 2009 |
| Saturn | Ion | 2003 | 2007 |
| Saturn | Outlook | 2007 | 2012 |
| Saturn | Relay | 2005 | 2007 |
| Saturn | Sky | 2007 | 2009 |
| Saturn | VUE | 2004 | 2012 |
| Saturn | VUE Hybrid | 2008 | 2009 |
| Smart | Fortwo | 2008 | 2012 |
| Subaru | Baja | 2003 | 2004 |
| Subaru | Baja | 2006 | 2006 |
| Subaru | Forester | 2003 | 2012 |
| Subaru | Impreza | 2002 | 2012 |
| Subaru | Impreza Wagon | 2010 | 2012 |
| Subaru | Legacy | 2001 | 2012 |
| Subaru | Outback | 2002 | 2012 |
| Subaru | Tribeca | 2006 | 2012 |
| Suzuki | Aerio | 2002 | 2007 |
| Suzuki | Equator Crew Cab | 2009 | 2012 |
| Suzuki | Equator King Cab | 2009 | 2012 |
| Suzuki | Forenza | 2004 | 2008 |
| Suzuki | Grand Vitara | 2006 | 2012 |
| Suzuki | Grand Vitara XL-7 | 2002 | 2006 |
| Suzuki | Kizashi | 2010 | 2012 |
| Suzuki | Reno | 2005 | 2008 |
| Suzuki | SX4 | 2007 | 2012 |

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|---|---|---|---|
| Suzuki | Verona | 2004 | 2006 |
| Suzuki | XL7 | 2007 | 2009 |
| Toyota | 4Runner | 2001 | 2012 |
| Toyota | Avalon | 2001 | 2012 |
| Toyota | Camry | 2001 | 2012 |
| Toyota | Camry Hybrid | 2007 | 2012 |
| Toyota | Celica | 2001 | 2005 |
| Toyota | Corolla | 2001 | 2012 |
| Toyota | Echo | 2001 | 2005 |
| Toyota | FJ Cruiser | 2007 | 2012 |
| Toyota | Highlander | 2002 | 2012 |
| Toyota | Highlander Hybrid | 2006 | 2012 |
| Toyota | Landcruiser | 2002 | 2012 |
| Toyota | Matrix | 2003 | 2012 |
| Toyota | MR2 | 2002 | 2005 |
| Toyota | Prerunner | 2006 | 2006 |
| Toyota | Prius | 2001 | 2012 |
| Toyota | Prius Plug-in | 2010 | 2012 |
| Toyota | RAV4 | 2001 | 2012 |
| Toyota | RAV4 EV | 2002 | 2003 |
| Toyota | Scion tC | 2005 | 2012 |
| Toyota | Scion xA | 2004 | 2006 |
| Toyota | Scion xB | 2004 | 2012 |
| Toyota | Scion xD | 2008 | 2012 |
| Toyota | Sequoia | 2002 | 2012 |
| Toyota | Sienna | 2001 | 2012 |
| Toyota | Solara | 2001 | 2008 |
| Toyota | Tacoma | 2001 | 2009 |
| Toyota | Tacoma Access Cab | 2010 | 2012 |
| Toyota | Tacoma Crew Cab | 2010 | 2012 |
| Toyota | Tacoma Regular Cab | 2010 | 2012 |
| Toyota | Tundra | 2001 | 2009 |
| Toyota | Tundra Crew Cab | 2010 | 2012 |
| Toyota | Tundra Double Cab | 2010 | 2012 |
| Toyota | Tundra Regular Cab | 2010 | 2012 |
| Toyota | Venza | 2009 | 2012 |
| Toyota | Yaris | 2007 | 2012 |
| Toyota | Yaris Liftback | 2007 | 2012 |
| Volkswagen | Cabrio | 2002 | 2002 |
| Volkswagen | CC | 2009 | 2012 |
| Volkswagen | Eos | 2007 | 2012 |
| Volkswagen | Eurovan | 2002 | 2003 |
| Volkswagen | GLI | 2008 | 2009 |

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|---|---|---|---|
| Volkswagen | Golf | 2001 | 2006 |
| Volkswagen | Golf | 2010 | 2012 |
| Volkswagen | Golf/GTI | 2002 | 2006 |
| Volkswagen | GTI | 2007 | 2012 |
| Volkswagen | Jetta | 2001 | 2012 |
| Volkswagen | Jetta Sportwagen | 2010 | 2012 |
| Volkswagen | New Beetle | 2001 | 2012 |
| Volkswagen | Passat | 2001 | 2012 |
| Volkswagen | Passat W8 | 2002 | 2003 |
| Volkswagen | Passat Wagon | 2010 | 2012 |
| Volkswagen | Phaeton | 2004 | 2004 |
| Volkswagen | Phaeton | 2006 | 2006 |
| Volkswagen | Phaeton (4 Pass.) | 2005 | 2005 |
| Volkswagen | R 32 Special Edition | 2008 | 2008 |
| Volkswagen | R32 | 2004 | 2004 |
| Volkswagen | Rabbit | 2007 | 2009 |
| Volkswagen | Routan | 2009 | 2012 |
| Volkswagen | Tiguan | 2009 | 2012 |
| Volkswagen | Touareg | 2004 | 2007 |
| Volkswagen | Touareg 2 | 2008 | 2012 |
| Volvo | C30 | 2008 | 2012 |
| Volvo | C70 | 2002 | 2012 |
| Volvo | S40 | 2002 | 2012 |
| Volvo | S60 | 2001 | 2009 |
| Volvo | S80 | 2001 | 2012 |
| Volvo | V40 | 2002 | 2004 |
| Volvo | V50 | 2005 | 2012 |
| Volvo | V70 | 2002 | 2012 |
| Volvo | V70XC | 2002 | 2003 |
| Volvo | XC60 | 2009 | 2012 |
| Volvo | XC70 | 2004 | 2012 |
| Volvo | XC90 | 2003 | 2012 |

