Evaluation of Advanced Airbag Performance: Child Injury Exposure

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Abstract

Airbags save lives; however, first generation airbags resulted in unintended fatal and injurious consequences for children and small statured adults seated in front of them. An immediate solution allowed for the development of less aggressive airbags (second generation), a subsequent revision to FMVSS 208 required further changes to airbags for the protection of children. These advanced airbags are required to either suppress or with a LRD in the presence of a child. Though car manufacturers have spent a considerable amount of time and money to meet the advanced airbag requirements, the effects of these airbags and characteristics of children seated in front of them have not been extensively studied. This thesis presents the requirements for advanced airbags, characteristics of children in MVCs, an evaluation of crashes involving children involved in crashes in the RFP seat for all airbag types and finally a case study of children seated in front of an advanced airbag during a crash.

Overall, vehicles with advanced airbags were found to be safer for children than vehicles equipped with earlier airbag generations including vehicles not equipped with airbags. These findings suggest that vehicles overall are safer since one option for an advanced airbag is suppression which would render the occupant without an airbag. Further, the advanced airbags appear to be working as intended during real-world crashes. However, the back seat remains the safest place for children; this work in no way advocates that children should be seated in the RFP seat.

Keywords: advanced airbag, child injury

Dedication

To Lynn Nystrom whose passion for life was unparalleled and dedication to her friends, family, coworkers and advisees was unwavering even in the face of the biggest battle she ever fought. Lynn, you are truly missed and were such a vital force in many people's lives within the College of Engineering - we are forever changed for the better because we had you in our lives.

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1 INTRODUCTION

Motor vehicle crashes (MVCs) remain a leading cause of injury and death among children in the United States (US). During 2013, 943 children aged 15 and younger died as a result of MVCs, 529 (56%) of which were less than 9 years old. Within that same year another 168,000 children (15 and younger) were injured in MVCs [1]. There is substantial evidence that airbags save lives [2], [3], [4], [5]. In fact, by 2012 it was estimated that frontal airbags saved approximately 37,000 lives [4]. However, it has been demonstrated that airbags can cause injury; this is especially true for children seated in close proximity to an airbag [2], [3], [5], [6], [7].

General Motors (GM) and Ford were the first car manufacturers to introduce airbags as standard equipment in 1972, though the early airbags were included mostly in experimental vehicles and automobiles sold for government or fleet use. During this time other manufacturer's implemented plans to incorporate similar technologies, however, these efforts were short lived. Starting in model year 1974 GM started offering the early dual airbags as optional (custom order) safety equipment and then shortly after discontinued the equipment all together [3]. Dual (driver and passenger) airbags were not included in all automobiles as standard equipment until a government regulation was established more than 20 years later.

In 1991, the US Congress mandated that the National Highway Traffic Safety Administration (NHTSA) revise FMVSS 208 (a part of the Code of Federal Regulations) to require that manufacturers of new passenger vehicles equip vehicles manufactured on or after September 1, 1998 with airbags as supplemental restraints which were intended to be complimentary to seat belts. This mandate required a phase-in of airbags; therefore airbags were included as standard equipment in all passenger cars starting in model year 1998 and light trucks and vans (LTVs) starting in model year 1999. Initially, airbags were implemented on the driver side only; it was not until later in the phase-in period that passenger-side airbags were made available. These airbags are referred to as first generation airbags.

Before the full phase-in of airbags as supplemental restraints, passenger airbags became the subject of serious controversy. At that time, disturbing reports of children sustaining fatal or serious injuries as a result of low-speed frontal crashes with airbag deployment began to emerge. Between 1993 and 2008 the Special Crash Investigations (SCI) division of NHTSA investigated crashes involving 221 (172 fatal) child occupants not in rear facing child safety seats (RFCSS) and 54 (41 fatal) infants restrained in RFCSS's due to airbag deployment at low delta-V's (20 mph and less). The cause of death was most often reported as head, brain and spinal cord injuries. A majority of the children fatally hurt were unrestrained or improperly restrained and the crashes involved pre-impact braking. Likewise, the same trend was noted for children who sustained life threatening, but non-fatal, injuries related to airbag deployment. An examination of children fatally injured as a result of passenger airbags, sorted by vehicle model year showed that vehicles model year (MY) 1995 had the highest prevalence of fatalities per million vehicle years [6].

The auto industry and researchers were rife with grief from these unintended tragedies and faced an ethical dilemma since the introduction of first generation airbags had also proven to save lives in crashes, particularly for those aged 13 and over [2], [3], [5], [6], [7]. In essence, the industry, regulatory boards and rule makers felt as if they were being forced to choose between saving the lives of newborns, infants and children or saving the lives of adults, older children and teenagers. One immediate solution was the back seat recommendation which was announced via press-release from a coalition formed by the Department of Transportation stating the following:

"Infants in rear-facing child safety seats should never be placed in the front seat if the vehicle has a passenger-side air bag. The safest place for children of all ages is the back seat. If riding in the back seat is not an option, toddlers and older children may ride in the front seat of a vehicle with a passenger-side air bag, but only if buckled up properly and with the seat moved as far back as possible." [3]

In February of 1997, in response to a petition by the American Automobile Manufacturers Association (AAMA), NHTSA revised testing requirements and protocols allowing airbags to be depowered, allowing sled-certification as opposed to rigid barrier certification for the unbelted condition. Sled testing and certification, though performed at the same speed as the rigid barrier tests, would allow for a more gradual deceleration pulse as the (simulated) crash would occur over a longer period of time. This revision also increased the injury assessment reference value (IARV) for the chest acceleration of unbelted dummies allowing manufacturers to depower airbags in hopes of decreasing the frequency of child and small statured injuries in low severity crashes [8]. Airbags that have been certified to this revision of Federal Motor Vehicle Safety Standard (FMVSS) 208 are referred to as second generation airbags or sled-certified airbags.

In May 2000, a final rule, FMVSS 208, was issued by NHTSA which required automobile manufacturers to provide crash protection for a wider range of occupant sizes and positions. One requirement was automatic suppression or benign airbag deployments for children and smaller adults [9]. By model year 2007 (starting September 1, 2006), most new vehicles were required to have advanced airbags which help protect out-of-position (OOP) occupants along with children and other small statured occupants from fatal or serious injuries resulting from airbag deployments. There were a few exceptions to the phase-in period for vehicles which were produced by smaller manufacturers (manufacturing 5,000 or fewer cars per year) or vehicles made by multiple manufacturers; the absolute phase-in was complete on September 1, 2010 [9]. These advanced airbags are sometimes also referred to as certified advanced or advanced 208 compliant airbags.

The performance of advanced airbags has been extensively tested under laboratory conditions; however, little is known about the performance of these airbags in the field. Further, widespread public education and in-vehicle warning labels have made it “common knowledge” not to place a child in the front seat of a vehicle equipped with airbags, though this does not mean that children are not sitting in the front seat.

An observational and driver interview survey performed in 1998 revealed that children (<13 years old) were less likely to be observed riding in a right front passenger (RFP) seat if the car had a passenger airbag (PAB). Though this study did not control for vehicles like pick-ups or smaller passenger vehicles without a backseat, the authors reported that roughly 4% of the 503 survey respondents had a vehicle with 2 to 3 seats, while 82% had 4 to 6 seats and the remaining 14% had 7 or more seats. They found that children rode in the right front seat in 30% of the vehicles surveyed without a PAB, but encouragingly only 17% of the vehicles with a PAB present. That same study found that driver safety belt use, younger child age, and the presence of an adult passenger were all associated with children being seated in the rear [10]. Another study published in 2010 based on data from a phone survey between 2001 and 2003 estimated that more than one million children (< 13 years old) rode in the front seat of a vehicle in the 30 days prior to the interview [11]. Further, a retrospective study performed by Arbogast, et al. in 2009 concluded that even with advanced airbags the results indicated that children were one half to two thirds less likely to sustain an injury while seated in a rear seat as compared to the front seat, thus substantiating the current seating recommendation for children - the back seat [12].

1.1 First Generation Airbags

A study published by Kahane in 1996 based on the Fatality Analysis Reporting System (FARS) confirmed the fatality reduction benefit of airbags for all drivers was 30% for purely frontal crashes and 11% overall for all crash types. This effectiveness level was essentially unchanged from the 1992 and 1994 analyses performed by NHTSA staff. The positive findings were that driver airbags saved lives in light trucks and in small cars, passenger airbags saved the lives of RFPs age 13 or older. Further, that driver airbags provided a significant supplemental life-saving benefit for the driver who buckles up (as well as saving lives of unbelted drivers). On the other hand, preliminary analyses of limited crash data showed a higher fatality risk for child passengers ages 0 to 12 in cars with then-current dual airbags than in cars without a passenger airbag [2].

Braver et al. (1997) assessed the effectiveness of passenger airbags in reducing the risk of death in frontal crashes for RFPs, using FARS 1992 – 1995 for vehicles with either driver only or dual airbags, excluding crashes with more than two vehicles. They found that airbags provided an 18% lower risk of fatality among all ages in frontal crashes and 11% overall (all crashes, all ages) which was consistent with the estimate reported in Kahane's study. However, they also found that children (< 10 years old) in the RFP seat were at a 34% increased risk of fatality in frontal crashes while riding in vehicles equipped with dual airbags, versus children in vehicles equipped only with driver airbags. The authors noted that there were 3 infants and 11 children fatally injured as a result of a passenger airbag deployment within the calendar years (1992 - 1995) studied [5].

Grisoni et al. (2000) performed a comparison study between injury risk resulting from airbag deployment of properly restrained children (<13 years old) and unrestrained children in RFP seats from patients treated in three regional hospitals in Ohio between January 1995 and September 1998. The cases were reviewed using the injury severity score (ISS). They concluded that airbags with or without restraints can lead to mortality or serious morbidity in children. Injuries in both groups were similar with abdominal injuries exclusive to restrained child passengers and decapitation exclusive to unrestrained children [13].

Weber (2000) reported that ten properly restrained rear-facing infants and another eight in unsecured or mis-belted RFCSS's had been killed in the US by deploying passenger airbags in otherwise survivable crashes. Among the 28 children ages 6-11 who were killed by a passenger airbag system through June of 2000, five had the shoulder belt behind their back, one was leaning forward and another two cases were still under investigation. The other 20 children were unrestrained [14].

Similarly, a retrospective study using a database of State Farm-insured vehicles, limited to model year 1990 or newer, was performed by Durbin et al. in 2003. The study aimed to estimate the prevalence of children's (3-15 y/o) exposure to PAB deployments and determine the relative risk of injury to restrained children exposed to PABs in frontal impact collisions. They found that children exposed to PABs were twice as likely to be "seriously" injured (AIS 2+) as those in similar crashes not exposed to a PAB (cars equipped only with a driver airbag, in crashes with deployment) [15]. It should be noted that Durbin et al., uses the terminology "serious" injuries, but relates them on the AIS as having a severity of 2 or greater which corresponds to a description of "moderate" on the AIS scale.

A retrospective study using the FARS database conducted by Braver et al. in 1998 compared risk of death among front and rear seated passengers aged 12 and younger who were involved in fatal crashes. The study looked at restraint use and included vehicles with and without passenger airbags. They found that restrained children in rear seats had the lowest risk of dying in crashes involving at least one fatality. However, it was not just restrained children that saw a benefit from back row seating, they found that both restrained and unrestrained children aged 0–12 were at lower risk of dying in fatal crashes when seated in rear seats. Rear seats also afforded additional protection to children aged 5–12 restrained only with lap belts when compared with lap/shoulder belted children in front seats. Further, they found that seating position in the back seat also matters; children were about 10–20% less likely to die in rear center than in rear outboard positions [16], [17].

However, not all children exposed to PAB are seriously injured or killed. A study performed by Huelke at the University of Michigan Transportation Research Institute (UMTRI) in 1997 examined the positive side of the PAB story. From a review of 7,212 airbag crashes investigated by UMTRI personnel, there were 117 front seat passengers exposed to PAB deployments. The majority of these passengers were 16 years of age or older (90 of the 117), with 20 passengers 11 years and younger. Two cases, both fatalities, were not described as these crashes were investigated by NHTSA's SCI Program personnel. In total 18 passengers were examined; 13 were children who had MAIS-1 (maximum abbreviated injury score) level injuries, two had sustained an MAIS-2 injury, one child was without injury, and two had MAIS-5 level injuries. There was one fatality due to intrusion and not attributed to the airbag which was coded as an MAIS of 5. This child was restrained in the RFP with another child about his age – both with the same seatbelt, the one closest to the center of the vehicle survived. The other MAIS-5 patient was improperly restrained; however, most of the children included in the study were properly restrained. Further, 11 of 18 of the vehicles included in this study were Ford, Mercury or Lincoln vehicles [18].

1.1.1 Injury Patterns & Case Studies Involving First Generation Airbags

Numerous studies have been published outlining the injury patterns and case studies of children fatally or seriously injured in crashes involving passenger airbag deployment, this section will outline the conclusions from these studies.

A review of 29 SCI cases between April 1993 and August 1996 was performed by Winston and Reed in 1996. They found that seven of the eleven infants and seventeen of the eighteen children older than one year suffered fatal injuries as a result of an airbag deployment. The eleven infants all of whom were seated in RFCSS's ranged in age from one week to nine months. The close proximity of the rear of the safety seat to the airbag module resulted in rearward displacement of the safety seat upon contact with either the airbag module flap or the airbag module cover. More than half of the infant cases involved contact with the cover flap of the airbag and the RFCSS demonstrated cracks at the site of contact with the airbag module flap cover. The interaction between the airbag and the RFCSS was thought to involve crush and resulted in skull fractures and brain injuries. One infant, case CA9516, experienced the most severe crash severity in the series, suffered from a fatal brain parenchymal fracture in addition to other skull fractures [19].

In that same study of SCI cases, fifteen of the seventeen children older than 1 year who were fatally injured were unrestrained RFP seat occupants and the other two only wore the lap portion of a lap-shoulder seat belt. The remaining older child in the series was a three year old who was seated in a belt-positioning booster and restrained, this child was both the only older child in the series who was properly restrained and the only older child who survived, although his (brain) injuries were severe. The authors found that the site of the most severe injuries in the older child group (greater than 1 year old) included: brain, antlanto-occipital ligament, cervical spine, and skull and neck injuries. Avoidance braking prior to a frontal crash brought the child in close proximity to the airbag module flap. Due to the child's forward position, he/she restricted the normal airbag deployment path allowing for pressure to mount within the airbag module. Upon forceful opening of the airbag module cover flap, the child was accelerated vertically, often hitting his/her head on the windshield, followed by a rearward acceleration that resulted in hyperextension of the neck [19].

Surprised that airbag injuries were observed on a child who was properly restrained in a state-of-the-art forward facing, five-point harness child seat, Huff et al. published a case review of the 3 year old boy who presented with facial abrasions and coma secondary to a crash at ~30 miles per hour where the airbag deployed. The patient had a Glasgow Coma Score (GCS) of 6 and was transported to a tertiary facility where it was found that he had an increased intracranial pressure (ICP). The patient was treated with a ventriculostomy and placed in a phenobarbital coma. He was released to a rehabilitation facility on day 20 [20].

In 1998, Marshall et al. conducted a cohort study to investigate the patterns of injury occurring in this new mechanism of pediatric trauma via radiological analysis. Patients were located with the assistance of victim advocacy groups, the media, and institutional networking, in addition to review of local cases. In total 11 cases were studied. The cause of death or serious injury in *every* case was the direct result of neurologic injury. Injury patterns differed according to the child's age and type of restraint used at the time of collision. Crush injury to the skull (denoted by the authors as a "nutcracker" force) predominated in infant victims traveling in RFCSS's (3 cases reviewed). Both cranial and cervical spine trauma occurred in older children traveling restrained (2 cases), improperly restrained or unrestrained (6 cases) in the vehicle's RFP seat [21].

A review of 79 studies within the literature was summarized by Sato et al. in 2002 to examine injuries resulting from airbag deployment. Injuries were identified as 'airbag-related' if the authors concluded that the injuries had been caused by the deployment of the airbag and/or if other crash dynamics would have not caused the injuries for the occupant. Most injuries were sustained in low- or moderate-velocity crashes. In one case, an injury was sustained due to spontaneous deployment of an airbag without a collision. The study did not control for restraint use as it was intended to serve forensic scientists with a survey of any injury sustained in a crash involving an airbag deployment. Typically, the child was either unrestrained or improperly restrained and as a result moved closer to the path of the inflating airbag during the crash. However, a few injury and fatal cases included in their study were sustained by children who were properly restrained. Compared to adults who sustained face, upper extremity and chest injuries, children appeared to have a greater risk for head and neck injuries. The authors reasoned that head and neck injuries maybe sustained by children because of their small stature, proximity to the airbag and the upward deployment path of the bag into the child's head and neck. The findings of this review are summarized in Table 1[22].

