

Frontal Crash Protection in Pre-1998 Vehicles versus 1998 and Later Vehicles

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ABSTRACT

This investigation addresses and evaluates: (1) belted drivers in frontal crashes; (2) crashes divided into low, medium, and high severity; (3) air-bag-equipped passenger vehicles separated into either model years 1985 - 1997 (with airbags) or model years 1998 - 2008; (4) rate of Harm as a function of crash severity and vehicle model year; and (5) injury patterns associated with injured body regions and the involved physical components, by vehicle model year.

Comparisons are made between the injury patterns related to drivers seated in vehicles manufactured before 1998 and those manufactured 1998 or later. The purpose of this comparative analysis is to establish how driver injury patterns may have changed as a result of the introduction of more recent safety belt technology, advanced airbags, or structural changes. More recent years of NASS/CDS have meant that additional 1998+ model year vehicles were available for analysis, and there were almost equal number of frontal crashes involving pre-1998 and 1998+ model year vehicles.

This investigation is based on the analysis of real-world crash data obtained from the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) between the years 1993-2008.

INTRODUCTION

In 1997, the Federal Motor Vehicle Safety Standard (FMVSS) 208 was amended to mandate that all new passenger vehicles sold in the USA have both driver and passenger airbags in addition to a seat-belt restraint system. In 1998 testing procedures were revised to allow for vehicle airbags to be evaluated based upon a 30-mph sled test. This change resulted in depowered second-generation airbags being installed in all new vehicles. These second-generation

airbags deployed with less force than their predecessors. The goal was to reduce the occurrence of crashes, especially at low severity, in which the airbag in and of itself caused trauma.

In 2003, Schneider [1] conducted a study comparing driver frontal crash protection between 318 pre-1998 vehicles and 249 vehicles manufactured 1998 or later. It was found that “airbags in 1998 and newer model vehicles are less injurious than pre-1998 vehicles.” Schneider also reported instances whereby the occupant seemingly overpowered the airbag, which resulted in serious or fatal chest injuries as a consequence.

Braver et al. (2008) [2] investigated the deaths among drivers and right front passengers in frontal collisions for redesigned airbags relative to first-generation airbags. This study provided “strong and consistent evidence that depowering airbags has reduced the toll of airbag related deaths among child right-front passengers” while the other occupant categories “did not appear to have suffered as a result.”

In 2006 Olsen et al. [3] performed a study investigating front seat occupant fatalities associated with first and second generation airbags. The study involved the analysis of 128,208 occupants from the Fatality Analysis Reporting System (FARS). Similar to the study by Braver [2], this paper also found that “the increased safety of airbags for children was not offset by less protection for older occupants.” Also in 2006, Kahane, using different analytical approaches, determined that the fatality risk for front-seat adults in sled certified vehicles was not higher than adults in barrier-certified vehicles with first-generation airbags [4].

In 2008, Ferguson and Schneider presented an overview of the findings of a Blue Ribbon Panel for the evaluation of advanced technology airbags [5]. They found persuasive

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confirmation that the redesign of frontal airbags-about the year 1997-had greatly reduced the danger of deploying airbags to children. They found little to no evidence that the safety of larger-size drivers or passengers had been denigrated by the redesign of frontal airbags. While the investigation was focused on vehicles with depowered and advanced airbag systems versus vehicles with first-generation airbags, Ferguson and Schneider noted that other key safety initiatives occurred circa 1997. They used seat-belt load limiters and belt pretension as examples.

Beginning with the 1998 model year, most passenger vehicles produced for sale in the US market were equipped with redesigned air bags. Park et al. investigated how the safety ratings in the New Car Assessment Program (NCAP) were affected by the introduction of redesigned air bags (installed in 1998 model year vehicles that had the same structure in model year 1997) in 33 passenger vehicles. [6] Their analysis suggested that-based just on the introduction of redesigned air bags-the new air bags had little effect on the NCAP rating of the 33 passenger vehicles going from 1997 to 1998.

Walz [7] documented that load-limiters and pretension devices in the safety belts appeared in US NCAP vehicles between 1997 and 2003. Walz also noted decreases in HIC, chest acceleration, and chest deflections were associated with these safety devices in the NCAP frontal crashes. A study by Brumbelow et al. [8] investigated the effectiveness of load-limiters in IIHS tested vehicles. This study found that “although load limiters perform well in rigid barrier tests with high deceleration, short duration and low intrusion, the forward movement they allow in crashes with longer duration and higher intrusion may increase head injury risk.”