## Table 33. List of Vehicles Equipped With Load Limiter

| Make | Model | First Model Year Equipped with Load Limiter | Last Model Year Equipped with Load Limiter |
|---|---|---|---|
| Acura | CL | 2002 | 2003 |
| Acura | MDX | 2002 | 2012 |
| Acura | RDX | 2007 | 2012 |
| Acura | RL | 2001 | 2012 |
| Acura | RSX | 2002 | 2006 |
| Acura | TL | 2001 | 2012 |
| Acura | TSX | 2004 | 2012 |
| Acura | ZDX | 2010 | 2012 |
| Audi | A3 | 2006 | 2012 |
| Audi | A4 | 2002 | 2012 |
| Audi | A4 Avant | 2002 | 2004 |
| Audi | A4 Avant | 2008 | 2012 |
| Audi | A4 Cabriolet | 2003 | 2004 |
| Audi | A4 Cabriolet | 2008 | 2009 |
| Audi | A4/S4 | 2007 | 2007 |
| Audi | A4/S4 Avant | 2007 | 2007 |
| Audi | A4/S4 Cabriolet | 2005 | 2005 |
| Audi | A4/S4 Cabriolet | 2007 | 2007 |
| Audi | A5 | 2008 | 2012 |
| Audi | A5 Cabriolet | 2010 | 2012 |
| Audi | A6 | 2002 | 2004 |
| Audi | A6 | 2006 | 2006 |
| Audi | A6 | 2008 | 2012 |
| Audi | A6 Avant | 2004 | 2004 |
| Audi | A6 Avant | 2007 | 2012 |
| Audi | A6 Avant/S6 Avant | 2002 | 2003 |
| Audi | A6 Sedan | 2005 | 2005 |
| Audi | A6/S6 | 2007 | 2007 |
| Audi | A8 | 2001 | 2012 |
| Audi | A8L | 2004 | 2004 |
| Audi | Allroad | 2002 | 2005 |
| Audi | Q5 | 2009 | 2012 |
| Audi | Q7 | 2007 | 2012 |
| Audi | R8 | 2008 | 2012 |
| Audi | RS4 | 2008 | 2008 |
| Audi | RS6 | 2003 | 2003 |
| Audi | S4 | 2002 | 2006 |
| Audi | S4 | 2008 | 2008 |
| Audi | S4 | 2010 | 2012 |

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|---|---|---|---|
| Audi | S4 Avant | 2002 | 2004 |
| Audi | S4 Avant | 2008 | 2008 |
| Audi | S4 Avant | 2010 | 2012 |
| Audi | S4 Cabriolet | 2008 | 2008 |
| Audi | S5 | 2008 | 2012 |
| Audi | S5 Cabriolet | 2010 | 2012 |
| Audi | S6 | 2008 | 2012 |
| Audi | S8 | 2002 | 2003 |
| Audi | S8 | 2008 | 2008 |
| Audi | TT | 2001 | 2006 |
| Audi | TT | 2008 | 2012 |
| Audi | TTS | 2009 | 2012 |
| Bentley | Continental Flying Spur | 2007 | 2009 |
| Bentley | Continental GT | 2005 | 2009 |
| Bentley | Continental GTC | 2007 | 2009 |
| Bentley | Continental T | 2004 | 2004 |
| BMW | 128i/135i | 2008 | 2012 |
| BMW | 3 Series | 2002 | 2012 |
| BMW | 3 Series Wagon | 2010 | 2012 |
| BMW | 5 Series | 2004 | 2012 |
| BMW | 5 Series GT | 2010 | 2012 |
| BMW | 5 Series Sport Wagon | 2002 | 2003 |
| BMW | 5 Series Wagon | 2010 | 2012 |
| BMW | 6 Series | 2004 | 2012 |
| BMW | 7 Series | 2002 | 2012 |
| BMW | Alpina Roadster | 2003 | 2003 |
| BMW | M3 | 2005 | 2006 |
| BMW | M3 Convertible | 2002 | 2004 |
| BMW | M3 Coupe | 2002 | 2004 |
| BMW | M5 | 2002 | 2003 |
| BMW | M5 | 2006 | 2006 |
| BMW | M6 | 2006 | 2006 |
| BMW | X3 | 2004 | 2012 |
| BMW | X5 | 2002 | 2012 |
| BMW | X6 | 2010 | 2012 |
| BMW | Z3 roadster/coupe | 2002 | 2002 |
| BMW | Z4 | 2003 | 2008 |
| BMW | Z4 | 2010 | 2012 |
| BMW | Z8 roadster | 2002 | 2002 |
| Buick | Century | 2001 | 2005 |
| Buick | Enclave | 2008 | 2012 |
| Buick | LaCrosse | 2005 | 2012 |

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|---|---|---|---|
| Buick | Lucerne | 2006 | 2012 |
| Buick | Rainier | 2004 | 2007 |
| Buick | Regal | 2001 | 2004 |
| Buick | Rendezvous | 2002 | 2007 |
| Buick | Terraza | 2005 | 2007 |
| Cadillac | CTS | 2003 | 2012 |
| Cadillac | CTS - V | 2009 | 2012 |
| Cadillac | Deville | 2001 | 2003 |
| Cadillac | DTS | 2006 | 2012 |
| Cadillac | Escalade | 2007 | 2012 |
| Cadillac | Escalade ESV | 2007 | 2012 |
| Cadillac | Escalade EXT | 2007 | 2012 |
| Cadillac | Escalade Hybrid | 2009 | 2012 |
| Cadillac | Seville | 2002 | 2003 |
| Cadillac | SRX | 2004 | 2012 |
| Cadillac | STS | 2005 | 2012 |
| Cadillac | XLR | 2004 | 2009 |
| Chevrolet | Astro | 2001 | 2002 |
| Chevrolet | Astro | 2004 | 2005 |
| Chevrolet | Avalanche | 2007 | 2012 |
| Chevrolet | Aveo | 2004 | 2012 |
| Chevrolet | Blazer | 2001 | 2005 |
| Chevrolet | Camaro | 2001 | 2001 |
| Chevrolet | Camaro | 2010 | 2012 |
| Chevrolet | Cavalier | 2001 | 2005 |
| Chevrolet | Cobalt | 2005 | 2012 |
| Chevrolet | Colorado | 2004 | 2009 |
| Chevrolet | Colorado Crew Cab | 2010 | 2012 |
| Chevrolet | Colorado Extended Cab | 2010 | 2012 |
| Chevrolet | Colorado Regular Cab | 2010 | 2012 |
| Chevrolet | Corvette | 2005 | 2012 |
| Chevrolet | Corvette Z06 | 2006 | 2012 |
| Chevrolet | Corvette ZR1 | 2009 | 2012 |
| Chevrolet | Equinox | 2005 | 2012 |
| Chevrolet | Express | 2004 | 2007 |
| Chevrolet | Express 1500 Cargo | 2008 | 2012 |
| Chevrolet | Express 1500 Passenger | 2008 | 2012 |
| Chevrolet | Express 3500 15 Passenger | 2004 | 2006 |
| Chevrolet | Express 3500 15 Passenger | 2008 | 2008 |
| Chevrolet | HHR | 2006 | 2012 |