Table 1. Outline of Airbag Related Injuries by Child Occupant Age and Body Region as Reported by Sato et al. 2002 [22]

Body Region	Child (1 - 12 years old)	Infant (<1 year old)
Head	Contusion; Laceration; Skull fracture; Subgaleal hematoma; Epidural hematoma; Subdural hematoma; Subarachnoid hemorrhage; Cerebral contusion; Diffuse axonal injury; Brainstem contusion; Brainstem laceration	Skull fracture; Subgaleal hematoma; Epidural hematoma; Subdural hematoma; Subarachnoid hemorrhage; Cerebral contusion
Face	Abrasion; Contusion; Laceration; Burn; Conjunctival hemorrhage; Eye injury; Fracture of mandible, orbit	
Neck	Abrasion; Contusion; Laceration; Burn; Ligament disruption of cervical spine; Dislocation or separation of cervical spine; Fracture of cervical spine; Spinal cord injury; Tear of vertebral artery;	
Chest	Cardiac contusion	
Abdomen	Liver injury; Splenic injury; Renal injury	
Upper Extremities	Abrasion; Contusion; Burn; Fracture of radius, ulna; Fracture of humorous	
Lower Extremities	Burn	

In 2002, Okamoto et al. presented a case review of a 4 year old child seated in a forward-facing child safety seat (FFCSS) who sustained bulbo-C1 spinal cord injuries secondary to airbag deployment in a "relatively low-velocity car crash" where the vehicle struck trees on side of road at approximately 30 mph without pre-impact braking. The 4 year old child was unconscious and not breathing after the crash, GCS of 3. His radiographs were normal except for a slight widening of the interspinous space at C1-2. On Day 3 in the hospital, the child became alert although apneic and demonstrated complete tetraplegia. There were minimal changes in neurologic functions at 5 months after the incident. The driver and the backseat passenger (10 month old) were not seriously injured. The child sustained spinal cord injury without radiographic abnormalities and the physical and MRI findings strongly suggested that either a transient atlanto-occipital dislocation or subluxation caused the bulbospinal injuries. An atlanto-occipital injury typically results from extreme hyperextension, lateral flexion, hyperflexion or distraction in the long axis of the body. It was presumed by the authors that the airbag came into contact with the patient as it was rapidly inflating and thus providing the forceful impact required to sustain an atlanto-occipital dislocation. Four other atlanto-occipital dislocation injuries of forward facing children 4 years old and older were found in the literature by the authors, all were resultant from airbags in crashes ranging from 20 – 25 mph [23].

From a review of national databases in 2006, Quinones-Hinojosa et al. determined the number and types of fatal and nonfatal injuries to children caused by airbag deployment and child restraint system use in low-velocity MVCs. The author reviewed 263 reported cases, occurring between January 1993 and December 2002, in which airbag deployment caused fatal or nonfatal injuries in children from reports released by NHTSA and the National Pediatric Trauma Registry. Of the 263 pediatric patients, 159 were fatally injured. The peak incidence was in 1998 (n = 58). Head injuries were most prevalent (n = 170), followed by spinal injuries (n = 100). For children in "their first year of life," head injuries were the sole mechanism of fatality. Of all 263 patients, only six were properly restrained. Fatal injuries included skull and cervical spine fractures, subdural hemorrhages, diffuse axonal injuries, cord transections, and decapitations. Only nine fatal and 20 nonfatal injuries did not involve either the head or the spine [24].

1.2 Second Generation Airbags

Several studies in the literature have examined the effects of second generation airbags, also known as sled certified airbags, on a child's risk of injury this section reviews these studies.

Arbogast et al. used a State Farm Insurance database which linked insurance claims to telephone surveys and crash investigation data to study children involved exposed to deployed airbags. The study identified 1,707 cases where restrained children between 3-15 years old were involved in crashes as part of an ongoing crash surveillance system, Partners for Child Passenger Safety (PCPS) (1998-2002). Vehicles were limited to 1990 and newer. They found that 3.5% of children who were exposed to a PAB deployment received an upper extremity fracture, making them 2.5 times more likely to sustain an upper extremity fracture than children in similar crashes who were not exposed to a PAB. Examination of the crash investigation cases revealed a relationship between direction of impact and side of fracture. In the three crashes where the principal impact was on the right side, the child passengers received left upper extremity fractures. Similarly, in the crash where the principal impact was on the left side, the child passenger received a right upper extremity fracture. The authors suggest that this may have been especially pronounced in children who had poor belt fit resulting from premature graduation to seatbelts. It was hypothesized that a loose belt would allow for rotation of the contralateral extremity during a crash which would position the extremity in the path of the airbag during deployment. Further, the survey data identified no significant difference in the prevalence of upper extremity fractures between those vehicles assumed to have fully powered airbags (prior to MY 1998) and those assumed to have depowered airbags (1998 and newer) [25].

Another study by Arbogast et al. also utilized the PCPS to study the effects of second generation airbags. Data were collected from December 1, 1998 to November 30, 2002 from 15 states in three US regions: east, mid-west, and west; vehicles qualifying for inclusion were State Farm-insured, model year 1990 or newer, and involved in a crash with at least one child occupant

≤15 years of age. The eligible study population consisted of all 430,308 children riding in 288,187 State-Farm-insured vehicles newer than 1990. Results showed that second generation airbags were beneficial in passenger cars and minivans. The children exposed to second generation airbags in those vehicles were half as likely to sustain serious injuries. Children in the second generation category for passenger cars (excluding SUVs and minivans) sustained fewer head injuries, including concussions and more-serious brain injuries, than children in the first generation category. However, in SUVs the data suggested no reduction in injury risk with the second generation bags [26]. The same authors published a paper in 2005 comparing the injury risk to children as a result of deployments of first and second generation airbags. They concluded that second generation airbags provided a 41% reduction in the likelihood of a "serious" injury, which they correlated to an AIS of 2 or greater [27].

A Crash Injury Research and Engineering Network (CIREN) case study which outlined the success of second generation airbags was performed on cases at the Ryder Trauma Center, a Level I trauma center, examining the risk of injury resulting from first and second generation airbags. For second generation airbags, there were no fatalities below 25 mph. In contrast, there were four fatalities at delta-V's of less than 20 mph with first generation airbags (two infants in RFCSS's, two unbelted children younger than 3, and one unexpected fatality at a moderate crash severity to an OOP adult). An examination of these cases revealed that among second generation passenger airbags there were no child fatalities, no fatal neck injuries to small statured (referred to as "close-in") drivers, and no elderly fatalities below a 30 mph delta-V crash severity. Preliminary data showed an eight percent higher overall fatality rate with later model (older) airbags. The authors had no examples of "success stories," defined as a case with a moderate (MAIS ≤ 2) or less severe injury involving passengers at delta-V's above 30 mph with first generation airbags [28].

Using a matched cohort design and FARS from 1990 to 2002 to compare first and second generation airbags, Olson et al. found that among children under 6 years old, first-generation airbags were associated with a statistically significant increased risk of fatality, compared to cases without an airbag. However, this was not true for second generation airbags (MY 1998 - 2003) [29].

In 2008, Braver et al., analyzed cases from FARS and the National Automotive Sampling System - General Estimates System (NASS - GES). They reported that child right-front passengers in age categories 0–4 and 5–9 within sled-certified vehicles had a statistically significant reduction in risk of dying in frontal collisions as compared to those with first generation airbags, including a 65% reduced risk among ages 0–4. Further that same study reported that children ages 0–4 who were fatally killed in a vehicle with a second generation airbag were more likely to be restrained than children the same age also fatally injured in a vehicle with first generation airbags, specifically 53% and 47% were restrained respectively. Likewise, among those ages 5–9 dying in crashes, the recorded restraint use rates were 42% in first-generation vehicles and 59% in sled-certified vehicles. Further, this study provides evidence that depowering airbags reduced the toll of airbag–related deaths among child RFPs. Whether this was due to changes in airbag designs or concurrent improvements in vehicle design or other factors is unknown [30].

In 2005 Prasad and Louden in order to investigate whether sled-certified airbags could pass advanced airbag tests, reviewed the findings of OOP airbag testing involving the 6 year old and 5th percentile female Hybrid III dummies for six 2001 MY sled-certified vehicles. They found that of the vehicles studied (Honda Accord, Chevy Impala, Dodge Caravan, Toyota Echo, Ford Escape, Ford F150) none of the vehicles could pass both the 5th percentile female and the 6 year old OOP performance requirements. Further, the first stages of the dual stage inflator airbags were powerful enough to prevent the 6 year old from meeting the OOP requirements. The predominant failure mode for the 6 year old and the 5th percentile female was neck injury criteria. The 5th percentile had an additional predominant failure mode of chest deflection [31].

1.3 CERTIFIED-ADVANCED AIRBAGS

In a summary of SCI cases published in 2005, there were four cases examined which involved children in the RFP seat and certified-advanced airbags ages 6, 11, 15 and 16 years old. These children either presented with no injury or minor injuries (AIS 1) of the face or lower extremities. There was however, one crash investigated by SCI that was not certified-advanced, but had advanced features where there was a 4 year old boy belted in the RFP seat that received an AIS 5 head injury [6].

In 2008, the Blue Ribbon Panel for the Evaluation of Advanced Air Bags stated that airbag–induced fatalities involving children and infants have decreased substantially since they were first noted in the early 1990s, especially in 1998 and newer vehicles. As of December 2007, the SCI program had not yet identified an airbag–induced fatality or life-threatening injury to a child or infant in a low-severity crash of a vehicle certified to the advanced passenger airbag test requirements that became effective in September 2003 [32]. This still holds true today in April 2016.

To determine whether front airbag changes have affected occupant protection, Braver et al. (2010) used FARS and the Highway Loss Data Institute (HLDI) database to compare frontal crash mortality rates of front outboard occupants in vehicles having certified-advanced airbags or sled-certified airbags with and without advanced features. Unadjusted mortality rates for child right-front passengers were lower (though the change was not significant) in vehicles having certified-advanced airbags compared with sled-certified airbags with advanced features and in vehicles having sled-certified airbags with advanced features relative to sled-certified airbags without advanced features. The mortality rate was higher, though not at a statistically significant level, for drivers having certified-advanced airbags compared with sled-certified airbags with advanced features; the difference was significant for belted drivers [33].

The revised FMVSS 208 provides several options to car manufacturers to achieve advanced-certification. One of those options is to suppress the airbag completely in the presence of an OOP or child passenger. A study by Menon et al. (2003) examining the benefits of suppression found that the performance of airbags for children varies widely among vehicle types. Of particular concern are sport utility vehicles (SUV) and passenger vans. Children in the front seat of these vehicles and not exposed to an airbag were at a very low risk of injury but children in similar severity crashes in these vehicles who were exposed to airbags were at a considerable increased risk of injury [34].

1.4 Summary of the Background Between Children & Airbags

In summary, airbags save lives; however, first generation airbags resulted in unintended fatal and injurious consequences for children and small statured adults seated in front of them. Fatal injuries sustained by children resulting from an airbag deployment included injuries to the head, neck and spine. A revision to FMVSS 208 allowed car manufacturers to depower airbags by allowing sled certification which decreased the test severity by allowing for a more gradual deceleration. Numerous studies have evaluated the benefit of second generation airbags with respect to children and have found that these intermediate airbags were effective at reducing the fatality and injury risk to children involved in crashes.

A subsequent revision to FMVSS 208 required further changes to airbags for the protection of children and small statured adults, effective for model year 2007 through the foreseeable future, airbags are required to either suppress or deploy in low risk manner in the presence of a child or small statured adult. Though car manufacturers have spent a considerable amount of time and money to meet the advanced airbag requirements, the effects of these airbags and characteristics of children seated in front of them have not been extensively studied. That may be because there are no reported cases of an advanced airbag fatally injuring a child. Nonetheless, advanced airbags warrant an investigation to evaluate their performance. This thesis will present the requirements for advanced airbags, characteristics of children in MVCs, an evaluation of crashes involving children involved in crashes in the RFP seat for all airbag types and finally present a case study of children seated in front of an advanced airbag during a crash.

2 Requirements for Advanced Airbags

Advanced airbags are tested and certified in accordance with Federal Motor Vehicle Safety Standard (FMVSS) 208. This standard requires that advanced airbags are tested with 50^{th} percentile male and 5^{th} percentile female Hybrid III dummies in frontal crashes. Further, the 5^{th} percentile female dummy must be included in one of the front seating positions for purposes of testing the advanced airbags when testing new vehicles. It also requires testing advanced airbags with the newborn infant, 12 month-, three and six year-old dummies. Car manufacturers are allowed to choose to certify their advanced airbags with the small statured child and adult dummies via the following techniques: suppression, low risk deployment (LRD) or dynamic auto suppression system (DASS) testing [9]. While the manufacturers are required to pick one technique for certification purposes, the technique can be different for the different size dummies and different vehicles (Figure 1).

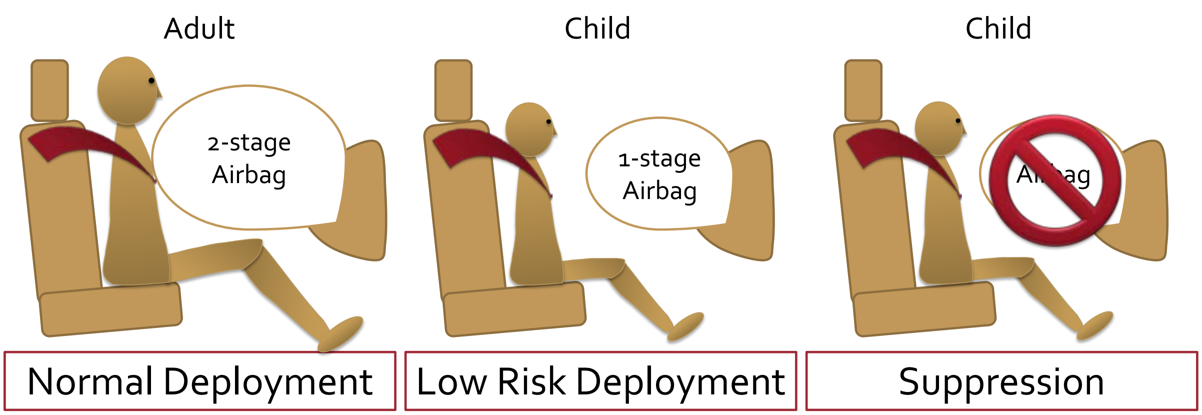

Figure 1. Illustration of the advanced airbag deployment techniques assuming a crash is severe enough to warrant an airbag deployment showing that for adults advanced airbags employs a two-stage deployment (*left*), but for children and small statured adults the airbag employs a single stage inflation (*middle*) or suppresses (*right*).

The suppression technique uses an occupant classification system (OCS) to identify children in the right front passenger (RFP) seat and suppresses the airbag to prevent potential injury from airbag deployment. This system also prevents the airbag from firing when the seat is not occupied, or if the seat has inanimate objects placed on it. The low risk deployment technique uses the same

OCS sensing, but instead of suppressing the airbag allows the airbag to deploy in a low risk manner. The low risk deployment typically changes the deployment times of the airbags to achieve a low risk to the passenger in front of the deploying airbag. The DASS test procedure has not yet been defined in the current version of the rule; however, it is reserved in subpart S28 of the rule [9]. To the author's knowledge, current advanced airbag systems can only detect certain *classes* of occupants, but cannot recognize whether an occupant is in a predetermined *zone*, such as the automatic suppression zone (ASZ) which is introduced in the limited verbiage explaining DASS in the rule.

Occupant classification systems can at a minimum classify a seat as being empty, having an infant or child placed in it, or having an adult seated in it. In general, there are three methods used to detect occupant classes within occupant classification systems, they are:

1. Pressure recognition, which uses a fluid filled bladder system to determine weight and location on the seat, such as the ones described by Delphi [35] [36],
2. Impedance detection, which employs an antenna to measure the impedance of the occupant, object on the seat or a child safety seat (CSS), such as the systems described by Delphi [37] and Nidec Elesys [38], and
3. Weight detection, which determines the weight of a person using strain gages, such as the systems described by Calsonic [39] and Bosch [40].

With the exception of the impedance system, these systems can determine where an occupant is on the seat based on the movement of the center of gravity (CG) on the seat, but they are not yet sophisticated enough to determine if the occupant is in a specific zone (e.g. out of position). A fourth method has been proposed, though the author is unable to find a commercially available system comprising the idea of pattern recognition, which distinguishes an adult from a child seat via camera or ultrasonic sensors. Some occupant classification systems also detect the seat track location. Further, the impedance systems could possibly be "fooled" by clothing textiles with polymeric coatings such as Gore-Tex which have a capacitance similar to plastic car seats.

The certifying technique (suppression or low risk deployment) can be different for each occupant class (i.e. infant, 3 year old, 6 year old, 5th percentile female). Many of the airbags that use a low risk deployment certification strategy for one or more occupant classes also use a suppression strategy for another occupant class. Hence, the manufacturer can decide to suppress the airbag for one passenger in a crash, but deploy in a low risk manner for a different passenger at the same location in the same crash. However, FMVSS 208 requires suppression for a newborn infant [9]. Typically, the suppression technique is also used for the older infant occupant class which employs the 12 month old CRABI (Child Restraint Airbag Interaction) dummy during testing.