The graph in [Figure 1](#), taken from Kent et al. [9], indicates the rapid increase of seat-belt load limiters and belt pretension after about 1997.

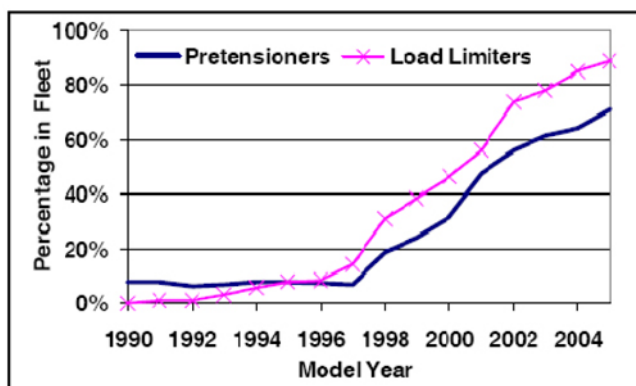


Figure 1. Introduction of Advanced Safety Belt Systems into Passenger vehicles within the U.S. [6]

In addition to changes in the design of the vehicle restraint systems, there were changes in the structural design of vehicles. Swanson et al. [10] examined the dynamic performance of the structure of passenger cars in NCAP frontal tests. They identified a considerable increase in vehicle stiffness beginning about 1998. In 2008, Blum et al. investigated the effects of structural design relative to serious injury outcome for belted occupants in frontal collisions [11]. The analysis of 119,000 actual crashes suggested that, at higher crash severity, the stiffness of the driver's own vehicle had the strongest correlation with lower injury (i.e., the higher the stiffness of the drivers own vehicle, the lower the risk to the driver). In a follow-up paper to the study in 2008, Blum et al. focused on the structural attributes of the striking vehicle that contributed to the occupant risk in the struck vehicle in head-on collisions (i.e., vehicle aggressivity) [12]. Based on the data of 107,000 actual crashes, the analysis suggested that crush-zone stiffness of the striking vehicle is not a primary or secondary correlate with risk of serious or fatal injury to the driver in the struck vehicle in frontal crashes.

In a frontal collision, although there is an airbag present in the vehicle, there are circumstances in which the airbag will fail to deploy. The Insurance Institute for Highway Safety (IIHS) compared 628 fatal frontal collisions using data from both the NASS/CDS and the Fatality Analysis Reporting System (FARS), to identify the incidence of airbag non-deployment [13]. The study identified that in eighty-seven percent of the cases, the frontal airbag was deployed. In ten percent of the cases the airbag was either turned off or removed from the vehicle, not expected to inflate due to the nature of the impact (e.g., underride), or it was indeterminable as to whether the airbag inflated due to catastrophic nature of the damage occurring to the vehicle. For the remaining three percent of fatal cases in which the airbag did not deploy, it was identified that based on the damage profile of the post-crash vehicle, the airbag should have possibly deployed as the result of impact.

At higher crash severities in which there are large amounts of intrusion, the functionality of the airbag can be compromised to the extent whereby even if the airbag were to deploy, it would not perform as intended to provide effective protection to the occupant (e.g., as the result of severe intrusion of the steering column to the occupant compartment). Rudd et al. [14] published a paper of the various factors associated with 121 fatal cases in NASS/CDS, involving airbag and belt restrained occupants in frontal collisions of post-1997 vehicles. Almost one-third of the 121 cases were deemed as being so severe that the crash avoidance technologies would be the best approach to either prevent or mitigate the severity of the event. For the remainder of the cases, the factors most prevalent in fatal frontal crashes were underride, limited vertical and horizontal structural engagements, and advanced occupant age. The study suggests that there remains an

opportunity for “potential improvements in crash performance through advance restraint technologies and structural enhancements.”

REAL WORLD CRASH ANALYSIS

NASS/CDS DATA

This study is based upon the analysis and examination of real-world crash data obtained from the NASS/CDS [15]. The NASS/CDS is a representative sample of police-reported motor vehicle collisions that occur on roadways within the United States, where at least one vehicle is towed from the scene. Each year NASS investigators conduct approximately 5,000 detailed crash case investigations.