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|---|---|---|---|
| Chevrolet | Impala | 2001 | 2012 |
| Chevrolet | Lumina | 2001 | 2001 |
| Chevrolet | Malibu | 2001 | 2012 |
| Chevrolet | Malibu Classic | 2008 | 2008 |
| Chevrolet | Malibu Hybrid | 2008 | 2009 |
| Chevrolet | Malibu Maxx | 2006 | 2007 |
| Chevrolet | Monte Carlo | 2001 | 2002 |
| Chevrolet | Monte Carlo | 2004 | 2007 |
| Chevrolet | Prizm | 2001 | 2002 |
| Chevrolet | S-10 | 2001 | 2003 |
| Chevrolet | Silverado | 2002 | 2003 |
| Chevrolet | Silverado | 2007 | 2008 |
| Chevrolet | Silverado 1500 | 2009 | 2009 |
| Chevrolet | Silverado 1500 Crew/Extended Cab | 2010 | 2012 |
| Chevrolet | Silverado 1500 Hybrid | 2009 | 2012 |
| Chevrolet | Silverado 1500 Regular Cab | 2010 | 2012 |
| Chevrolet | Silverado 2500 | 2009 | 2009 |
| Chevrolet | Silverado 2500 Crew/Extended Cab | 2010 | 2012 |
| Chevrolet | Silverado 2500 Regular Cab | 2010 | 2012 |
| Chevrolet | Silverado 3500 | 2009 | 2009 |
| Chevrolet | Silverado 3500 Crew/Extended Cab | 2010 | 2012 |
| Chevrolet | Silverado 3500 Regular Cab | 2010 | 2012 |
| Chevrolet | SSR | 2004 | 2006 |
| Chevrolet | Suburban | 2007 | 2009 |
| Chevrolet | Suburban 1500 | 2010 | 2012 |
| Chevrolet | Suburban 2500 | 2010 | 2012 |
| Chevrolet | Tahoe | 2007 | 2012 |
| Chevrolet | Tahoe Hybrid | 2008 | 2012 |
| Chevrolet | Tracker | 2001 | 2004 |
| Chevrolet | Trailblazer | 2002 | 2009 |
| Chevrolet | Trailblazer EXT | 2002 | 2006 |
| Chevrolet | Traverse | 2009 | 2012 |
| Chevrolet | Uplander | 2005 | 2008 |
| Chevrolet | Venture | 2002 | 2005 |
| Chrysler | 300 | 2005 | 2012 |
| Chrysler | 300M | 2001 | 2004 |
| Chrysler | Aspen | 2007 | 2009 |
| Chrysler | Concorde | 2001 | 2004 |

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|---|---|---|---|
| Chrysler | Concorde Ltd. | 2002 | 2004 |
| Chrysler | Crossfire | 2004 | 2008 |
| Chrysler | Crossfire Roadster | 2005 | 2008 |
| Chrysler | LHS | 2001 | 2001 |
| Chrysler | Pacifica | 2004 | 2008 |
| Chrysler | PT Cruiser | 2002 | 2012 |
| Chrysler | PT Cruiser w/SAB | 2002 | 2005 |
| Chrysler | Sebring | 2001 | 2012 |
| Chrysler | Town & Country | 2001 | 2012 |
| Chrysler | Voyager | 2001 | 2003 |
| Dodge | Avenger | 2008 | 2012 |
| Dodge | Caliber | 2007 | 2012 |
| Dodge | Caravan | 2001 | 2007 |
| Dodge | Challenger | 2009 | 2012 |
| Dodge | Charger | 2006 | 2012 |
| Dodge | Dakota | 2001 | 2009 |
| Dodge | Dakota Crew Cab | 2010 | 2012 |
| Dodge | Dakota Extended Cab | 2010 | 2012 |
| Dodge | Durango | 2001 | 2009 |
| Dodge | Grand Caravan | 2001 | 2012 |
| Dodge | Grand Caravan Cargo | 2010 | 2012 |
| Dodge | Intrepid | 2001 | 2004 |
| Dodge | Journey | 2009 | 2012 |
| Dodge | Magnum | 2005 | 2008 |
| Dodge | Neon | 2001 | 2005 |
| Dodge | Nitro | 2007 | 2012 |
| Dodge | Ram | 2002 | 2004 |
| Dodge | Ram 1500 | 2005 | 2009 |
| Dodge | Ram 1500 Crew Cab | 2010 | 2012 |
| Dodge | Ram 1500 Quad Cab | 2010 | 2012 |
| Dodge | Ram 1500 Regular Cab | 2010 | 2012 |
| Dodge | Ram Van | 2001 | 2003 |
| Dodge | Ram Wagon | 2002 | 2003 |
| Dodge | Sprinter | 2007 | 2009 |
| Dodge | Stratus | 2001 | 2006 |
| Dodge | Viper | 2003 | 2004 |
| Dodge | Viper | 2006 | 2006 |
| Dodge | Viper | 2008 | 2012 |
| Dodge | Viper Roadster | 2008 | 2012 |
| Dodge | Viper SRT-10 | 2005 | 2005 |
| Ferrari | 575 MM | 2002 | 2003 |
| Ford | Crown Victoria | 2001 | 2012 |