According to Mr. Jeff Lewandowski, a Project Engineer at MGA Research Corporation responsible for overseeing a majority of the regulatory advanced airbag tests, the choice to certify advanced airbags with an LRD strategy is made by the manufacturer and can be based on the demographics, safety and cost for that model and in some part to provide due diligence [41]. Some car manufacturers have used a single advanced airbag strategy. For instance, several manufacturers use a suppression strategy for all child and small adult airbag scenarios, while others like Chrysler employ an LRD strategy for most child and small adult airbag scenarios, as allowable. Yet, other manufacturers such as BMW and Mercedes employ a LRD strategy for the three- and six-year-olds and suppression strategy for younger passengers. Yet other manufacturers may use an overlapping strategy, where the airbags deploy using an LRD strategy for the three- and six-year-olds in the proper position, but suppress when the three- and six-year-olds are out of position (OOP). This technique removes the sharp cut-off between suppression and LRD strategies [41]. Further, most advanced airbags in passenger cars use the windshield of the car to guide the deployment path of the passenger airbag regardless of where the airbag is mounted (i.e. mid-mounted, top-mounted, etc.). This is evident in the test reports of several LRD tests where deployment of the airbag alone (in an otherwise stationary vehicle) cracks the windshield upon deployment.

Many advanced airbags, especially ones that employ a low risk deployment feature, employ a two-stage deployment technique wherein there are two inflators which either fire into the bag at the same time or with a delay between the two stages. All LRD airbags deploy both stages of the two stage bag during low risk deployments. However, in many LRD airbags, the second stage firing time can be late in the event (i.e. >100 ms) thus discharging the remaining charge in the system after the crash is over. Airbags are typically fired using pyrotechnics. These explosives present a potential safety concern for first responders when these explosive charges have not been completely discharged from the airbags prior to their arrival. Firing the remaining charge late in the event, after the passenger has been safely restrained from forcefully contacting the windshield or dashboard, reduces the risk of the airbags spontaneously firing later. However, not all LRD strategies deploy the second stage of the airbag late in the event, a detailed analysis of the FMVSS 208 compliance test reports available on NHTSA's website revealed that many of these systems do deploy the second stage in low risk deployment cases around 100 milliseconds or later. As will be shown later, the deployment time of the second stage can range from 10 to 255 milliseconds after the first stage deploys.

2.1 Suppression

Suppression tests are static tests wherein small-statured anthropomorphic test devices (ATD) or human volunteers are seated in front of the appropriate airbag and the suppression of the bag is verified. Child volunteers are used when the suppression systems are not activated by dummies. The volunteers are required to meet age, height and weight requirement and asked to sit in various positions in the RFP seat. Suppression tests are performed in the right front passenger

(RFP) seat with the passenger airbag (PAB). The driver airbag does not have the option to suppress.

These tests are performed in conjunction with the FMVSS 208-required "telltale" airbag light on the dash board. The "telltale" light indicates when the passenger airbag is turned off and is required to be visible to all front seat passengers. "Telltale" requires the light to be yellow and to use the phrases "Passenger Air Bag Off" or "Pass Air Bag Off." Because the telltale light indicates whether the airbag is suppressed, suppression tests are conceivably less expensive and time consuming than LRD tests which require firing airbags for several scenarios. The suppression test presents a very low risk to child volunteers as the switches are tested statically where the key is turned in the ignition to the accessory position, but the vehicle is not running.

The suppression technique is required for newborn babies, but is optional for older children. To perform the test with the newborn, the dummy is placed in a secured car bed with the RFP seat in the full-rearward, mid-position and full-forward positions. Tests with the older 12 month-old CRABI dummy, requires that the dummy is placed in several different positions secured with the RFP seat again in each of the full-rearward, mid-position and full-forward positions for each of the car seats. Depending on the sensor system employed within the occupant classification system, the infant and CRABI tests are also to be tested with blankets or sun visors over the car seat, to ensure that these items will not cause the airbag to deploy or activate [9].

For the three- and six-year-old suppression tests, children or dummies are unbelted and positioned in numerous positions to ensure the airbag suppresses in all cases, these positions are outlined in Table 2. The positions vary from lying on the seat to restraint within various child safety seat (CSS) configurations.

Once the dummy or child is positioned, the key is placed in the ignition and the car ignition is turned to the position in which the "telltale" light must illuminate. There is a ten second period between turning on the ignition and reading the "telltale" light which should indicate that the passenger airbag is OFF. Following each test, a 5th percentile female dummy is placed on the RFP seat and the same procedure followed; however, for the 5th percentile female test, the "telltale" light must indicate that the passenger airbag is on [9].

Table 2. Outline of Positions Required for Suppression Testing per FMVSS 208 for the 3 & 6 Year Old ATDs [9]

	3 Year Old	**6 Year Old**
Belted test with FFCSS or booster seat	X	X
FFCSS	X	X
Booster seat	X	X
Sitting on seat with back against seatback	X	X
Sitting on seat with back not against seatback	X	
Sitting on seat edge, spine vertical, hands by the dummy's sides	X	X
Standing on seat, facing forward	X	
Kneeling on seat, facing forward	X	
Kneeling on seat, facing rearward	X	
Lying on seat*	X	

*only performed on vehicles with three front seating positions

Until recently, FMVSS 208 also allowed new vehicles to have a manual suppression option wherein the driver of the vehicle is required to take some specific action to manually suppress the passenger airbag [9]. Manual suppression was allowed on vehicles manufactured before September 1, 2012 if the vehicle:

1. Either had no forward-facing seating to the rear of the RFP (i.e. no backseat) or the distance between the backseat and the back of the front seat was less than 720mm (measured as described in FMVSS 208), and
2. The manual suppression device was operable via the ignition key for the vehicle, so that it required some action from the driver, and

3. There was a “telltale” light indicating when the passenger airbag is turned off which was visible to all front seat passengers. “Telltale” meaning it must be yellow, must use the words “Passenger Air Bag Off” or “Pass Air Bag Off”, and
4. The vehicle owner’s manual clearly explained the operation of the on/off switch, conditions under which it was to be used and a warning about the safety risks in using the switch inappropriately.

2.2 Low Risk Deployment

Low risk deployment (LRD) tests are dynamic tests wherein the airbag is fired while the vehicle remains stationery; these tests are only performed for vehicles and occupant classes certified by the automakers to be using a LRD technique. Unlike suppression tests, LRD tests are performed exclusively with instrumented dummies. The LRD tests were designed to mimic the “worst-case” scenarios, there is no interest in whether the dummy is classified by the system, the test assumes that the occupant has been classified as a child and that the bag will deploy in a low risk manner – a big assumption. The airbag is fired in this low risk fashion with the child dummy placed in the worst-case locations for the child dummies: in child seats, for the three- and six-year-old children and with their head or chest directly on the cover of the airbag module.

Since the LRD tests actually deploy the airbag, only one test configuration can be conducted using the original equipment manufacturer (OEM) airbag installation. The remaining tests use what the industry has termed "dealer bags," these are airbags that are purchased at a dealership but are still sold by the OEM. NHTSA decides on a case by case basis which test will used the OEM airbag. The test performer completes the repair of the airbags for the following 10 – 15 tests using "dealer bags." According to Mr. Lewandowski, the first LRD takes about one hour to perform, but re-wiring and re-installing the new "dealer bag" can take a much longer time especially for the passenger side [41].

According to FMVSS 208, the number of stages and their deployment times shall be determined via a frontal rigid barrier test at a speed up to and including 16 mph. But, the firing time is not determined from a frontal rigid barrier test, directly by the test performer, rather, these deployment times are provided by the manufacturer to the test performer prior to testing. The frontal barrier test may be a threshold test to ensure that advanced airbags will not deploy in low severity cases. The number of airbag deployment stages and their second-stage deployment times are then recorded in the test report and that configuration is used for the LRD testing. As noted above, the deployment of the second stage can range from 10 ms to 255 ms after the first stage deploys. The manufacturers determine the second stage deployment time as a design metric via crash tests, sled tests or mathematical models which are performed by the manufacturer during their airbag development. The manufacturer has to justify these numbers with good engineering sense and some data; the manufacturer has to show how they came up with the threshold to fire or not fire the airbag [41].

During LRD testing, the airbags are fired via an input directly connected to the airbag inflator thereby bypassing any other input to the bag. According to Mr. Lewandowski, the airbag control units are first divorced from the airbag control system completely. Then, a Diversified Technical Systems, Inc. (DTS) using a TDAS Pro Timed Output Module (TOM) fires a squib directly into the airbag inflator via the first and second stage deployment plugs. The plug locations and stages are defined by the manufacturer prior to testing [41].

LRD tests employing the 12 month-old CRABI ATD are performed in the RFP seat with various child safety seats. Each type of seat is tested in three seat track positions: full-forward, middle, full-rearward. There are two positions tested for the three and six year old dummies: position one with the dummy's chest on the instrument panel, and position two, with the dummy's head on the instrument panel of the PAB. Where the instrument panel is the door opening of the airbag. Tape with a maximum breaking force of 70 pounds may be used, and frequently is for the three- and six-year-old tests, to hold the dummy in position. LRD tests with the 5th percentile female are also tested in two positions: position 1 chin on the airbag module, and position 2 chin on the rim of the steering wheel. These two positions are aimed to exemplify two of the worst-case conditions the small statured driver could be in when an airbag fires [9].

To further analyze the LRD test method and the suppression and LRD strategies used by auto makers to certify their advanced airbags, NHTSA's vehicle crash test database was downloaded and queried using the Statistical Analysis Software (SAS) package version 9.3 (SAS Institute, Inc. Cary, NC). A total of 617 observations were returned when the database was queried for LRD tests. These tests were then tabulated by dummy size as presented in Table 3. As shown, the most frequently tested dummy size was the 5th percentile female. Since each dummy size is typically tested in two positions, the number of vehicle models tested is about half the number of tests performed. That is just a rough estimate though; there are a number of confounding factors, such as failed tests or tests with surprisingly high results which have been known to be retested. Conversely, there were some vehicles that tested only one position for a particular dummy size.

Table 3. Tabulation of the Number of LRD Tests Available via NHTSA's Website by Dummy Size as of January 2016

Dummy Size	No. of LRD Tests
5th Percentile	327
6 Year Old	120
3 Year Old	97
12 Month Old	73

From the NHTSA database LRD query, vehicles that employed a LRD strategy for at least one child occupant were further queried. The reports for these tests were then downloaded from NHTSA's website via their unique test number identifier. A total of 57 unique vehicle models were identified. The reports were then searched to find the second stage deployment times used in the

LRD testing for all occupant sizes, these times are tabulated in Table 4. Where applicable, the suppression strategy is noted in lieu of a second stage deployment time.

Table 4. Tabulation of the Second Stage Deployment Times in Milliseconds for LRD Tests Available via NHTSA's Website by Occupant Class

			Second Stage Deployment Time (ms)				
Make	**Model**	**Year**	**Newborn Infant**	**12 Month Old - CRABI**	**3 yo Hybrid III**	**6 yo Hybrid III**	**5th% Female Hybrid III**
Audi	**A3**	**2006**	Supp	Supp	40	40	40
BMW	**128i**	**2009**	Supp	Supp	240	240	60
	328i	**2008**	Supp	Supp	100	100	60
Cadillac	**CTS**	**2010**	Supp	Supp	30	35	100
Chevrolet	**Cobalt**	**2009**	Supp	Supp	40	40	100
	Equinox	**2010**	Supp	Supp	35	35	100
	Impala	**2014**	Supp	Supp	100	100	100
	Silverado	**2009**	Supp	Supp	120	120	120
	Silverado 1500	**2014**	Supp	Supp	120	120	120
	Volt	**2011**	Supp	Supp	120	120	120
Dodge	**Avenger**	**2013**	NT	10	40	40	100
	Caliber	**2008**	NT	20	40	40	100
	Charger	**2007**	NT	10	60	60	150
	Durango	**2004**	Supp	Supp	130	130	130
	Grand Caravan	**2008**	NT	20	150	150	150
	Journey	**2009**	NT	20	150	150	100
	Magnum	**2005**	Supp	Supp	150	150	150
	Ram 1500	**2006**	NT	10	150	150	150
		2007	NT	10	NT	NT	60
Fiat	**500**	**2012**	NT	5	120	120	120
	500L	**2014**	NT	5	120	120	120
Ford	**Explorer**	**2011**	Supp	Supp	Supp	Supp	150
Honda	**Accord**	**2004**	Supp	Supp	Supp	20	30
		2008	Supp	Supp	Supp	150	150
		2013	Supp	Supp	Supp	150	40
	Accord Crosstour	**2010**	Supp	Supp	Supp	150	40
	Civic	**2007**	Supp	Supp	Supp	130	40
	Civic Hybrid	**2013**	Supp	Supp	Supp	150	40
	CRV	**2008**	Supp	Supp	Supp	130	40
	Fit	**2007**	Supp	Supp	Supp	130	30
	Insight	**2010**	Supp	Supp	Supp	150	40

Second Stage Deployment Time (ms)

Make	Model	Year	Newborn Infant	12 Month Old - CRABI	3 yo Hybrid III	6 yo Hybrid III	5th% Female Hybrid III
	Odyssey	**2011**	Supp	Supp	Supp	130	30
	Pilot	**2009**	Supp	Supp	Supp	150	30
Hyundai	**Santa Fe Sport**	**2014**	Supp	Supp	100	100	100
	Sonata	**2011**	Supp	Supp	120	120	150
Jeep	**Compass**	**2010**	NT	20	40	40	100
	Grand Cherokee	**2011**	NT	20	80	80	100
	Patriot	**2014**	NT	10	40	40	100
	Wrangler	**2007**	Supp	Supp	150	150	150
Kia	**Borrego**	**2009**	Supp	Supp	35	35	150
	Forte	**2010**	Supp	Supp	120	120	120
	Optima	**2009**	Supp	Supp	100	100	100
	Sorrento	**2011**	Supp	Supp	120	120	120
	Soul	**2010**	Supp	Supp	120	120	120
Mercedes	**C230**	**2005**	Supp	Supp	200	NT	200
	C300	**2008**	Supp	Supp	200	200	200
	E350	**2006**	Supp	Supp	200	200	200
	CLA250	**2014**	Supp	Supp	200	200	200
Mini	**Cooper**	**2007**	Supp	Supp	255	255	255
Mitsubishi	**Outlander**	**2007**	Supp	Supp	Supp	100	100
Porshe	**Boxster**	**2006**	Supp	Supp	0	NT	150
Smart	**ForTwo**	**2008**	Supp	Supp	200	200	200
Subaru	**Forester**	**2014**	Supp	Supp	100	100	100
	Impreza	**2013**	Supp	Supp	100	100	100
Toyota	**Avalon**	**2013**	Supp	Supp	100	100	100
	Corolla	**2014**	Supp	Supp	100	100	100
Volkswagen	**Jetta**	**2007**	Supp	Supp	200	200	N/A
		2011	Supp	Supp	200	200	N/A
	Passat	**2013**	Supp	Supp	200	200	N/A
	Routan	**2009**	NT	20	150	150	150
	Tiguan	**2009**	Supp	Supp	200	200	N/A

Supp = Suppression Technique; NT = Not Tested; N/A = Single Stage Airbag

Some of the second stage firing times appear to be what are known as "disposal deployments," where the remainder of the charge or propellant in the airbag inflator is used up to prevent exposing first responders or bystanders to risk of a subsequent deployment. These disposal deployments occur so late (> 100 milliseconds) with respect to a crash that the deployment would not prevent injury. In contrast, some of the second stage deployment times are aggressive considering the occupant size, such as the Chrysler, Fiat, Jeep and Volkswagen times for the CRABI ATD which were all 20 milliseconds or less. In these cases, the airbag module is mounted in the top of the instrument panel such that the airbag deploys towards the windshield during the first deployment stage and then out towards the occupant during the second stage deployment. This can be seen by viewing videos of the above tests which are available on NHTSA's web-based vehicle database.

The results of LRD tests are analyzed with respect to injury criteria. The following section introduces the relevant injury criteria.

2.3 INJURY CRITERIA

Injury criteria relate the mechanical loads experienced by an ATD during a crash with likely injury outcomes in humans. Injury criteria are typically derived from retrospective, cadaveric, or modeling studies on human impact and loading limits. An understanding of these criteria allows researchers and NHTSA to scale and define the acceptable limits for each criterion and occupant class. These acceptable limits are called injury assessment reference values (IARVs). That is not to say that vehicles or vehicle systems which are tested and meet the defined IARVs will not injure a real-life occupant in a real-world crash. Rather, the IARVs are selected to minimize the risk of serious injury to occupants in vehicles meeting these requirements under very specific crash conditions. These criteria also serve to pose limits on the allowable impacts and loading the vehicle can impose on a person during crash testing and/or actual crashes. This section will outline and define two injury criteria: head injury criteria (HIC) and the neck injury criterion (Nij). These injury criteria were selected for inclusion here due to their relevance to the injuries sustained by children critically injured by first generation airbags; other injury criteria are measured and reported within the LRD test reports. This section will also present the current limits imposed by NHTSA for these criteria by occupant size.

The first injury criteria and perhaps one of the most controversial is the head injury criteria (HIC) which was developed originally to predict skull fractures. The head injury criterion is defined as:

$$\boldsymbol{HIC = max[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt]^{2.5}\,(t_2 - t_1)} \qquad \textbf{Equation 1}$$

where ***a(t)*** is the resultant head acceleration in G's and ***t*** is time in seconds. NHTSA imposes regulatory limits on the auto-maker industry to ensure the safety of occupants throughout the United States. These limits have evolved over time. These limits and their history timeline are outlined in Table 5. Not only have the regulatory HIC limits changed over time, but the maximum time interval in which the HIC is taken have also changed; injury criteria, like crash pulses, are more severe when they occur over shorter time periods.