As NASS/CDS is a representative sample, each case is assigned a weighting factor (Ratio Inflation Factor). The weighting factor provides an estimate as to the frequency in which a similar crash occurs within the overall population of police-reported tow-away crashes. The weighing factor is the inverse probability of a sampled collision being selected from the overall population of these real-world crashes. High weighting factors are representative and associative with those events that are likely to occur more frequently.

The following criteria were applied to the NASS/CDS data to ensure that cases specific to the study objective were selected for analysis:

- NASS/CDS 1993-2008
- Vehicles model year 1985+ with installed driver airbags
- General Area of Damage to the Front of the vehicle [16]
- Direction of Force of 11, 12, or 1 o'clock [16]
- Maximum Extent of Secondary Damage ≤ 2 [16]
- Passenger cars or Light Trucks and Vans
- Vehicle was not involved in a rollover during the collision
- Cases where the occupant was fully ejected from the vehicle were excluded from the analysis

The focus of the study was on the injuries associated with occupants aged 16 years old or older, seated in the driver (left-front) seating position. Only drivers that were identified as being restrained by a manual 3-point belt were included. For the analysis of both pre-1998 and 1998 or later vehicles, the airbag was available, but not necessarily deployed during the collision. The status of airbag deployment for each of the cases was known. The restraint usage and airbag deployment status was determined by the NASS/CDS crash investigator.

Injury in NASS/CDS is coded using the Abbreviated Injury Scale (AIS), which was developed by the Association for the Advancement of Automotive Medicine (AAAM) to provide

additional details related to each injury sustained by an occupant involved in a motor vehicle collision [17]. The AIS coding assigns a severity rating to each injury based upon the threat to life that each individual injury poses to the occupant. These AIS injury severities range from 1 (minor) to 6 (maximum), threat to life. Injury analysis was conducted based upon the crash conditions that an occupant was exposed to when involved in a frontal impact.

HARM ANALYSIS

To complement the direct use of the AIS scale, the injury analysis in this study incorporated a AIS scale weighting system known as Harm [18, 19]. The Harm metric was developed as a method of providing an estimation of the societal costs brought about as the result of an occupant injury. A societal cost is defined as being not only the direct costs incurred by an injury (e.g., medical costs) but also the indirect costs (e.g., legal, insurance and workplace costs and lost productivity). The original Harm metric assigns a societal cost value to the highest severity injury (based on the AIS scale) that was sustained by each occupant [19]. Other researchers such as Fildes et al. [20], have assigned the Harm weighting factors to the AIS injuries sustained by each body region. In this paper, Harm will be calculated using the method applied by Fildes.

The highest severity injury to a specific body region is the Body-Region AIS (BAIS). For example, an injured occupant sustains an AIS 2 head injury, and AIS 4 head injury, and an AIS 2 thorax injury. This occupant would have a Head BAIS of 4 and a Thorax BAIS of 2. The MAIS is 4. The $\text{BAIS} \geq 2$ and $\text{BAIS} \geq 3$ body region injury risk is calculated for each body region by dividing the number of injured body regions at a given AIS severity level, by the total number of exposed body regions. The upper and lower extremities are assigned as being one body region each.

An occupant's overall Harm is calculated by taking the sum of the costs associated with each maximum severity injury to each injured body region (Blincoe et al.) [18]. Harm costs are normalized relative to the overall cost of a fatality. This ensures that cost values are not affected by external economic factors such as inflation and currency changes when considering multiple years of injury data or data from a country with different currency (Equation 1).

$$\text{Harm} = \sum_{i=1}^{\text{Num Injuries}} \text{Cost}_i(\text{body region, AIS})$$

$$\text{Harm}_{\text{norm}} = \frac{\text{Harm}}{\text{Harm}_{\text{fatality}}}$$

Equation 1: Calculating Harm relative to the cost of a fatality (Harm_{norm})

Table 1 provides the normalized Harm costs associated with occupant injuries relative to both the injured body region and the degree of injury severity to each body region.