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|---|---|---|---|
| Ford | E-150 | 2005 | 2009 |
| Ford | E-150 (Wagon) | 2010 | 2012 |
| Ford | E-350 12 Passenger | 2008 | 2012 |
| Ford | E-350 15 Passenger | 2006 | 2012 |
| Ford | Econoline | 2004 | 2004 |
| Ford | Edge | 2007 | 2012 |
| Ford | Escape | 2001 | 2012 |
| Ford | Escape Hybrid | 2005 | 2012 |
| Ford | Escort | 2001 | 2002 |
| Ford | Escort ZX2 | 2001 | 2001 |
| Ford | EV Ranger | 2001 | 2002 |
| Ford | Excursion | 2002 | 2003 |
| Ford | Excursion | 2005 | 2005 |
| Ford | Expedition | 2001 | 2012 |
| Ford | Expedition Extended | 2010 | 2012 |
| Ford | Explorer | 2002 | 2012 |
| Ford | Explorer Sport | 2002 | 2003 |
| Ford | Explorer Sport Trac | 2002 | 2005 |
| Ford | Explorer Sport Trac | 2007 | 2012 |
| Ford | F-150 | 2001 | 2009 |
| Ford | F-150 Extended Cab | 2010 | 2012 |
| Ford | F-150 Heritage | 2004 | 2004 |
| Ford | F-150 Regular Cab | 2010 | 2012 |
| Ford | F-150 Supercab | 2010 | 2012 |
| Ford | F-250 | 2008 | 2009 |
| Ford | F-250 Regular Cab | 2010 | 2012 |
| Ford | F-250 Supercab/Supercrew | 2010 | 2012 |
| Ford | F-350 | 2008 | 2009 |
| Ford | F-350 Regular Cab | 2010 | 2012 |
| Ford | F-350 Supercab/Supercrew | 2010 | 2012 |
| Ford | Five Hundred | 2005 | 2007 |
| Ford | Flex | 2009 | 2012 |
| Ford | Focus | 2001 | 2012 |
| Ford | Freestar | 2004 | 2007 |
| Ford | Freestyle | 2005 | 2007 |
| Ford | Fusion | 2006 | 2012 |
| Ford | Fusion Hybrid | 2010 | 2012 |
| Ford | GT | 2005 | 2006 |
| Ford | Mustang | 2001 | 2012 |
| Ford | Ranger | 2001 | 2009 |
| Ford | Ranger Regular | 2010 | 2012 |

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|---|---|---|---|
| Ford | Ranger Supercab | 2010 | 2012 |
| Ford | Taurus | 2001 | 2012 |
| Ford | Taurus X | 2008 | 2009 |
| Ford | Thunderbird | 2002 | 2005 |
| Ford | Transit Connect Van/Wagon | 2010 | 2012 |
| Ford | Windstar | 2001 | 2003 |
| Ford | ZX2 | 2002 | 2003 |
| Freightliner | Sprinter | 2010 | 2012 |
| GMC | Acadia | 2007 | 2012 |
| GMC | Canyon | 2004 | 2009 |
| GMC | Canyon Crew Cab | 2010 | 2012 |
| GMC | Canyon Extended Cab | 2010 | 2012 |
| GMC | Canyon Regular Cab | 2010 | 2012 |
| GMC | Envoy | 2002 | 2009 |
| GMC | Envoy XL | 2002 | 2006 |
| GMC | Envoy XUV | 2004 | 2005 |
| GMC | Jimmy | 2001 | 2001 |
| GMC | Safari | 2001 | 2002 |
| GMC | Safari | 2004 | 2005 |
| GMC | Savana | 2004 | 2007 |
| GMC | Savana 1500 Cargo | 2010 | 2012 |
| GMC | Savana 1500 Passenger | 2010 | 2012 |
| GMC | Savana 3500 15 Passenger | 2004 | 2006 |
| GMC | Savana 3500 15 Passenger | 2008 | 2008 |
| GMC | Savana Cargo 1500 | 2008 | 2009 |
| GMC | Savana Passenger 1500 | 2008 | 2009 |
| GMC | Sierra | 2007 | 2008 |
| GMC | Sierra 1500 | 2009 | 2009 |
| GMC | Sierra 1500 Crew/Extended Cab | 2010 | 2012 |
| GMC | Sierra 1500 Hybrid | 2010 | 2012 |
| GMC | Sierra 1500 Regular Cab | 2010 | 2012 |
| GMC | Sierra 2500 | 2009 | 2009 |
| GMC | Sierra 2500 Crew/Extended Cab | 2010 | 2012 |
| GMC | Sierra 2500 Regular Cab | 2010 | 2012 |
| GMC | Sierra 3500 | 2009 | 2009 |
| GMC | Sierra 3500 | 2010 | 2012 |

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|---|---|---|---|
| | Crew/Extended Cab | | |
| GMC | Sierra 3500 Regular Cab | 2010 | 2012 |
| GMC | Sierra Hybrid | 2009 | 2009 |
| GMC | Sonoma | 2001 | 2004 |
| GMC | Terrain | 2010 | 2012 |
| GMC | Yukon | 2007 | 2012 |
| GMC | Yukon Hybrid | 2008 | 2012 |
| GMC | Yukon XL | 2007 | 2009 |
| GMC | Yukon XL 1500 | 2010 | 2012 |
| GMC | Yukon XL 2500 | 2010 | 2012 |
| Honda | Accord | 2001 | 2012 |
| Honda | Accord Crosstour | 2010 | 2012 |
| Honda | Accord Hybrid | 2005 | 2007 |
| Honda | Civic | 2001 | 2012 |
| Honda | Civic CNG | 2010 | 2012 |
| Honda | Civic Hybrid | 2006 | 2001 |
| Honda | CR-V | 2001 | 2012 |
| Honda | Element | 2003 | 2012 |
| Honda | FCX | 2004 | 2006 |
| Honda | FCX | 2009 | 2012 |
| Honda | Fit | 2007 | 2012 |
| Honda | Insight | 2001 | 2006 |
| Honda | Insight | 2010 | 2012 |
| Honda | Odyssey | 2001 | 2012 |
| Honda | Passport | 2001 | 2002 |
| Honda | Pilot | 2003 | 2012 |
| Honda | Ridgeline | 2006 | 2012 |
| Honda | S2000 | 2001 | 2009 |
| Hummer | H2 | 2008 | 2009 |
| Hummer | H2 Pickup | 2010 | 2012 |
| Hummer | H2 SUV | 2010 | 2012 |
| Hummer | H3 | 2005 | 2012 |
| Hummer | H3T | 2009 | 2012 |
| Hyundai | Accent | 2001 | 2012 |
| Hyundai | Accent Hatchback | 2009 | 2012 |
| Hyundai | Azera | 2006 | 2012 |
| Hyundai | Elantra | 2001 | 2002 |
| Hyundai | Elantra | 2004 | 2012 |
| Hyundai | Elantra Touring | 2009 | 2012 |
| Hyundai | Entourage | 2007 | 2012 |
| Hyundai | Genesis | 2009 | 2012 |
| Hyundai | Genesis Coupe | 2010 | 2012 |