Table 5. History of HIC IARVs for Adult Dummies

	Max Time Interval	***HIC Limit***
Original	None	1000
1986	36 ms	1000
2001	15 ms	700

The next injury criteria of interest is neck injury, this criteria is referred to as Nij. To understand the Nij, it is first necessary to examine the four different possible modalities of neck injury as shown in Figure 2. In regulatory tests with Hybrid III ATDs, the neck loads are measured in the upper neck with a load cell at the occipital-condyle. The 12 month-old CRABI ATD does not have a Hybrid III neck, but its neck is based on the Hybrid III design. The neck is a unique part of our body; it is flexible and therefore highly susceptible to injury because it supports our heavy heads. Further, the degrees of freedom in our necks allow for the four injury modalities to be most commonly coupled in the following ways: axial loading and flexion, axial loading and extension, where axial loading could be in compression or tension. The neck also serves as the only pathway to connect the head with the rest of the body; therefore it is a key area to protect to prevent injury.

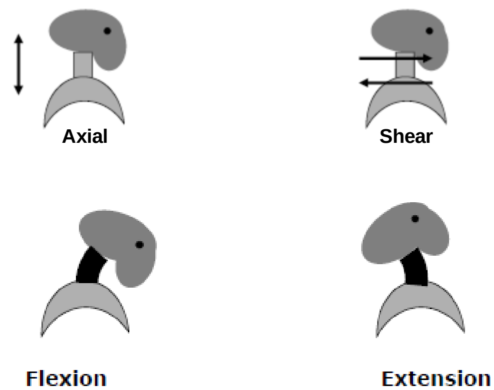

Figure 2. Neck Injury Modalities

With the neck injury modalities defined, it is possible to define the neck injury criteria, Nij. Nij is defined as:

$$\boldsymbol{N_{ij}} = \frac{\boldsymbol{F_i}}{\boldsymbol{F_{i,int}}} + \frac{\boldsymbol{M_j}}{\boldsymbol{M_{j,int}}}$$

Equation 2

where $\boldsymbol{F_i}$ is the tensile or compressive force, $\boldsymbol{F_{i,\,int}}$ is the critical value or intercept (as outlined in Figure 3) of the tensile or compressive force, $\boldsymbol{M_j}$ is the extension or flexion bending moment and $\boldsymbol{M_{j,\,int}}$ is the critical value or intercept of the bending moment. Equation 2 can be broken down into two components; the first ratio is the y-axis ratio, the second the z-moment ratio as shown in Figure 3.

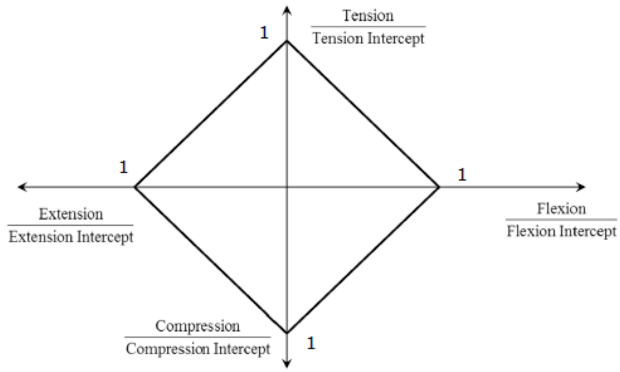

Figure 3. NHTSA Nij Criterion Limits Established in 2000

The IARV's for the mid-sized male, small female, six and three year-old children and the 12 month infant are tabulated in Table 6. The newborn infant is not listed because the only option is suppression for newborns in car beds, so no injury criteria or IARV is needed. Further, FMVSS 208 only requires that these injury criteria be met for the first 100 milliseconds for the three and six year old child dummies, this may be why several airbags are designed to deploy the second stage after 100 milliseconds; for 5th percentile females the data is recorded to 125 milliseconds after the initial deployment stage [9].

Table 6. Overview of HIC and Nij Injury Assessment Reference Values (IARVs) for Various Dummies

Criteria	Mid-Sized Male (50th %)	Small Female (5th %)	6 yo Child	3 yo Child	12 mo. Infant
HIC15	700	700	700	570	390
Nij	1.0	1.0	1.0	1.0	1.0
Nij Critical Intercept Values:					
Tension & Compression (N)	4500	3370	2800	2120	1460
Flexion (Nm)	310	155	93	68	43
Extension (Nm)	125	62	37	27	17

2.4 Summary of Advanced Airbag Requirements

Under the final advanced airbag ruling, vehicle manufacturers must suppress an advanced airbag in the presence of an infant (< 1 year old), but can choose whether to suppress or deploy the airbag in a low risk fashion in the presence of three different child occupant classes: 1-, 3- and 6 year olds. FMVSS 208 requires that the suppression or deployment strategy is tested under laboratory conditions with dummies, or, at the option of the manufacturer, child volunteers (for suppression tests only). This chapter examined how these extensive tests are performed: suppression tests use the "telltale" dashboard light to determine whether the airbag is suppressed or not, while LRD tests are performed by firing several airbags for each occupant class incorporating an LRD technique. In addition, the NHTSA test database was queried for their results by occupant class and second stage deployment times commonly exceeded 100 milliseconds which is after the crash event is over, though some were more aggressive and deployed the second stage at 5 milliseconds. In addition, relevant injury criteria for the head and the neck were examined along with their respective IARVs for various dummy sizes. The IARV for the head injury criteria is the same for a 6 year old as it is for a 5th percentile female and a 50th percentile male; however as expected the values are lower for the 3 year old and 1 year old. With this understanding of advanced airbags an analysis of child fatalities in motor vehicle crashes was performed to investigate the effect advanced airbags has had on child fatalities.

3 CHARACTERISTICS OF CHILD FATALITIES IN MOTOR VEHICLE CRASHES (MVCS)

Motor vehicle crashes remain a leading cause of injury and death among children in the United States (US). While the motor vehicle fatalities among children aged 12 and under have decreased considerably since 1995, traffic related incidents are responsible for approximately 1,000 children continue to die in the US each year. During the 19 year period between 1995 and 2013 children 12 and younger accounted for an average of 4% of the total Fatality Analysis Reporting System (FARS) reported fatalities yearly. While this is a small percentage overall, these fatalities are preventable and child fatalities carry a very large social and economic burden on society.

This chapter investigates child fatalities as a result of MVCs in the US using FARS for case years 1995 – 2013 in order to identify specific crash characteristics that lead to child fatalities. The distribution of child fatalities by crash mode, seating position, age, restraint, and vehicle type may provide some important insight to MVC injuries and fatalities amongst children. To put the fatality information from FARS in perspective, the exposure estimates for children during the same years using National Automotive Sampling System – General Estimate System (NASS-GES) are also presented for each FARS scenario examined. The chapter first outlines methods used herein, then reviews fatalities for all children including bicyclists and pedestrians and finally analyzes fatality and exposure data for child occupants of passenger vehicles (cars and light trucks and vans (LTVs)) with respect to crash mode, seating position, age, restraint use and vehicle type.

3.1 METHODS

The Fatality Analysis Reporting System is a database of all MVCs in the US involving at least one traffic-related fatality within 30 days following the crash. FARS is a nationwide census which accounts for all occupants and persons such as bicyclists or pedestrians involved in a crash involving a fatality. The National Automotive Sampling System – General Estimate System is a database containing a nationally representative sample of police reported MVCs ranging in severity from minor to fatal crashes. To obtain a nationally representative estimate, NASS-GES provides weighting factors which estimate the total number of each crash exposure annually within the US. Crashes included in both FARS and NASS—GES have occurred on public traffic ways.

The fatality and exposure analyses were performed for the 19 year period between 1995 and 2013, including the years 1995 and 2013. This period was selected to capture the peak incidence of passenger airbag (PAB) related fatalities investigated by the Special Crash Investigations (SCI) division of the National Highway Traffic Safety Administration (NHTSA) corresponding to vehicles in the 1995 model year. Starting the analysis in 1995 also provides a sampling of the child fatalities occurring prior to the introduction of second generation airbags in model years 1998 and 1999.

The analysis was performed for children 12 and under for consistency with the age range most commonly used by NHTSA and the Insurance Institute of Highway Safety (IIHS) to classify children. While 0 – 12 years is a commonly used category for children, other researchers have used different definitions. At times, such as in their Traffic Safety Facts reports, NHTSA has grouped children aged 10 to 15 years old together. The Children's Hospital of Philadelphia typically includes ages 3 to 15 years when defining children as a group, thus clearly delineating a difference between infants and children. The Center for Disease Control (CDC) defines children as being between 0 and 14 years old. For reference, the current recommendation is that children less than 16 years old sit in the back seat [1].

FARS was queried using the Statistical Analysis Software (SAS) version 9.3 (SAS Institute Inc. Cary, NC) for children 12 and under sustaining fatal injuries during the period investigated. A total of 29,172 observations were obtained. These FARS-reported fatalities included fatalities for child: passengers, pedestrians, bicyclists and drivers. Crash modes (i.e. frontal, rear and near or far side impacts) were defined for the FARS data using the FARS impact clock position to define the general area of damage (GAD). In FARS, 12 o'clock corresponds to the front of the vehicle. The front seat group included all front seat observations including: right front seat passengers, middle front seat passengers, driver seat passengers as well as other and unknown front seat locations. The back seat group includes all observations in the 2^{nd}, 3^{rd}, and 4^{th} row seating locations in the middle, left and right, positions, as well as other and unknown positions in these rear rows. Vehicle type was classified using the body type variable in both FARS and GES to place vehicles into classes such as cars, LTVs, and motorcycles. Observations for the occupant study were limited to cars and LTVs only. The LTV group included minivans which is particularly relevant to child occupant studies.

The FARS child fatality dataset included a total of 19,608 children who were occupants of vehicles. These fatalities were limited to: drivers, passengers and unknown occupants (occupants with an unknown seating position or role) in a motor vehicle in transit who were travelling in cars or LTVs only. These child occupants were again between 0 and 12 years of age at the time of the crash. In the analysis which follows, the 19 year period was broken up into three groups of calendar years: 1995 – 1998, 1999 – 2006, and 2007 – 2013, these calendar years *roughly* align with the airbag generations, though the groups are calendar years, not model years

The FARS data and the NASS-GES data were used to calculate the fatality risk and relative risk. The fatality risk was calculated via the following equation:

$$Fatality\ Risk\ = \frac{Number\ of\ Fatalties}{Total\ Cases};$$

Similarly the relative risk can be calculated using data obtained using the risk values as follows:

$$Relative\ Risk = \frac{Fatality\ Risk_A}{Fatality\ Risk_B},$$

that is, the ratio of the fatality risk for situation A to the fatality risk for situation B, provides the relative risk of situation A with respect to situation B. For example, if the relative risk of sitting in the front seat to sitting in the back seat is more than one, the fatality risk in the front seat exceeds the fatality risk in the back seat.

3.2 Overall Results

A tabulation of the overall child fatalities studied are outlined in Table 7 by calendar year group, person category, crash mode, occupant location, restraint used and type of vehicle occupied. Observations for each analysis group were sorted by number of fatalities, since the calendar years are not divided evenly, percentages for each crash scenario within the calendar year groups. As implied by the heading rows indicate, the percentages for each calendar year group sum to 100%. Limiting the study to passengers in cars and LTVs reduces the sample size slightly. However, limiting the study to these vehicle types also controls for other variables such as children in buses or as passengers within other vehicles such as motorcycles, mopeds, etc. all which do not have airbags. The table also highlights how prevalent fatalities are for child passengers as compared to pedestrian fatalities. The most common crash mode among fatally injured children was frontal crashes (which passenger airbags are designed to protect against) and rollovers. Though rear seat fatalities are far more prevalent, exposure data presented within the chapter underscores the relative risk for children seating in the front seat versus the back seat. It should be also noted that as a result of knowledge campaigns – the exposure of children seated in the front seat has declined during the period examined. Notably, roughly twice as many children were fatally injured while riding unrestrained in a vehicle. Finally, cars are more prevalent in the sample of fatally injured children; however, for this MVC group, the exposure follows the same trend.

Table 7. Tabulation of the Overall FARS Results for All Years and Each Respective Calendar Year Group

	All Years	***1995-1999***	***2000-2005***	***2006-2013***
Child Fatalities	**29,172**	**10,524**	**10,073**	**8,575**
Passengers	20,127	5,451	9,563	5,113
Passengers in Cars & LTVs	19,608	5,351	9,292	4,965
Pedestrians	6,289	2,144	2,693	1,452
Bicyclists	1,797	685	797	315
Drivers	431	100	225	106
Crash Mode	**19,608**	**100%**	**100%**	**100%**
Front	5,537	34.2%	32.3%	29.6%
Rollover	6,110	28.1%	31.5%	33.9%
Near Side	2,974	16.3%	15.3%	13.7%
Far Side	2,064	11.5%	10.3%	9.9%
Back	1,562	6.7%	7.8%	9.6%
Other	603	3.3%	2.8%	3.3%
Child MVC Fatalities	**19,608**	**100%**	**100%**	**100%**
Rear Seats	12,266	50.5%	63.1%	74.6%
Front Seat	5,537	38.8%	28.0%	17.3%
Other Seats	1,805	10.7%	8.9%	8.1%
Restraint Use	**17,897**	**100%**	**100%**	**100%**
None Used	8,569	50.6%	43.8%	36.1%
Belt Use	4,921	22.6%	26.5%	25.2%
CSS	4,407	15.9%	21.6%	31.3%
Vehicle Type	**19,608**	**100%**	**100%**	**100%**
Car	11,251	65.5%	56.4%	50.4%
LTV	8,357	34.5%	43.6%	49.6%

3.3 ALL CHILD FATALITIES & EXPOSURES

To put child fatalities among passengers, drivers, pedestrians and bicyclists in perspective, first an analysis of all traffic related child fatalities was analyzed from 1995 to 2013. Child traffic fatalities account for roughly 4% of all traffic fatalities in the US (Figure 5). The percentage of fatally injured children has decreased significantly from 8.8% during the years 1995 to 1999 to 6.1% for the years 2006 through 2013; a positive trend, but there is still a large potential for improvement since many of these fatalities are preventable. In comparison, the trend for all FARS persons over this time period has plateaued and even slightly increased with the exception of a marked decrease which corresponds with the economic downturn in the US as shown in Figure 4. According to the National Bureau of Economic Research the "Great Recession" was between December 2007 and June 2009 [42], the only time in the 19 year period exhibiting a significant reduction in traffic fatalities to less than 40,000 per year. Following the significant decrease the fatality rate appeared to have plateaued below 35,000.

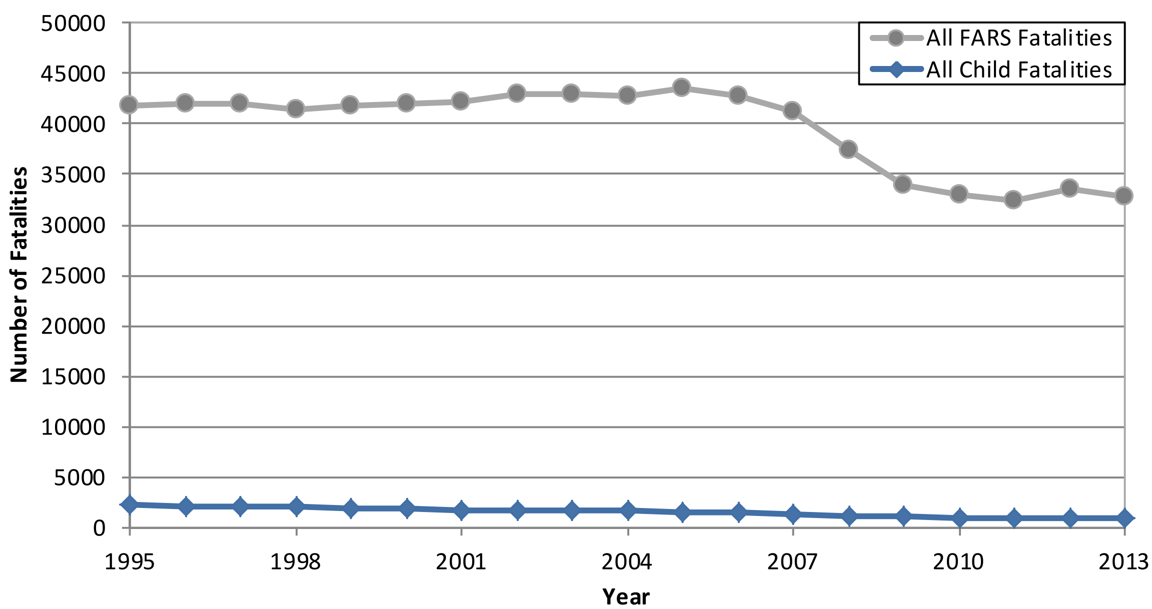

Figure 4. FARS Fatalities over Time for All (*grey*) and Child (*blue*) Car & LTV Occupants

Over the 19 year period, child fatalities in pure numbers exhibit a downward trend as shown in Figure 5. These fatalities have decreased by 57% overall during the period of analysis. The number of fatalities for all children 12 and under fell from 2,201 in 1995 to 939 in 2013. While the latter years of this trend could be explained by a reduction in the vehicle miles traveled due to an economic downturn, the downward trend is consistent over time.