<table 1 here>

CRASH SEVERITY

To further assess the frontal crash protection for both pre-1998 and 1998+ vehicles, the cases were classified into three categories that were indicative of the severity of each crash, i.e., a given crash case was classified as being either a low, medium, or high severity crash.

In NASS/CDS, the estimated ΔV is derived using the WINSMASH algorithm and is calculated based upon (1) the input of a series of vehicle crush measurements, and (2) contingent upon the assurance that specific crash conditions are not in violation of the assumptions on which the algorithm was based. If it is not possible to calculate a ΔV estimate using WINSMASH, a heuristic estimation of the severity is assigned based on the experience of the crash investigator.

Those crashes estimated by the NASS/CDS investigator as being minor were combined with crashes whereby the ΔV was 0 km/h to 24 km/h to comprise the low severity crash group. Vehicle crashes estimated as being moderate were combined with crashes with a ΔV was in the range of 25 km/h and 54 km/h to comprise the medium severity crash group. Finally, those crashes that were estimated as severe were matched with those cases with a ΔV greater than 54 km/h to comprise the high severity crash group [23, 24].

The following sections present a breakdown analysis of the driver injury risks and frontal crash protection associated with both pre-1997 and 1998+ model year vehicles.

CRASH INJURY RISK AND HARM

The MAIS is the highest severity injury sustained. For a given crash severity, the MAIS injury risk is calculated by dividing the number of involved occupants that were injured within a given severity threshold, by the total number of involved occupants.

For each given crash severity, the total Harm distributions by occupant body regions were also calculated using the HARM analysis method previously described. The Harm per body region is expressed in terms of Harm-equivalent fatality costs. As previously mentioned, Harm costs are normalized to the cost of a fatality. Harm-equivalent fatalities are the cost of occupant injuries expressed in terms of the corresponding number of fatalities. For comparison between model years at each of the severity levels, low, medium, and high, the Harm-equivalent fatality costs are normalized to equivalent fatalities per 1,000 involved occupants (Equation 2).

$$\text{Harm Equivalent Fatalities (per 1,000 occupants)} = \frac{\sum \text{Cost of Occupant Injuries (Harm)}}{\sum \text{Involved Occupants}} \times 1,000$$

Equation 2: Normalized Harm-equivalent fatality cost per 1,000 occupants

When analyzing Harm based on the involved physical component, consideration was given to those instances when there were multiple, separate, similar severity injuries to the same body region that were the result of interaction with different injuring contacts. In these cases, the HARM cost associated with the highest severity injuries to each body region were divided equally between each of the injuring contacts.

NON-WEIGHTED ANALYSIS

The authors believe that it was necessary to exercise caution when using the ratio inflation factor to establish a national representation. As explained in NASS Analytical User's Manual [15] the NASS observations are a probability sample. Each year roughly 5,000 crashes are sampled and multiplied by a factor, called a ratio inflation factor, to give a nationwide estimate for the entire USA. There were some cases present in the analysis with extremely high ratio inflation factors that caused a dramatic shift in the distributions of the weighted and non-weighted results. As a result, the authors carried out this study using the samples in the NASS/CDS database without employing the ratio inflation factor. This paper is therefore an engineering study based on the non-weighted data, and is not necessarily representative of the overall crash population within the United States.

RESULTS

OVERVIEW

Based upon the aforementioned NASS/CDS selection criteria, the figures in Table 2 indicates involved drivers, moderately injured drivers (MAIS 2+ injury), and seriously injured drivers (MAIS 3+ injury). These data involved frontal collisions, for both pre- and post-1998 model year vehicles. The data is further dissected by low-, medium-, and high-severity collisions.

<table 2 here>

When the HARM costs were calculated for the drivers seated in both the pre-1998 and 1998+ model year vehicles, the costs of injury were equivalent to approximately 172 fatalities in the pre-1998 vehicles, and approximately 207 fatalities in 1998+ model year vehicles.

AIRBAG DEPLOYMENT

Figure 2 shows the distribution of airbag deployment and non-deployment for left-front seated occupants involved in frontal collisions, for both pre-1998 and 1998+ model year vehicles that were involved in low, medium and high severity collisions. In lower severity collisions, there was a reduction in the percentage of crashes in which the frontal airbag deployed during a frontal collision. There was a similar reduction in airbag deployment rates at the medium crash severity.