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|---|---|---|---|
| Hyundai | Santa Fe | 2002 | 2012 |
| Hyundai | Sonata | 2001 | 2012 |
| Hyundai | Tiburon | 2002 | 2008 |
| Hyundai | Tucson | 2005 | 2012 |
| Hyundai | Veracruz | 2007 | 2012 |
| Hyundai | XG 350 | 2002 | 2005 |
| Infiniti | EX35 | 2008 | 2009 |
| Infiniti | EX35 Wagon | 2010 | 2012 |
| Infiniti | FX35/45 | 2004 | 2008 |
| Infiniti | FX35/50 | 2009 | 2012 |
| Infiniti | FX45 | 2003 | 2003 |
| Infiniti | G20 | 2002 | 2002 |
| Infiniti | G35 | 2003 | 2004 |
| Infiniti | G35 | 2008 | 2008 |
| Infiniti | G35 Coupe | 2005 | 2007 |
| Infiniti | G35 Sedan | 2005 | 2007 |
| Infiniti | G37 | 2008 | 2012 |
| Infiniti | I30 | 2001 | 2001 |
| Infiniti | I35 | 2002 | 2004 |
| Infiniti | M35/45 | 2006 | 2012 |
| Infiniti | M45 | 2003 | 2004 |
| Infiniti | Q45 | 2002 | 2006 |
| Infiniti | QX4 | 2001 | 2003 |
| Infiniti | QX56 | 2005 | 2012 |
| Isuzu | Ascender 5 | 2005 | 2007 |
| Isuzu | Ascender 7 | 2005 | 2007 |
| Isuzu | Axiom | 2002 | 2004 |
| Isuzu | I-280 | 2006 | 2006 |
| Isuzu | I-290 | 2007 | 2008 |
| Isuzu | I-350 | 2006 | 2006 |
| Isuzu | I-370 | 2007 | 2008 |
| Isuzu | Rodeo | 2001 | 2004 |
| Isuzu | Rodeo Sport | 2002 | 2003 |
| Isuzu | Trooper | 2002 | 2002 |
| Jaguar | New X-Type | 2006 | 2006 |
| Jaguar | S-Type | 2002 | 2008 |
| Jaguar | XF | 2008 | 2012 |
| Jaguar | XJ | 2005 | 2012 |
| Jaguar | XJ Series | 2002 | 2004 |
| Jaguar | XK | 2006 | 2012 |
| Jaguar | XK Series | 2002 | 2003 |
| Jaguar | XK8 | 2005 | 2005 |
| Jaguar | XKR | 2005 | 2005 |

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|---|---|---|---|
| Jaguar | X-Type | 2002 | 2008 |
| Jaguar | X-Type Wagon | 2007 | 2008 |
| Jeep | Commander | 2006 | 2012 |
| Jeep | Compass | 2007 | 2012 |
| Jeep | Grand Cherokee | 2001 | 2012 |
| Jeep | Liberty | 2002 | 2012 |
| Jeep | Patriot | 2007 | 2012 |
| Jeep | Wrangler | 2002 | 2012 |
| Jeep | Wrangler Unlimited | 2009 | 2012 |
| Kia | Amanti | 2004 | 2009 |
| Kia | Borrego | 2009 | 2012 |
| Kia | Forte | 2010 | 2012 |
| Kia | Optima | 2002 | 2012 |
| Kia | Rio | 2001 | 2012 |
| Kia | Rondo | 2007 | 2012 |
| Kia | Sedona | 2002 | 2012 |
| Kia | Sephia | 2001 | 2001 |
| Kia | Sorento | 2003 | 2009 |
| Kia | Soul | 2010 | 2012 |
| Kia | Spectra | 2002 | 2009 |
| Kia | Sportage | 2005 | 2012 |
| Land Rover | Discovery Series II | 2002 | 2004 |
| Land Rover | Freelander | 2002 | 2005 |
| Land Rover | LR2 | 2007 | 2012 |
| Land Rover | LR3 | 2005 | 2009 |
| Land Rover | LR4 | 2010 | 2012 |
| Land Rover | Range Rover | 2002 | 2012 |
| Land Rover | Range Rover Sport | 2006 | 2012 |
| Lexus | ES300 | 2001 | 2003 |
| Lexus | ES330 | 2004 | 2006 |
| Lexus | ES350 | 2007 | 2012 |
| Lexus | GS300 | 2002 | 2004 |
| Lexus | GS300/430 | 2005 | 2006 |
| Lexus | GS350/460 | 2008 | 2012 |
| Lexus | GS450h | 2007 | 2008 |
| Lexus | GS450h Hybrid | 2009 | 2012 |
| Lexus | GX470 | 2003 | 2009 |
| Lexus | HS250h Hybrid | 2010 | 2012 |
| Lexus | IS F | 2008 | 2012 |
| Lexus | IS250/350 | 2006 | 2012 |
| Lexus | IS250C/350C | 2010 | 2012 |
| Lexus | IS300 | 2001 | 2005 |
| Lexus | IS300 Sportcross | 2004 | 2005 |