The fatality trend for child passengers appears to follow the fatality trend for children overall especially in 2002 and later; child passenger fatalities accounted for 68% of all child traffic fatalities on average over the 19 year period and this proportion is increasing as shown. Child pedestrian and child bicyclist fatalities have also followed a similar but less pronounced downward trend over the period investigated. Child driver fatalities which make up the smallest proportion of child fatalities, however, do not follow the same general downward trend over investigated time period; these fatalities appear to stay relatively constant over the 19 year time frame.

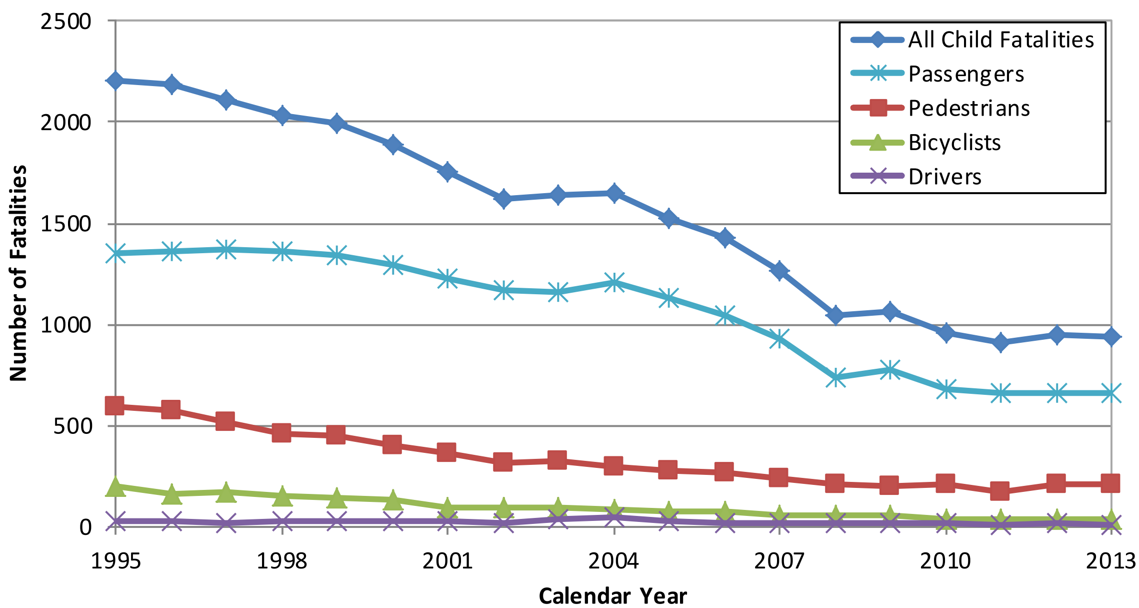

Figure 5. FARS 1995 – 2013 Child (12 & Under) Fatalities Over Time for All Child Fatalities, Passengers, Pedestrians, Bicyclists and Drivers

Further perspective may be gained by examining the NASS-GES estimated exposure for children 12 and under riding in vehicles during the period of interest. The NASS-GES estimates corresponding to the fatalities presented in Figure 5 are presented in Figure 6. It should be noted that NASS-GES is biased towards passengers in vehicles as cases are selected from police accident reports involving a vehicle. Child exposures also trend downward over the period examined; the estimated exposure for all children decreased by 24% during this time. Since both the FARS fatality data and the NASS-GES exposure data trend downward, fatality risks were calculated for each of the 19 years examined. The fatality risks exhibited a downward trend as well; the fatality risk for all children involved in traffic incidents decreased from 188 to 105 per 100,000 exposures over the 19 year period. This decrease was found to be statistically significant when grouping calendar years. The fatality risk per 100,000 exposures between 1995 and 1999 on average was 180.1, for the years 2000 to 2005 the average fatality risk was 150.8 and finally for calendar years 2006 through 2013 the average fatality risk was 114.8.

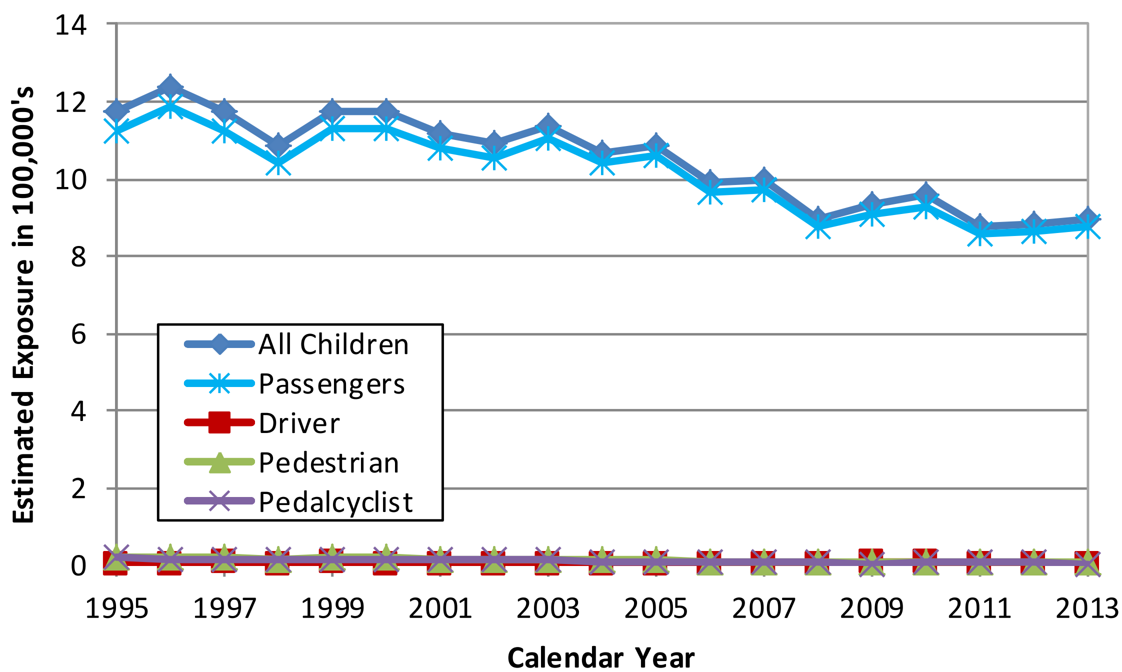

Figure 6. NASS-GES 1995 – 2013 Estimated Child (12 & Under) Exposures for All Children, Passengers, Pedestrians, Bicyclists and Drivers in 100,000's

To examine the relationship between child drivers and passengers by vehicle types, a pie chart of child fatalities grouped by type was examined as shown in Figure 7. While some child drivers indeed drove passenger cars and LTVs, the majority of child drivers drove vehicles in the other/unknown category. The other/unknown vehicle type includes vehicles such as: limousines, three wheel automobiles, van motorhomes, recreational vehicles (RVs), all-terrain vehicles (ATVs), snowmobiles, and farm equipment. Children are most often passengers in cars and LTVs. Since the goal of this study is to examine airbags and their interaction with children, the remainder of this fatality analysis, the focus will be cars and LTVs.

While it was not the express interest of this study to examine the incidence of child drivers, we were surprised to find numerous children coded as drivers in FARS. A total of 431 cases had drivers between 0 – 12 years of age. To verify that these fatalities were not incorrectly coded in FARS, a cursory analysis of child drivers was performed. Roughly sixty percent of all child driver fatalities between 1995 and 2013 occurred in the other/unknown vehicle category. More than half (65%) of these other/unknown vehicle type driver fatalities occurred on ATVs. Motorcycles are the second most common vehicle type amongst child driver fatalities. Child drivers were generally older children aged 9 to 12 years old (mean = 8.5 years, median = 9 years, mode = 11 years).

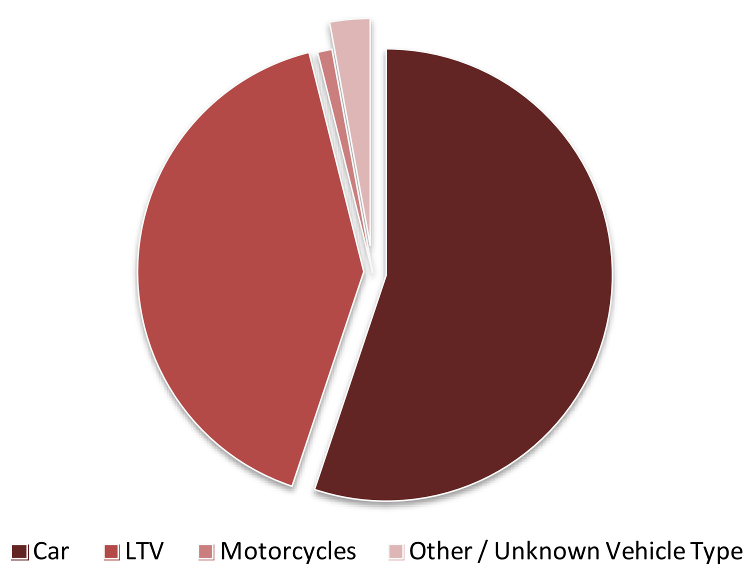

Figure 7. FARS 1995 – 2013 Child Fatalities by Vehicle Type for Child Drivers, Passengers, and Unknown Child Occupants in Motor Vehicles During Transport

While fatalities of child pedestrians and drivers are interesting, preventable though some are particularly difficult particularly difficult to protect [43], [44], [45], such as motorcycles [46], the main focus of this work is to assess the effects of advanced airbags. As outlined above, the remainder of this fatality analysis focuses on child occupants in cars and LTVs. The following section provides a detailed analysis of the characteristics of these child fatalities over the 19 year period from 1995 to 2013.

3.4 Child Occupant Fatalities

This analysis presents fatality and exposure data for child occupants of cars and LTVs with respect to crash mode, seating position, age, restraint use and vehicle type.

3.4.1 Fatalities by Crash Mode

The distribution of child fatalities by crash type over time for restrained and unrestrained children, as shown in Figure 8, reveals that frontal and rollover crashes were the most common crash modes among fatally injured children. The data also indicates that the proportion of child fatalities in frontal and side impact (far and near) crashes has decreased over time. However, the frequency of child fatalities in rear and rollover crashes has increased over time. The "other" crash mode group includes crashes where the area of damage was to the undercarriage, top of the vehicle or unknown.

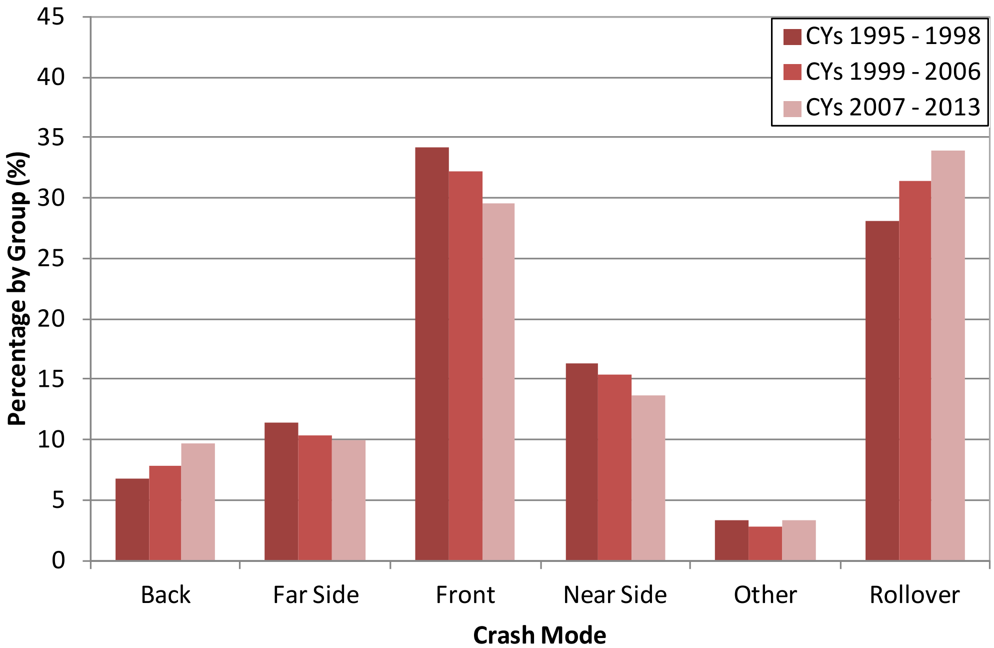

Figure 8. FARS 1995 – 2013 Fatalities by Crash Mode for Children 12 & Under

The same analysis with respect to model year group indicates that fatalities resulting from frontal crashes are actually on the rise for the later model year group and conversely decreasing as a result of rollovers as shown in Figure 9. In addition, it appears that in the later model year group child fatalities resulting from rear or backside crashes are increasing more than the calendar year grouped plot indicated. One significant difference between the calendar year groups and the model year groups are the number of vehicles or cases included since the model year groups limit the cases included to those occurring within vehicle model years 1995 – 2013. The reduction in rollover fatalities in the later model year group may be attributed to the incorporation of NHTSA recommended and/or mandated technologies such as electronic stability control (ESC).

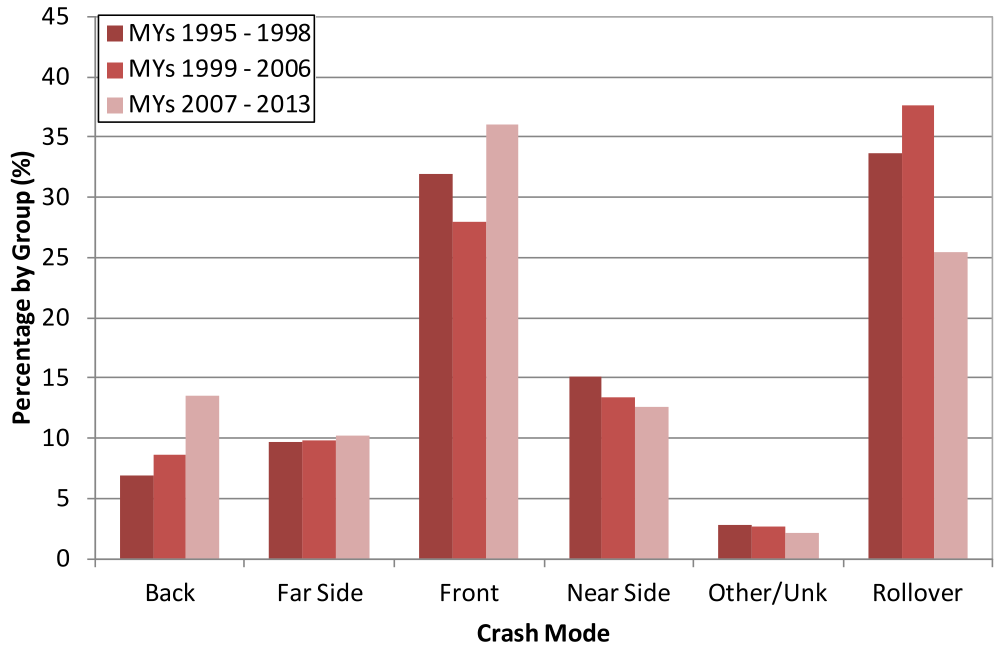

Figure 9. FARS 1995 – 2013 Fatalities by Crash Mode for Children 12 & Under Limited to Model Years 1995 - 2013

Figure 10 examines the exposure of children to these types of crashes using NASS-GES. Children are most often exposed to crashes involving frontal impact. As might be expected, children are exposed to rear impact crashes more often than rollover crashes. Moreover, while the exposure to and fatalities from rear impact crashes are nearly constant at 25%, child fatalities in rear impact crashes only accounts for roughly 9% of all of the fatalities by crash mode. This indicates that rear impact crashes present less of a risk for child fatalities than crash modes such as frontal, and side collisions where the fatality and exposure frequencies are within 10% of each other. Conversely, rollovers appear to present a very high risk of fatality to child passengers as the fatality frequency is close to 35% of all crash modes, but the exposure is much less than 5%.

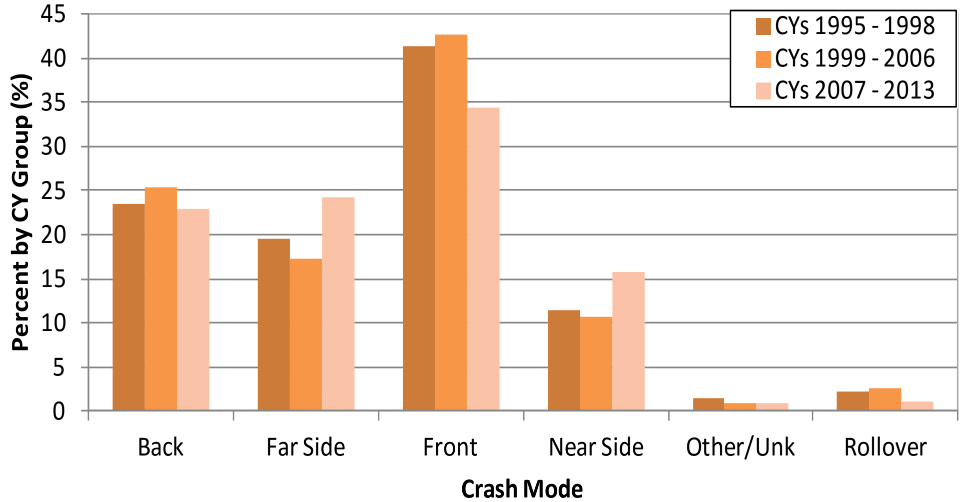

Figure 10. NASS-GES 1995 – 2013 Crash Mode Exposure for Children 12 & Under

The same analysis was run with model years as shown in Figure 11. When limited to and grouped by model years 1995 – 2013, the decrease in exposure to frontal crash modes is similar for the later model years as the later calendar years, but the exposure to rear or back side crashes is markedly increased (~33%) in the later model year group as compared to the later calendar year group (~23%).