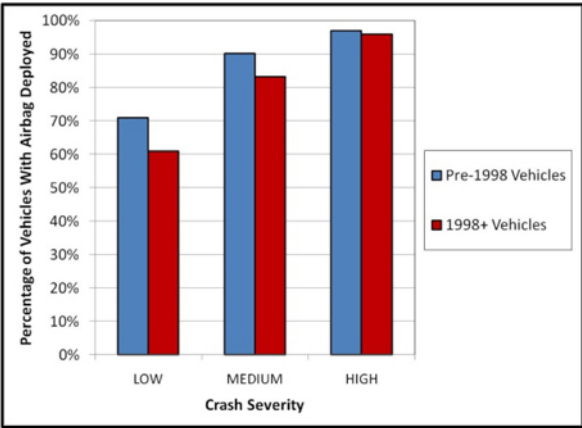


Figure 2. NASS/CDS 1993-2008 Vehicle airbag deployment rates for low, medium, and high severity collisions by vehicle model year.

Cases of non-deployment of the vehicle airbag under various frontal-impact configurations and crash conditions were also observed in an aforementioned study that was conducted by the IIHS [13].

Figure 3 shows the changes in MAIS 2+ injury risk (cf. Crash Injury Risk and Harm) for pre-1997 and 1998+ model year vehicles based upon the varying degrees of impact severity respectively. At each of the three severity levels, there was a reduction in the MAIS 2+ driver injury risk when compared to the pre-1998 model year vehicles.

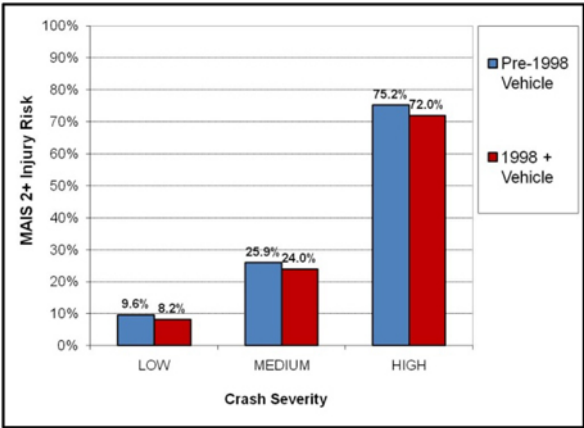


Figure 3. NASS/CDS 1993-2008 MAIS 2+ Occupant Injury Risk by crash severity and vehicle model year.

The MAIS and Harm injury measures provide an overview as to the overall severity to specific occupant body region injuries. The following sections provide an overview of the changes in the AIS injury risk and associated Harm costs for pre-1998 and 1998+ model year vehicles for low, medium, and high severity frontal impacts. The injury analysis focuses on the AIS severity risk and the cost of injuries sustained to each occupant body region.

LOW SEVERITY COLLISIONS

Figure 4 shows the BAIS 2+ injury risk in low severity collisions respectively. In 1998+ model year vehicles, there has been a reduction in the BAIS 2+ injury risk associated with the upper extremities.

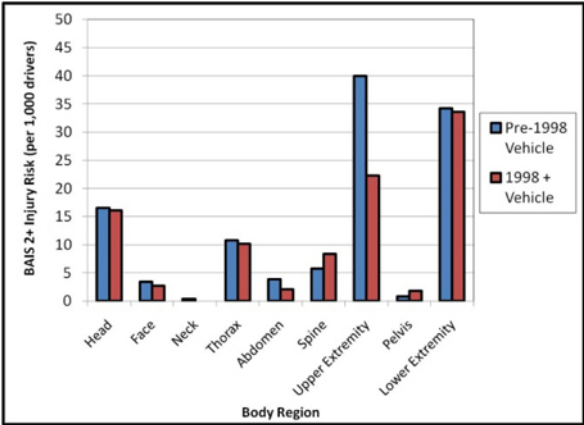


Figure 4. NASS/CDS 1993-2008 BAIS 2+ Injury Risk per 100 drivers for Pre-1998 and 1998+ model year vehicles in low severity collisions.

Figure 5 shows the distribution of driver HARM by injured body region. The percentage of total Harm for all body regions totals 100% for both pre-1998 and 1998+ model year