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|---|---|---|---|
| Lexus | LS430 | 2002 | 2006 |
| Lexus | LS460/460L | 2007 | 2012 |
| Lexus | LS600hL | 2008 | 2008 |
| Lexus | LS600hL Hybrid | 2009 | 2012 |
| Lexus | LX470 | 2002 | 2007 |
| Lexus | LX570 | 2008 | 2012 |
| Lexus | RX300 | 2001 | 2003 |
| Lexus | RX330 | 2004 | 2006 |
| Lexus | RX350 | 2007 | 2012 |
| Lexus | RX400h | 2005 | 2008 |
| Lexus | RX450h Hybrid | 2010 | 2012 |
| Lexus | SC430 | 2002 | 2012 |
| Lincoln | Aviator | 2003 | 2005 |
| Lincoln | Blackwood | 2002 | 2003 |
| Lincoln | LS | 2001 | 2006 |
| Lincoln | Mark LT | 2006 | 2008 |
| Lincoln | MKS | 2009 | 2012 |
| Lincoln | MKT | 2010 | 2012 |
| Lincoln | MKX | 2007 | 2009 |
| Lincoln | MKZ | 2007 | 2012 |
| Lincoln | Navigator | 2001 | 2012 |
| Lincoln | Navigator Extended | 2010 | 2012 |
| Lincoln | Town Car | 2001 | 2012 |
| Lincoln | Zephyr | 2006 | 2006 |
| Mazda | 626 | 2001 | 2002 |
| Mazda | B-Series | 2001 | 2009 |
| Mazda | CX-7 | 2007 | 2012 |
| Mazda | CX-9 | 2007 | 2012 |
| Mazda | Mazda3 | 2004 | 2012 |
| Mazda | Mazda5 | 2006 | 2012 |
| Mazda | Mazda6 | 2003 | 2012 |
| Mazda | Miata | 2001 | 2001 |
| Mazda | Miata MX-5 | 2002 | 2005 |
| Mazda | Millenia | 2001 | 2002 |
| Mazda | MPV | 2001 | 2006 |
| Mazda | MX-5/ Miata | 2006 | 2012 |
| Mazda | Protege | 2001 | 2003 |
| Mazda | RX-8 | 2004 | 2012 |
| Mazda | Tribute | 2001 | 2006 |
| Mazda | Tribute | 2008 | 2012 |
| Mazda | Tribute Hybrid | 2008 | 2012 |
| Mercedes-Benz | C230 | 2002 | 2003 |

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|---|---|---|---|
| Mercedes-Benz | C-Class | 2002 | 2012 |
| Mercedes-Benz | CL-Class | 2002 | 2012 |
| Mercedes-Benz | CLK-Class | 2002 | 2009 |
| Mercedes-Benz | CLS-Class | 2006 | 2012 |
| Mercedes-Benz | E-Class | 2002 | 2012 |
| Mercedes-Benz | G500 | 2002 | 2003 |
| Mercedes-Benz | G-Class | 2005 | 2005 |
| Mercedes-Benz | G-Class | 2008 | 2012 |
| Mercedes-Benz | GL-Class | 2007 | 2012 |
| Mercedes-Benz | GLK-Class | 2010 | 2012 |
| Mercedes-Benz | Maybach | 2006 | 2006 |
| Mercedes-Benz | Maybach | 2008 | 2008 |
| Mercedes-Benz | Maybach | 2010 | 2012 |
| Mercedes-Benz | Maybach 57 | 2005 | 2005 |
| Mercedes-Benz | Maybach 57 | 2009 | 2009 |
| Mercedes-Benz | Maybach 62 | 2005 | 2005 |
| Mercedes-Benz | Maybach 62 | 2009 | 2009 |
| Mercedes-Benz | ML-Class | 2002 | 2003 |
| Mercedes-Benz | ML-Class | 2005 | 2012 |
| Mercedes-Benz | ML-Class Hybrid | 2010 | 2012 |
| Mercedes-Benz | R-Class | 2006 | 2012 |
| Mercedes-Benz | S-Class | 2002 | 2012 |
| Mercedes-Benz | SL-Class | 2002 | 2012 |
| Mercedes-Benz | SLK | 2002 | 2004 |
| Mercedes- | SLK-Class | 2005 | 2012 |

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|---|---|---|---|
| Benz | | | |
| Mercedes-Benz | SLR-Class | 2005 | 2006 |
| Mercedes-Benz | SLR-Class | 2008 | 2009 |
| Mercury | Cougar | 2001 | 2001 |
| Mercury | Grand Marquis | 2001 | 2012 |
| Mercury | Marauder | 2004 | 2004 |
| Mercury | Mariner | 2005 | 2012 |
| Mercury | Mariner Hybrid | 2006 | 2012 |
| Mercury | Milan | 2006 | 2012 |
| Mercury | Montego | 2005 | 2007 |
| Mercury | Monterey | 2004 | 2007 |
| Mercury | Mountaineer | 2002 | 2012 |
| Mercury | Sable | 2001 | 2005 |
| Mercury | Sable | 2008 | 2009 |
| Mercury | Villager | 2001 | 2002 |
| MINI | Clubman | 2008 | 2012 |
| MINI | Clubman S | 2008 | 2012 |
| MINI | Clubman S John Cooper Works | 2010 | 2012 |
| MINI | Cooper | 2002 | 2012 |
| MINI | Cooper S | 2004 | 2004 |
| MINI | Cooper S | 2008 | 2012 |
| MINI | John Cooper Works | 2009 | 2012 |
| Mitsubishi | Diamante | 2002 | 2004 |
| Mitsubishi | Eclipse | 2001 | 2008 |
| Mitsubishi | Eclipse Hatchback | 2009 | 2012 |
| Mitsubishi | Eclipse Spyder | 2002 | 2012 |
| Mitsubishi | Endeavor | 2004 | 2012 |
| Mitsubishi | Galant | 2001 | 2012 |
| Mitsubishi | Lancer | 2002 | 2012 |
| Mitsubishi | Lancer Evolution | 2004 | 2006 |
| Mitsubishi | Lancer Evolution | 2008 | 2012 |
| Mitsubishi | Lancer Sportback | 2004 | 2004 |
| Mitsubishi | Lancer Sportback Hatchback | 2009 | 2012 |
| Mitsubishi | Mirage | 2002 | 2002 |
| Mitsubishi | Montero | 2002 | 2006 |
| Mitsubishi | Montero Sport | 2001 | 2004 |
| Mitsubishi | Outlander | 2003 | 2012 |
| Mitsubishi | Raider Club | 2007 | 2012 |
| Mitsubishi | Raider Quad | 2007 | 2012 |
| Nissan | 350Z | 2003 | 2008 |