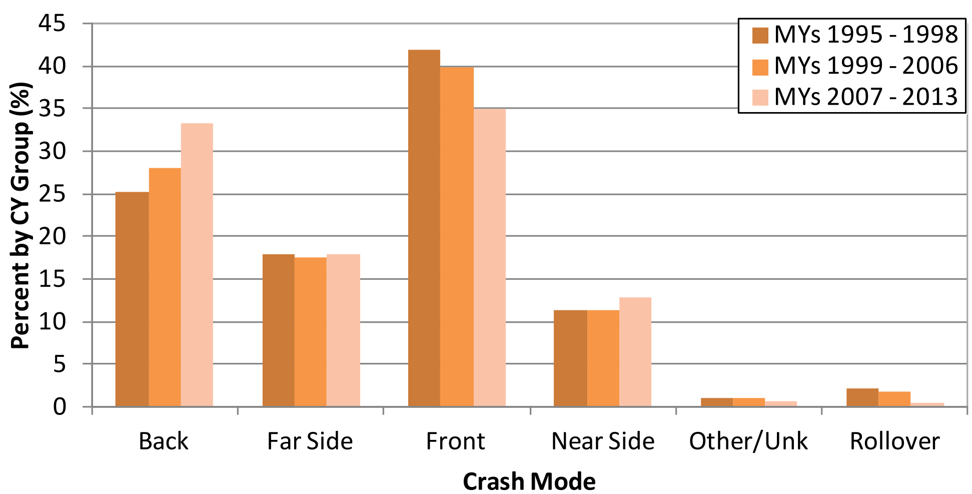

Figure 11. NASS-GES 1995 – 2013 Crash Mode Exposure for Children 12 & Under Limited to Model Years 1995 - 2013

The relative risk for rollovers to frontal crashes between 1995 and 2007 was 16; meaning rollovers were about 16 times more deadly for children than frontal crashes during that period.

During the period between 2008 and 2013, the relative fatality risk for rollovers to frontal crashes involving children rose significantly to roughly 140 (Figure 12). Further, the relative risk of near side crashes with respect to frontal crashes is higher than the relative risk of far side crashes with respect to frontal crashes as would be expected. Finally, the relative risk for rear or back side crashes with respect to frontal crashes has increased slightly over time, but their risk has been nearly equivalent throughout the majority of the period under consideration.

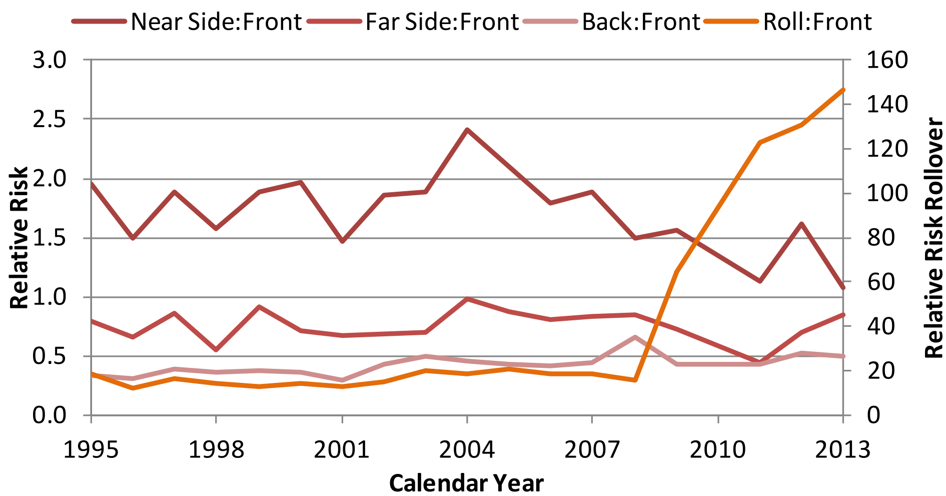

Figure 12. Relative Risks for Crash Modes with Respect to Frontal Crashes as a Function of Time

When the relative risk is compared by calendar year generation of children fatally injured over the time examined for crash modes, the rise in rollover risk is remarkably evident as expected. The remaining crash modes have decreased in risk for the latest calendar year generation (2007 – 2013) when the risk for calendar year generation 1995 – 1998 was used as the reference (Figure 13).

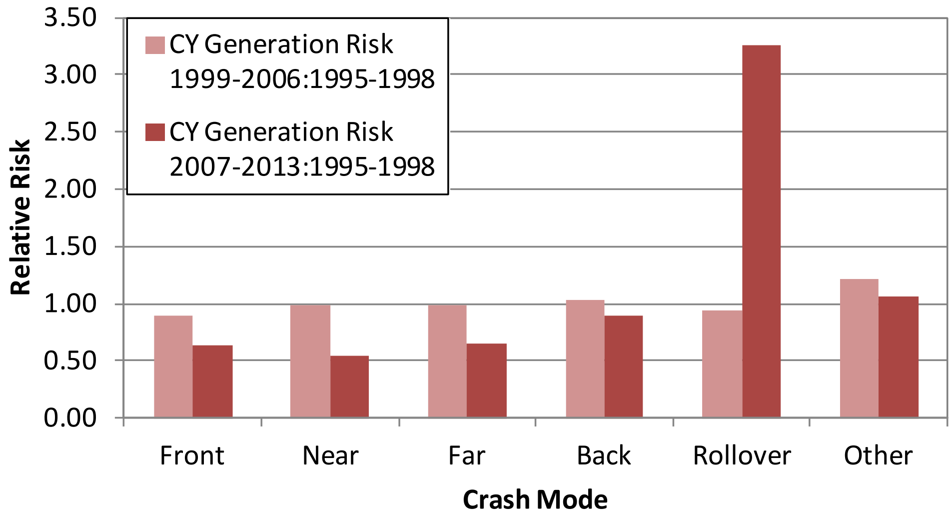

Figure 13. Relative Risk for Crash Modes by Calendar Year Generation with Respect Calendar Year Generation 1995 – 1998

To analyze whether the fatality and exposure trends for children followed the national trends for crash mode, the same analysis was performed for adults aged 25 – 65, this age range was selected to represent adults to align with age groups reported by NHTSA to exclude teens and young adults (15 – 24 years old) whose risk varies from adults in the 25 – 65 age group, and also excluded adults over 65 as their risk also differs from the group selected [47]. FARS-reported fatalities for adults aged 25 to 65 by crash mode follow trends similar to those seen for children with slight differences (Figure 14). Adults are also most commonly fatally injured in frontal and rollover crashes; however adult fatalities for frontal and rollover crash modes account for more than 35% in each group, whereas child fatalities for frontal and rollover crash modes are less than 35% each. These differences may be attributed to the increased incidence of child fatalities in rear and right side crash modes as compared to the adult groups which are less than 5% and about 10% for adults, respectively.

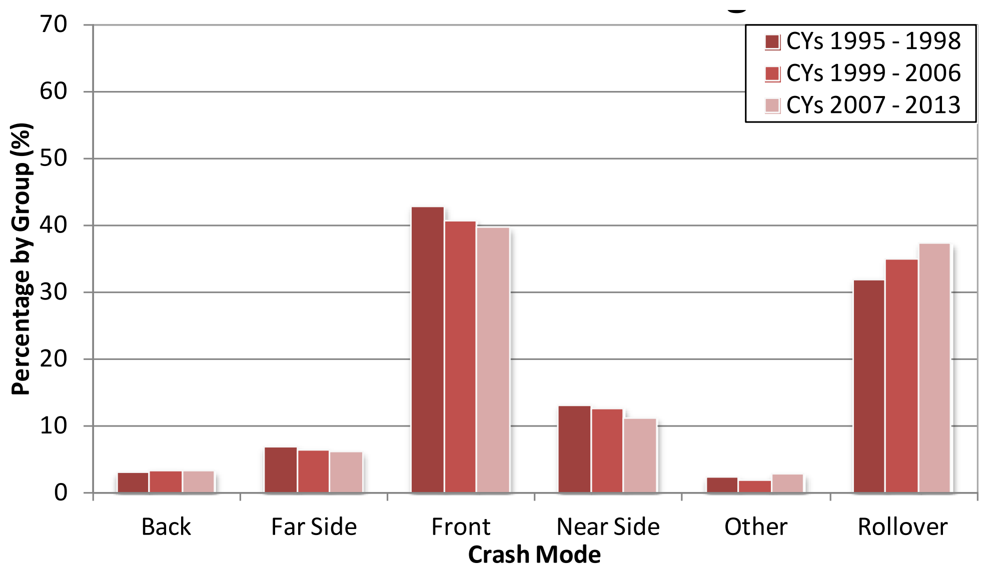

Figure 14. FARS 1995 – 2013 Fatalities by Crash Mode for Adults Aged 25 – 65 Years Old

Exposure for adults again indicates that rear impact crashes are more common in terms of exposure than they are fatal, indicating that the fatality risk in a rear collision is relatively low (32 per 100,000 crashes) (Figure 15). The adult group also exhibits similar exposures for frontal and side impacts. The fatality risk for rollovers is even higher for adults than for children; the relative risk for rollovers to frontal crashes for adults between 1995 and 2007 was 32. Adults similarly saw a significant increase in the relative risk for rollovers to frontal crashes between 2008 and 2013 which rose to 85.

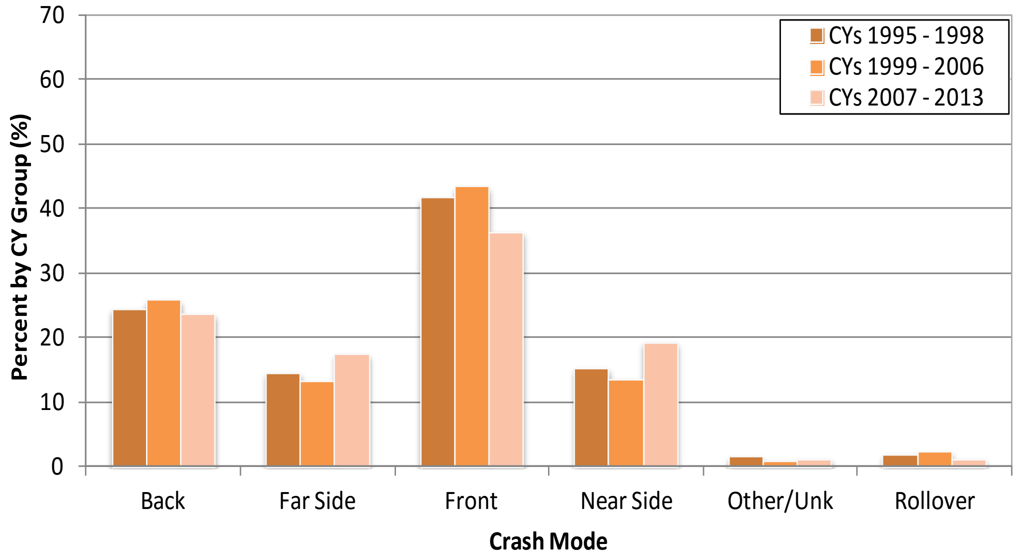

Figure 15. NASS – GES 1995 – 2013 Crash Mode Exposure for Adults Aged 25 – 65

3.4.2 Fatalities by Seating Position

The distribution of child fatalities by seating position, as shown in Figure 16, indicates that child fatalities in the front seat have continually declined between 1995 and 2013. This may be a result of increased public awareness about airbags and the back seat recommendation. After realizing that airbags can pose significant risk to children seated in front of passenger airbags, along with a variety of other reasons NHTSA began publicizing that children under 12 years old are safest when seated in a rear seat of a vehicle [1]. Further, the fatalities in the back seat appear to have increased during this period as well; however, from the FARS data alone it is not clear whether this is secondary to an increased exposure among children. The front seat group included all forward seating positions comprising: right-front, left-front, middle-front, other-front and unknown-front. Likewise the back seat group included all seating positions in the second, third and fourth rows. Finally, the other/unknown group included codes for: 'Cab Sleeper,' 'Other Enclosed,' 'Other Unenclosed,' 'Other Unknown,' 'Trailing Unit,' 'Vehicle Exterior' and 'Unknown'.

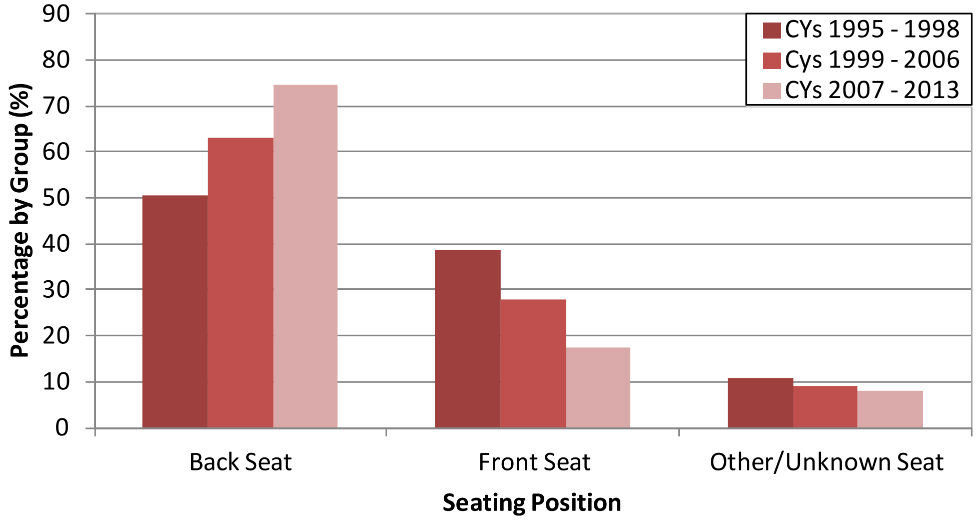

Figure 16. FARS 1995 – 2013 Fatalities by Seating Position for Children 12 & Under

An examination of the NASS-GES data for children by seating position (Figure 17) reveals that over the 1995 – 2013 time period the incidence of children sitting in the back seat has increased as suspected. Conversely, front seat exposure among children decreased over the 19 year time period; the same is true for the other/unknown seating position category. By comparing the FARS seating position data to the NASS-GES data, it is clear that more children are exposed in the back seat than are fatally injured in the back seat. However, for the front seat the contrary is true, though the fatality rate and exposures are within 10%, the difference in fatalities and exposure for the back seat are much larger indicating that the front seat presents a higher fatality risk than the back seat.

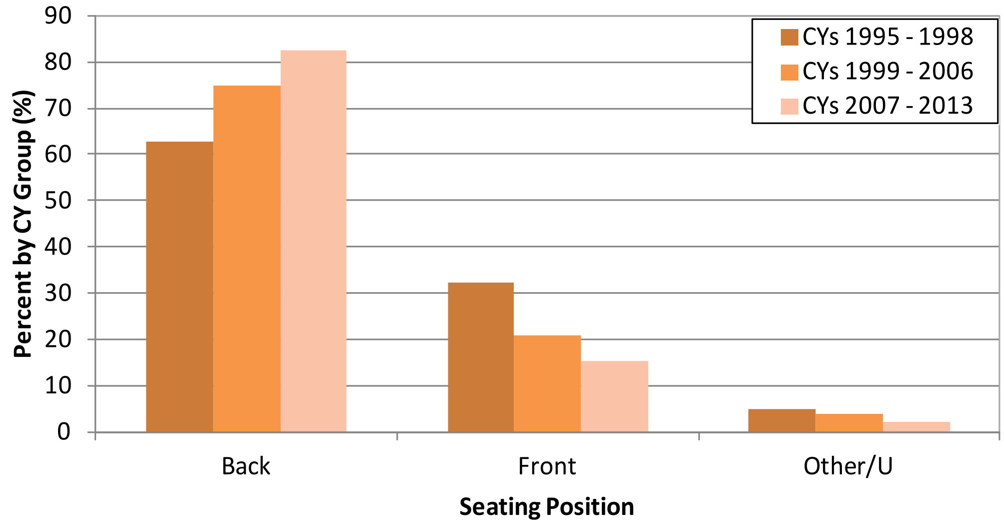

Figure 17. NASS-GES 1995 – 2013 Seat Position Exposure for Children 12 & Under

When the seating position of children fatally injured is analyzed by model year instead of calendar year, it appears that children are fatally injured more frequently in the back seat as model year increases and conversely less frequently in the front seat (Figure 18). The frequency of fatalities in the back seat by model year is larger than the calendar year generations indicate and again conversely lower for the front seat by calendar year generation, though this may again be explained by exposures.

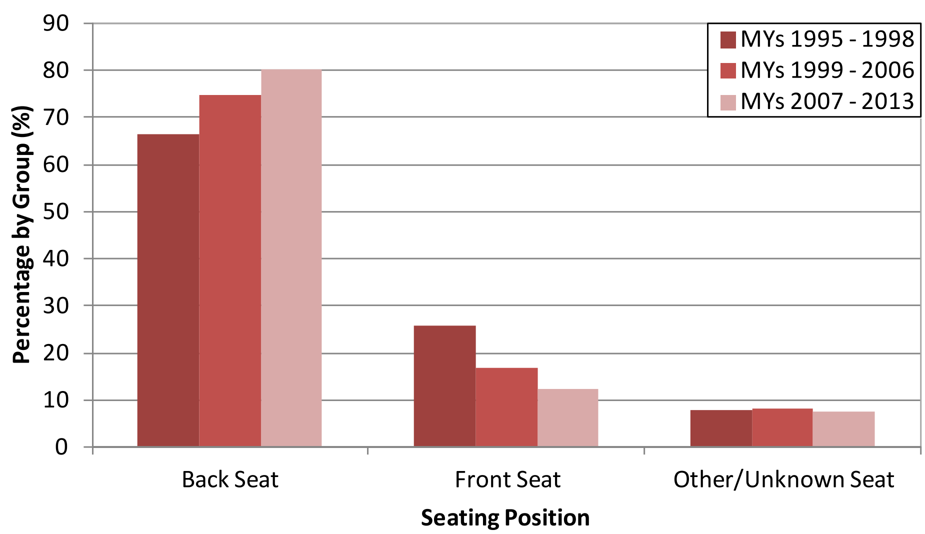

Figure 18. FARS 1995 – 2013 Fatalities by Seating Position for Children 12 & Under Limited to Model Years 1995 - 2013

As might be expected, when analyzed by model year, the exposure rates indicate that the increase in fatalities in the backseat amongst children can again be attributed to an increased exposure (Figure 19). The front seat again appears less benign especially for the earlier model year generations as the fatalities are by proportion larger than the exposure is for those groups. It should be noted that some NASS-GES cases included in the calendar year analysis did not have model year information which led to an excess of 7,000 weighted cases missing model year information. Since this can significantly affect the relative risk calculations, relative risk was calculated with respect to calendar year instead of model year.

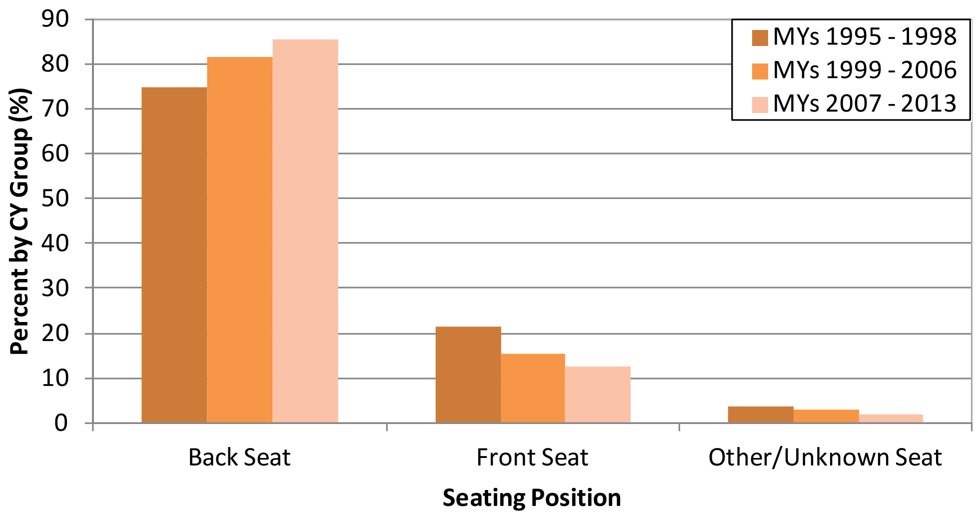

Figure 19. NASS-GES 1995 – 2013 Seat Position Exposure for Children 12 & Under Limited to Model Years 1995 - 2013

The fatality risks for the front and back seat were calculated for each year examined in the 19 year time period. From that analysis the relative risk for the front seat to the back seat was computed over time. If the relative risk is greater than one, the fatality risk in the front seat is greater than in the back seat. The fatality risk for the front seat and back seat per 100,000 exposures are plotted over time along with the relative risk in Figure 20. While the front seat fatality risk for children has decreased considerably over the 19 year time period, the relative risk has consistently remained greater than one. The back seat fatality risk for children has remained relatively constant over the period examined, with a general downward trend. While this data represents all children 12 and under, it would be useful to better understand the age distribution of children fatally injured and exposed to the front and back seats. In 2013, children had roughly a 20% higher risk of being fatally injured if they were seated in a front seat than if they were seated in a back seat during a crash. For some years this increased risk was greater than 60%.

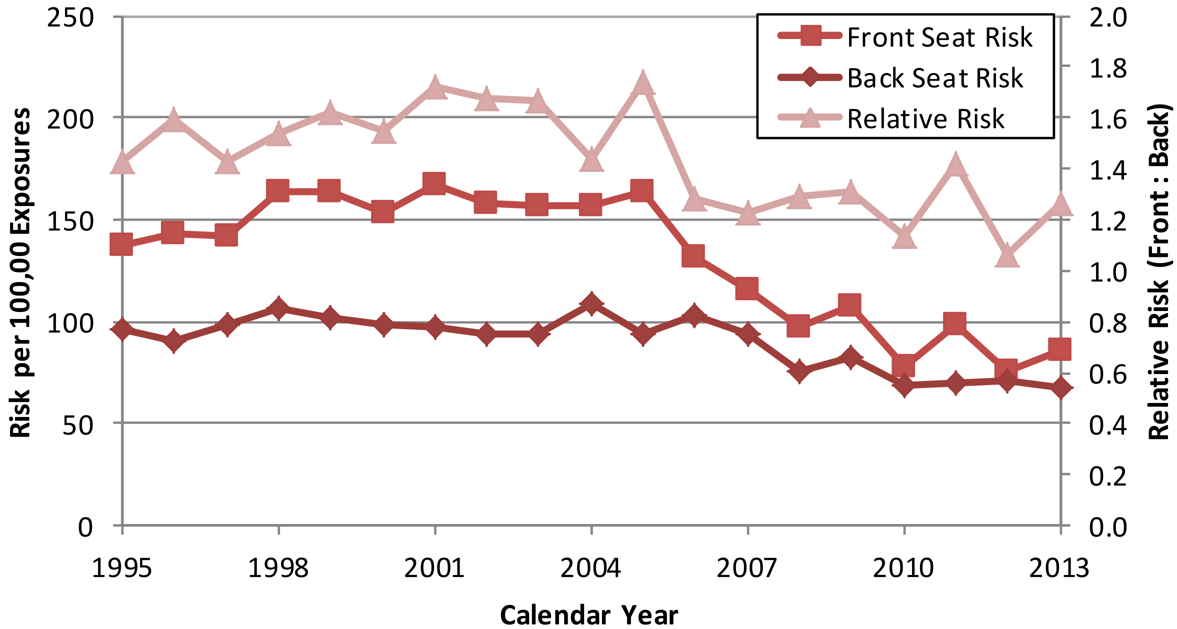

Figure 20. Risk per 100,000 Exposure's for Children 12 & Under Seated in the Front and Back Seats and Relative Fatality Risk Front Seat to Back Seat Over Time

Front seat child fatalities as a function of age are presented in Figure 21. This data highlights the elevated incidence of infant fatalities in the front seat during the late 90's. More than 10% of the children who died in the front seat in the years between 1995 and 1999 were infants (age 0); during this time more infants sustained fatal injuries in the front seat than any other age groups. The data shows that the percent of front seat fatalities for children aged 0 to 3 years old have decreased over time while front seat fatalities for older children, aged 8 to 12 years old, have increased over time. To investigate whether this is due to increased exposure the same analysis was performed using NASS-GES.

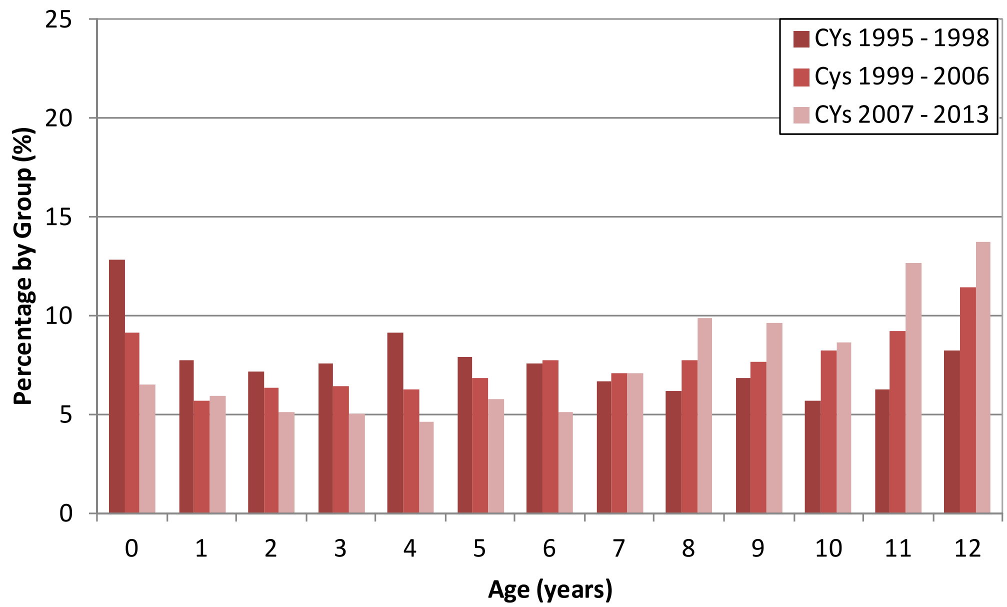

Figure 21. FARS 1995 – 2013 Front Seat Fatalities for Children 12 & Under by Age

The front seat exposure for children as a function of age (Figure 22) verifies that the incidence of older children sitting in the front seat is increasing. Of the children sitting in the front seat, for the latest calendar year group (2006 – 2013), over 20% of these children were 12 years old. From this analysis it appears that the fatality risk for 12 year old children sitting in the front seat is relatively low since the estimated exposure is higher than the fatalities for the same group. Further, NASS-GES estimated that 5% of the children exposed to crashes in the front seat from 1995 to 1999 were infants (age 0), indicating that the fatality risk for this group is particularly high compared to the other ages (1 – 12 years) during the same time frame.

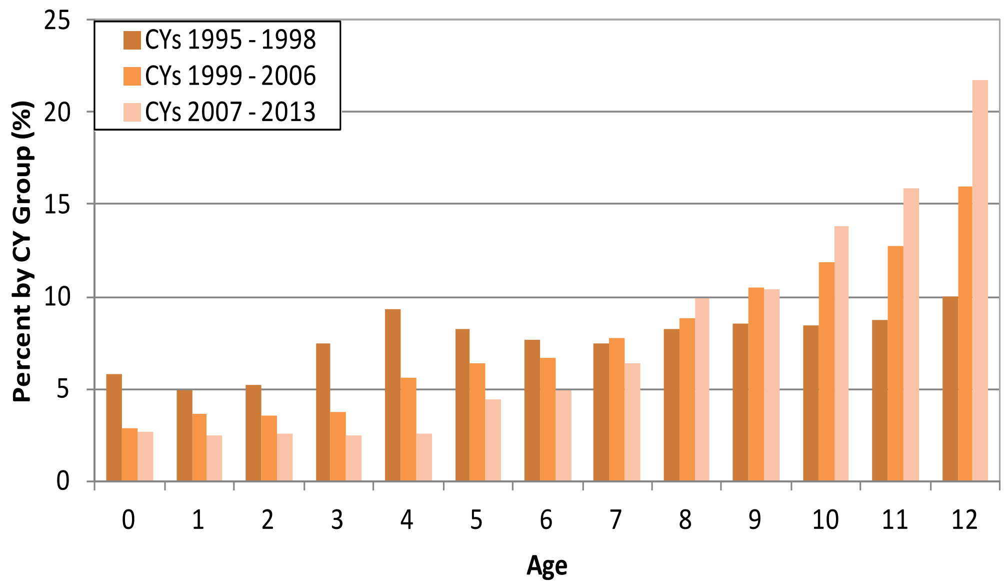

Figure 22. NASS-GES Front Seat Exposure for Children 12 & Under by Age

What about the back seat? Child fatalities in the back seat as a function of age over time are presented in Figure 23. Overall, it appears that fatally injured younger children were more likely to be seated in the back seat; as age increases the incidence of fatality decreases.

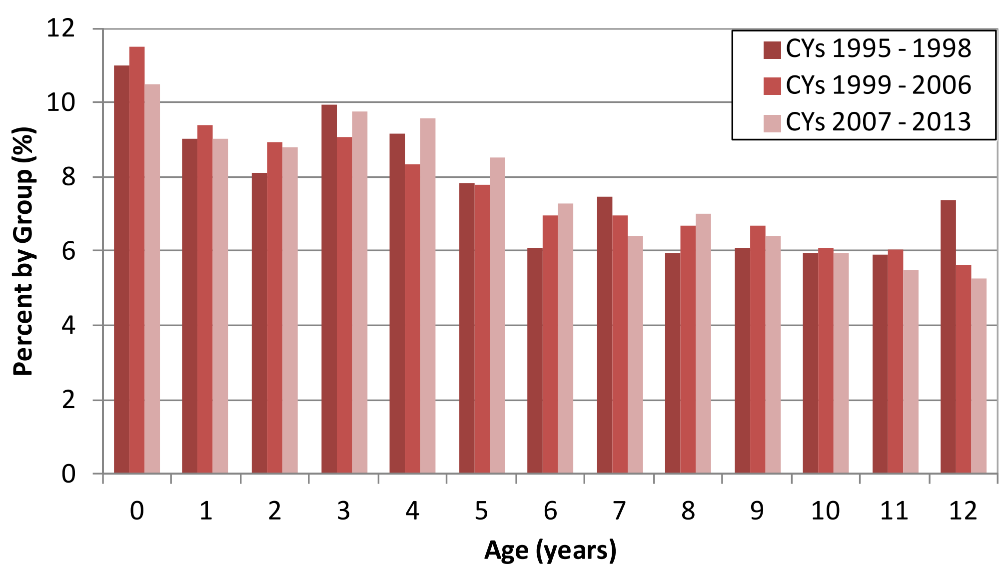

Figure 23. FARS 1995 – 2013 Back Seat Fatalities for Children 12 & Under by Age

The NASS-GES estimated back seat exposure for children as a function of age (Figure 24) verifies that the incidence of infants exposed to the back seat has also increased consistently from 1995 to 2013. As could be expected, more of the younger children are seated in the back seat than older children. However, it appears that the back seat exposure for infants, while increasing over time, is particularly low; this would indicate relatively high fatality risk in the back seat for infants as well. This could be due to any number of things including a lower injury tolerance or improper installation of, or restraint use within, child safety seats.

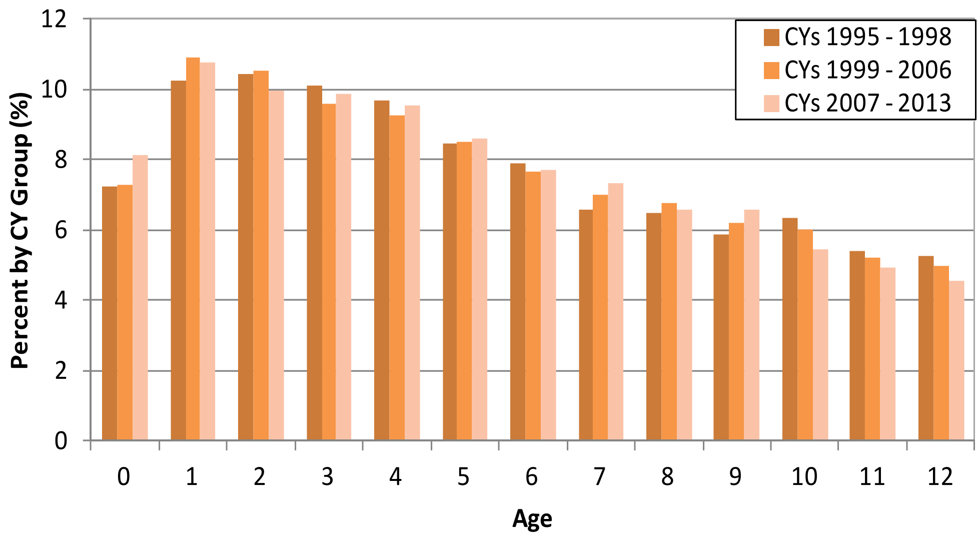

Figure 24. NASS-GES Back Seat Exposure for Children 12 & Under by Age

The relative risk for infants sitting in the front seat to the back seat over the 19 year period analyzed is consistently above unity, indicating that the front seat presents a higher fatality risk than the back seat. While there is no clear trend for this relative risk over time, as evidenced in Figure 25, the average relative risk between 1995 and 2013 is 3. Thus, infants were on average 3 times more likely to be fatally injured in the front seat than the back seat.