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|---|---|---|---|
| Nissan | 350Z Roadster | 2007 | 2009 |
| Nissan | 370Z | 2009 | 2012 |
| Nissan | 370Z Roadster | 2010 | 2012 |
| Nissan | Altima | 2001 | 2012 |
| Nissan | Altima Hybrid | 2008 | 2012 |
| Nissan | Armada | 2004 | 2012 |
| Nissan | Cube | 2009 | 2012 |
| Nissan | Cube Cargo | 2009 | 2012 |
| Nissan | Frontier | 2001 | 2004 |
| Nissan | Frontier Crew Cab | 2005 | 2012 |
| Nissan | Frontier King Cab | 2005 | 2012 |
| Nissan | GT-R | 2009 | 2012 |
| Nissan | Maxima | 2001 | 2012 |
| Nissan | Murano | 2003 | 2007 |
| Nissan | Murano | 2009 | 2012 |
| Nissan | Pathfinder | 2001 | 2012 |
| Nissan | Quest | 2001 | 2002 |
| Nissan | Quest | 2004 | 2009 |
| Nissan | Rogue | 2008 | 2012 |
| Nissan | Sentra | 2001 | 2012 |
| Nissan | Titan | 2004 | 2009 |
| Nissan | Titan Crew/King Cab | 2010 | 2012 |
| Nissan | Versa | 2007 | 2012 |
| Nissan | Versa Hatchback | 2008 | 2012 |
| Nissan | Xterra | 2001 | 2012 |
| Oldsmobile | Alero | 2001 | 2004 |
| Oldsmobile | Bravada | 2001 | 2004 |
| Oldsmobile | Intrigue | 2001 | 2002 |
| Oldsmobile | Silhouette | 2002 | 2004 |
| Plymouth | Neon | 2001 | 2001 |
| Pontiac | Aztek | 2002 | 2005 |
| Pontiac | Firebird | 2001 | 2001 |
| Pontiac | G3 | 2009 | 2009 |
| Pontiac | G5 | 2007 | 2009 |
| Pontiac | G6 | 2005 | 2012 |
| Pontiac | G8 | 2008 | 2009 |
| Pontiac | Grand Am | 2001 | 2005 |
| Pontiac | Grand Prix | 2001 | 2008 |
| Pontiac | GTO | 2004 | 2006 |
| Pontiac | Montana | 2002 | 2005 |
| Pontiac | Montana SV6 | 2005 | 2006 |
| Pontiac | Solstice | 2006 | 2009 |
| Pontiac | Sunfire | 2001 | 2005 |

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|---|---|---|---|
| Pontiac | Torrent | 2006 | 2009 |
| Pontiac | Vibe | 2003 | 2012 |
| Porsche | 911 | 2007 | 2007 |
| Porsche | 911 Carrera | 2004 | 2006 |
| Porsche | 911 Carrera | 2008 | 2012 |
| Porsche | 911 Carrera 4 | 2006 | 2006 |
| Porsche | 911 Carrera 4 | 2008 | 2012 |
| Porsche | 911 Carrera 4 Cabriolet | 2008 | 2012 |
| Porsche | 911 Carrera 4S/Carrera 4 Cabrio | 2002 | 2004 |
| Porsche | 911 Carrera Cabriolet | 2005 | 2006 |
| Porsche | 911 Carrera Cabriolet | 2008 | 2012 |
| Porsche | 911 Carrera/Carrera Cabrio | 2002 | 2003 |
| Porsche | 911 Convertible | 2007 | 2007 |
| Porsche | 911 GT | 2005 | 2005 |
| Porsche | 911 GT | 2008 | 2008 |
| Porsche | 911 GT2/Targa/Turbo | 2002 | 2003 |
| Porsche | 911 GT3 | 2010 | 2012 |
| Porsche | 911 GT3/Targa/Turbo | 2004 | 2004 |
| Porsche | 911 Targa | 2008 | 2012 |
| Porsche | 911 Turbo | 2005 | 2005 |
| Porsche | 911 Turbo | 2008 | 2012 |
| Porsche | 911 Turbo Cabriolet | 2005 | 2005 |
| Porsche | 911 Turbo Cabriolet | 2008 | 2012 |
| Porsche | Boxster | 2002 | 2012 |
| Porsche | Boxster S | 2002 | 2002 |
| Porsche | Boxster S | 2004 | 2004 |
| Porsche | Cayenne | 2004 | 2006 |
| Porsche | Cayenne | 2008 | 2012 |
| Porsche | Cayenne Turbo | 2005 | 2005 |
| Porsche | Cayman | 2007 | 2012 |
| Porsche | Cayman S | 2006 | 2006 |
| Porsche | Panamera | 2010 | 2012 |
| Rolls Royce | Phantom | 2005 | 2008 |
| Rolls Royce | Phantom EWB | 2008 | 2008 |
| Saab | 9-2X | 2005 | 2006 |
| Saab | 9-3 | 2003 | 2012 |
| Saab | 9-3 Wagon | 2007 | 2012 |
| Saab | 9-5 | 2002 | 2012 |
| Saab | 9-5 Wagon | 2004 | 2004 |

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| Saab | 9-5 Wagon | 2007 | 2009 |
| Saab | 9-7X | 2005 | 2009 |
| Saturn | Astra | 2008 | 2009 |
| Saturn | Aura | 2007 | 2012 |
| Saturn | Aura Hybrid | 2008 | 2009 |
| Saturn | Ion | 2003 | 2007 |
| Saturn | L | 2001 | 2001 |
| Saturn | L-Series | 2002 | 2005 |
| Saturn | Outlook | 2007 | 2012 |
| Saturn | Relay | 2005 | 2007 |
| Saturn | Sky | 2007 | 2009 |
| Saturn | SL | 2001 | 2002 |
| Saturn | VUE | 2002 | 2012 |
| Saturn | VUE Hybrid | 2008 | 2009 |
| Smart | Fortwo | 2008 | 2012 |
| Subaru | Baja | 2003 | 2006 |
| Subaru | Forester | 2001 | 2012 |
| Subaru | Impreza | 2002 | 2012 |
| Subaru | Impreza Wagon | 2010 | 2012 |
| Subaru | Legacy | 2001 | 2012 |
| Subaru | Outback | 2002 | 2012 |
| Subaru | Tribeca | 2006 | 2012 |
| Suzuki | Aerio | 2002 | 2007 |
| Suzuki | Equator Crew/King Cab | 2009 | 2012 |
| Suzuki | Esteem | 2002 | 2002 |
| Suzuki | Forenza | 2004 | 2008 |
| Suzuki | Grand Vitara | 2001 | 2012 |
| Suzuki | Grand Vitara XL-7 | 2002 | 2006 |
| Suzuki | Kizashi | 2010 | 2012 |
| Suzuki | Reno | 2005 | 2008 |
| Suzuki | SX4 | 2007 | 2012 |
| Suzuki | Verona | 2004 | 2006 |
| Suzuki | Vitara | 2001 | 2005 |
| Suzuki | XL7 | 2007 | 2009 |
| Toyota | 4Runner | 2001 | 2012 |
| Toyota | Avalon | 2001 | 2012 |
| Toyota | Camry | 2001 | 2012 |
| Toyota | Camry Hybrid | 2007 | 2012 |
| Toyota | Celica | 2001 | 2005 |
| Toyota | Corolla | 2001 | 2012 |
| Toyota | Echo | 2001 | 2005 |
| Toyota | FJ Cruiser | 2007 | 2012 |

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|---|---|---|---|
| Toyota | Highlander | 2002 | 2012 |
| Toyota | Highlander Hybrid | 2006 | 2012 |
| Toyota | Landcruiser | 2002 | 2012 |
| Toyota | Matrix | 2003 | 2012 |
| Toyota | MR2 | 2002 | 2005 |
| Toyota | Prerunner | 2006 | 2006 |
| Toyota | Prius | 2001 | 2012 |
| Toyota | Prius Plug-in | 2010 | 2012 |
| Toyota | RAV4 | 2001 | 2012 |
| Toyota | RAV4 EV | 2002 | 2003 |
| Scion | tC | 2005 | 2012 |
| Scion | xA | 2004 | 2006 |
| Scion | xB | 2004 | 2012 |
| Scion | xD | 2008 | 2012 |
| Toyota | Sequoia | 2002 | 2012 |
| Toyota | Sienna | 2001 | 2012 |
| Toyota | Solara | 2001 | 2008 |
| Toyota | Tacoma | 2001 | 2009 |
| Toyota | Tacoma Access Cab | 2010 | 2012 |
| Toyota | Tacoma Crew Cab | 2010 | 2012 |
| Toyota | Tacoma Regular Cab | 2010 | 2012 |
| Toyota | Tundra | 2001 | 2009 |
| Toyota | Tundra Crew/Double Cab | 2010 | 2012 |
| Toyota | Tundra Regular Cab | 2010 | 2012 |
| Toyota | Venza | 2009 | 2012 |
| Toyota | Yaris | 2007 | 2012 |
| Toyota | Yaris Liftback | 2007 | 2012 |
| Volkswagen | Cabrio | 2002 | 2002 |
| Volkswagen | CC | 2009 | 2012 |
| Volkswagen | Eos | 2007 | 2012 |
| Volkswagen | Eurovan | 2002 | 2003 |
| Volkswagen | GLI | 2008 | 2009 |
| Volkswagen | Golf | 2001 | 2006 |
| Volkswagen | Golf | 2010 | 2012 |
| Volkswagen | Golf/GTI | 2002 | 2006 |
| Volkswagen | GTI | 2007 | 2012 |
| Volkswagen | Jetta | 2001 | 2012 |
| Volkswagen | Jetta Sportwagen | 2010 | 2012 |
| Volkswagen | New Beetle | 2001 | 2012 |
| Volkswagen | Passat | 2001 | 2012 |
| Volkswagen | Passat W8 | 2002 | 2003 |
| Volkswagen | Passat Wagon | 2010 | 2012 |

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|---|---|---|---|
| Volkswagen | Phaeton | 2004 | 2004 |
| Volkswagen | Phaeton | 2006 | 2006 |
| Volkswagen | Phaeton (4 Pass.) | 2005 | 2005 |
| Volkswagen | R 32 Special Edition | 2008 | 2008 |
| Volkswagen | R32 | 2004 | 2004 |
| Volkswagen | Rabbit | 2007 | 2009 |
| Volkswagen | Routan | 2009 | 2012 |
| Volkswagen | Tiguan | 2009 | 2012 |
| Volkswagen | Touareg | 2004 | 2007 |
| Volkswagen | Touareg 2 | 2008 | 2012 |
| Volvo | C30 | 2008 | 2012 |
| Volvo | C70 | 2002 | 2005 |
| Volvo | C70 | 2007 | 2012 |
| Volvo | S40 | 2002 | 2012 |
| Volvo | S60 | 2001 | 2009 |
| Volvo | S80 | 2001 | 2012 |
| Volvo | V40 | 2002 | 2004 |
| Volvo | V50 | 2005 | 2012 |
| Volvo | V70 | 2002 | 2012 |
| Volvo | V70XC | 2002 | 2003 |
| Volvo | XC60 | 2009 | 2012 |
| Volvo | XC70 | 2004 | 2012 |
| Volvo | XC90 | 2003 | 2012 |