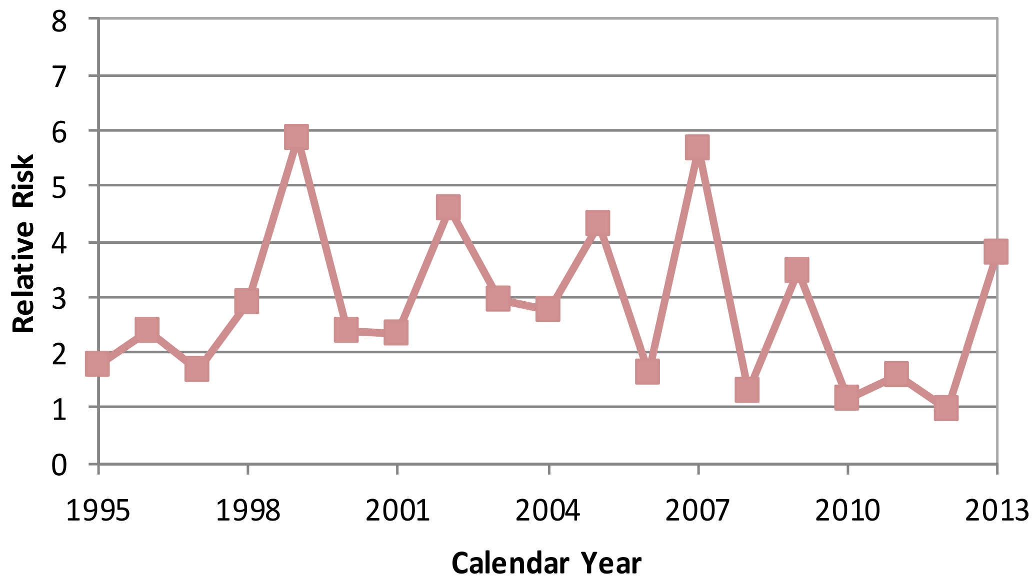

Figure 25. Relative Risk for Infants Seated in the Front Seat to the Back Seat Over Time

3.4.3 Fatalities by Age

To further examine child fatality trends by age, a bar graph of all child fatalities by age is presented in Figure 26. Alarmingly, the infant fatality frequency exceeds that of all other ages examined from 1 to 12 years old. This large fatality frequency among infants may be due to lower injury tolerance; or perhaps, it can be attributed to something that can be controlled and designed for, such as child safety seats specifically developed for infants. The NASS-GES exposure data can help provide some insight on the occurrence of these infant fatalities.

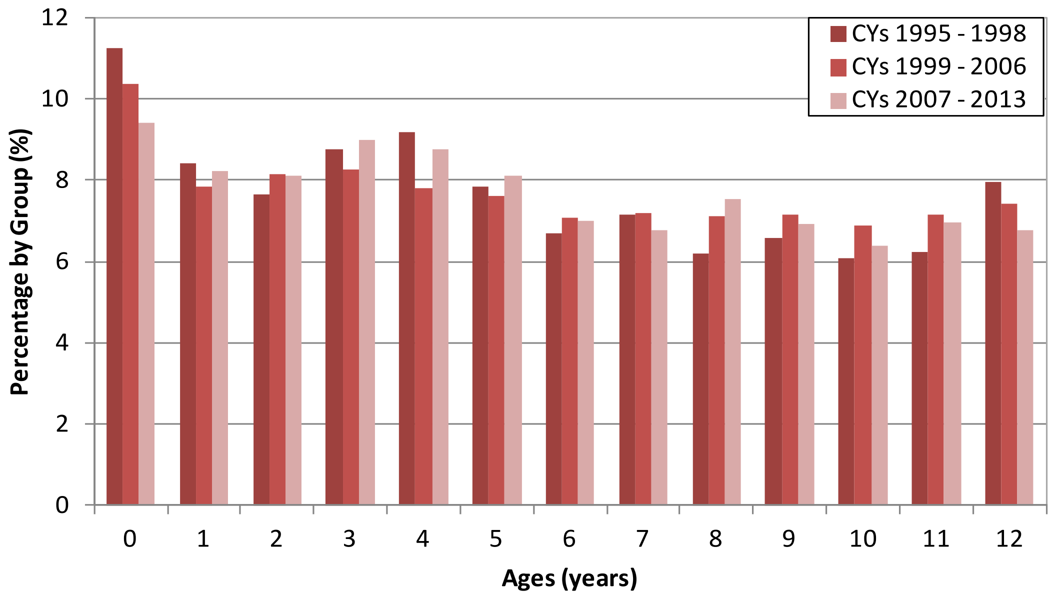

Figure 26. FARS 1995 – 2013 Fatalities by Age for Children 12 & Under

The NASS-GES estimated exposures for all children by age are presented in Figure 27. Sadly, NASS-GES estimates that exposures for infants are far lower than older children, indicating that infants are at much higher risk of fatality than older children when exposed to a vehicle crash. Conversely, the slight decrease in infant fatalities in the latest calendar year group (2007 – 2013) combined with the rise in infant exposure during that time period is encouraging.

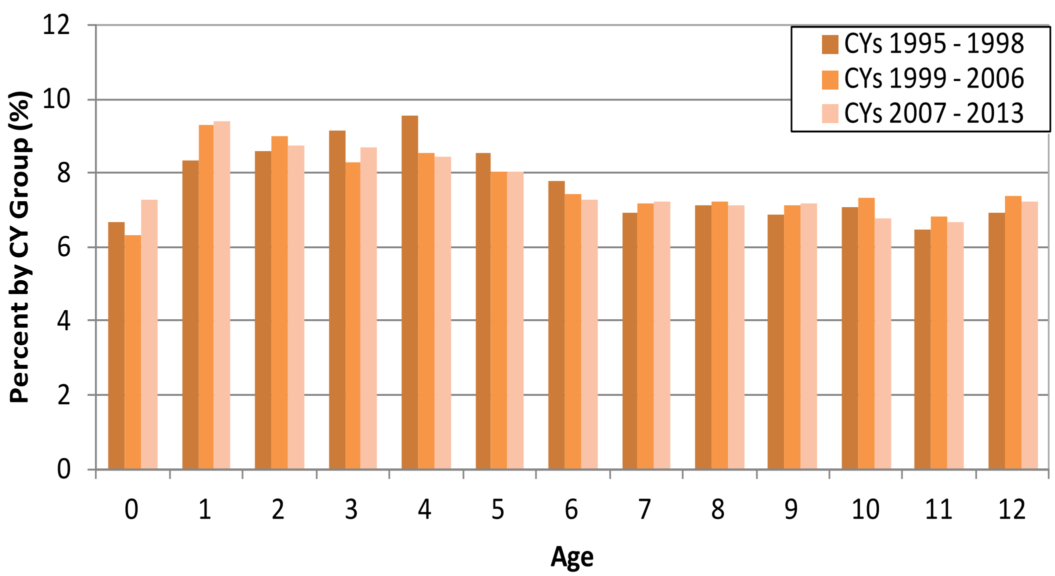

Figure 27. NASS-GES 1995 – 2013 Exposure by Age for Children 12 & Under

3.4.4 *FATALITIES BY RESTRAINT USE & TYPE*

Another factor affecting children's safety during car crashes is the use of restraints; this section will evaluate the influence of restraint type upon child fatalities. Restraints were grouped by general type, for instance child safety seat (CSS) which included forward facing child safety seats (FFCSS), rear facing child safety seats (RFCSS) and booster seats. Similarly, seat belts included shoulder only, lap only and shoulder and lap belts. Though the lap belt is the most effective portion of the seat belt, a few shoulder only coded cases exist within the dataset, it was a popular passive safety feature included in passenger vehicles in late 1990's model vehicles wherein the shoulder belt would automatically engage as the door closed [3], [48]. A bar graph providing the distribution of restraint use among child fatalities is shown in Figure 28. Most notably, the majority of the children fatally injured were unrestrained. However, it is encouraging that the frequency of child fatalities occurring while unrestrained has decreased over time. Conversely, it appears that child fatalities occurring while children are in CSS have increased over time, but it is likely that this increase can be attributed to an increase in CSS use.

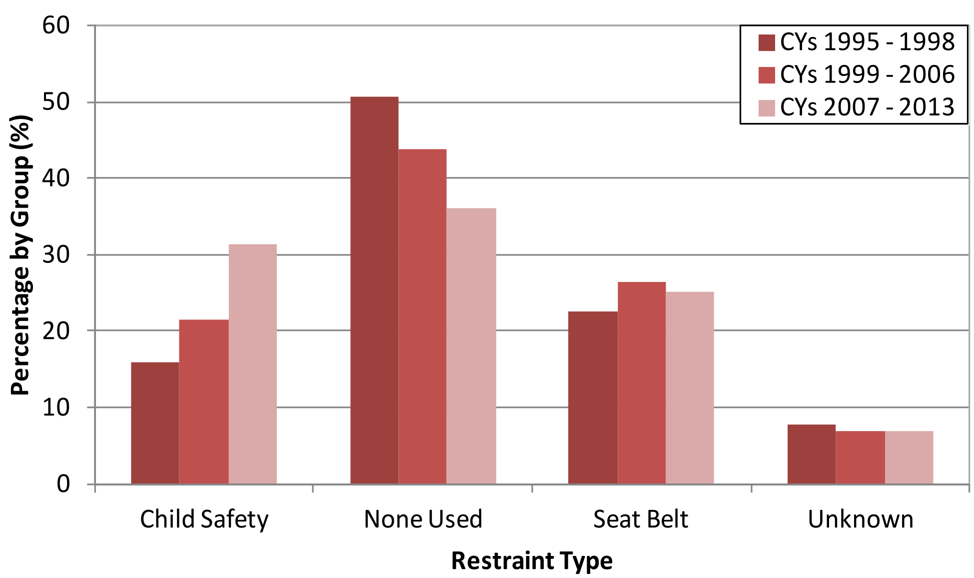

Figure 28. FARS 1995 – 2013 Fatalities by Restraint Type for Children 12 & Under

NASS-GES exposure estimates for children by restraint type (Figure 29) indicate that there are fewer children riding unrestrained – implying that it is considerably more likely that a child will sustain a fatal injury if travelling unrestrained. Conversely, there are more children riding in CSS and wearing seat belts than the FARS data would indicate which suggests that safety seats and seat belts are functioning as intended during crashes. Also the exposure estimates indicate a marked increase CSS use over time, as was predicted above during the FARS analysis. Children are estimated more frequently to be wearing seat belts or restrained in CSSs than they are fatally injured while using these restraint types indicating that the use of these restraints presents little to no specific fatality risk to children.

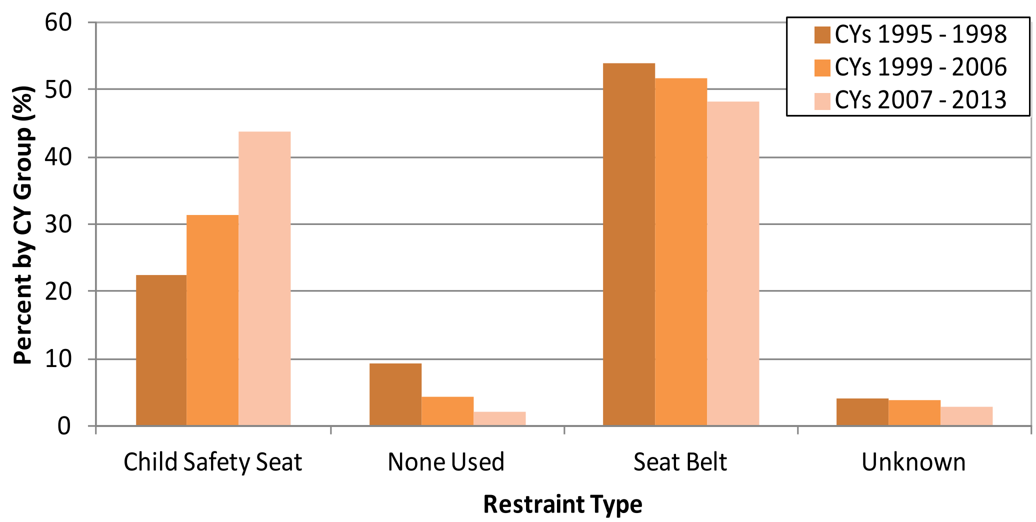

Figure 29. NASS-GES Restraint Type Exposure for Children 12 & Under

The relative risk for children unrestrained and restrained in child safety seats with respect to children wearing seatbelts over time is presented in Figure 30. Children restrained in child safety seats during the time examined are approximately at the same risk of being fatally injured in a crash as a child wearing a safety belt, but that is not to say that child safety seats could be replaced with seat belts. Age appropriate child safety seat use protects younger children whose heads are proportionally large and neck muscles are not fully developed more so than a seat belt. One reason that child safety seats may present a higher risk to children than seat belts could possibly be attributed to installation. Interestingly, from 1995 through 1998, the relative risk for children unrestrained in a vehicle crash was nearly constant around 12, but then began to rise fairly steadily until 2012 to nearly 40.

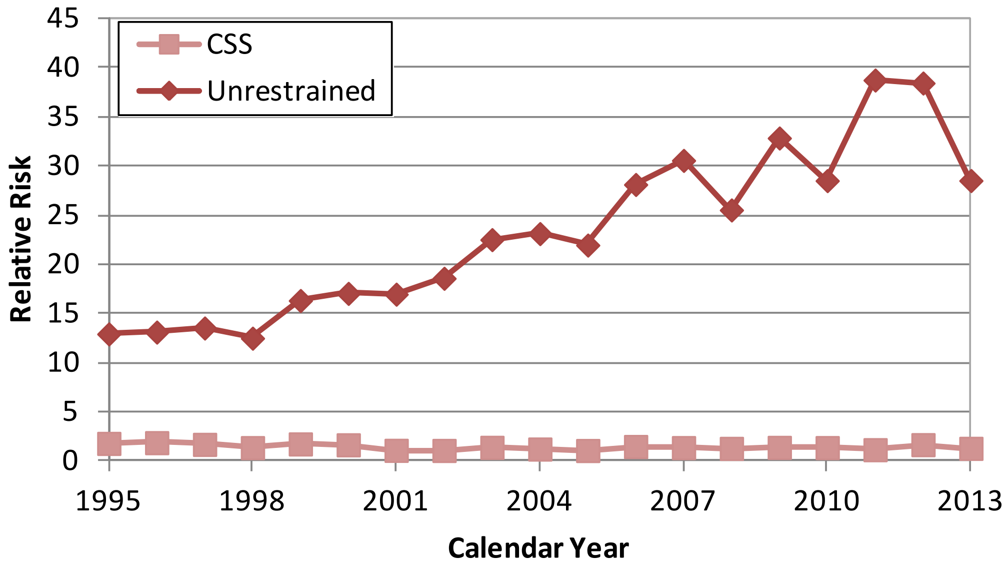

Figure 30. Relative Risk as a Function of Time for CSS and Unrestrained Children in Crashes with Respect to Children Wearing Seat Belts

3.4.5 FATALITIES BY VEHICLE TYPE

Different classes of vehicles can have very different impact responses to MVCs due to different masses, geometries, stiffnesses, crush characteristics and general energy absorption techniques. The discussion which follows evaluates the effect of vehicle type on risk of fatality. Child fatalities as a function of vehicle type, cars versus light trucks and vans (LTVs), are shown in Figure 31. The general trend for cars decreases over time, but for LTV's appears to increase, but as will be shown this is primarily the result of changes in exposure. The LTV group includes minivans which have become increasingly synonymous with family vehicles. Further, the LTV group also includes sport utility vehicles (SUV's) which have also become more popular during the past decade.

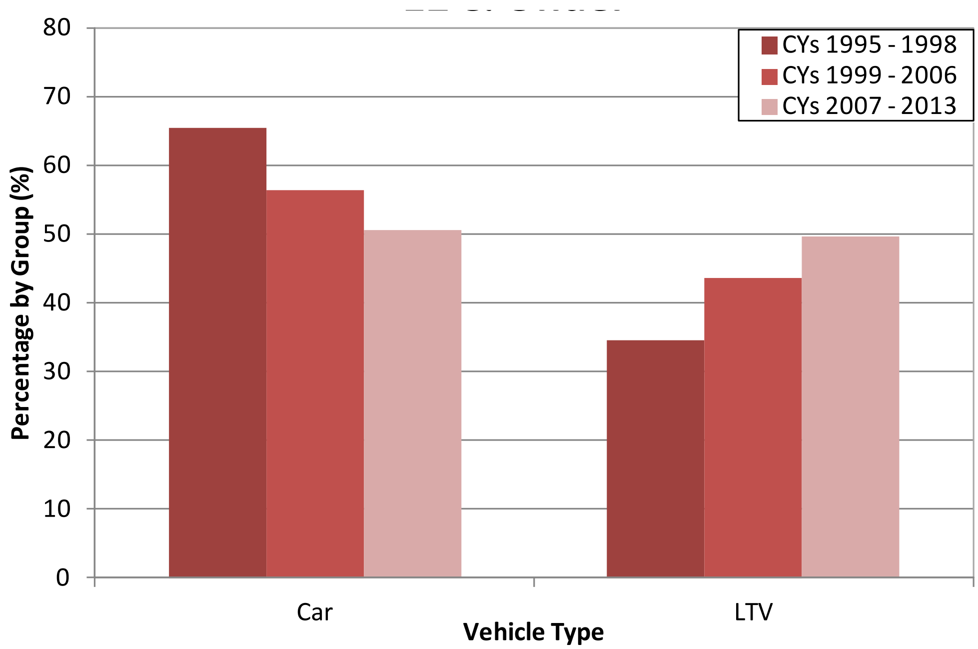

Figure 31. FARS 1995 – 2013 Fatalities by Vehicle Type for Children 12 & Under

Exposure estimates from NASS-GES also show similar trends over the 19 years for cars and LTVs as shown in Figure 32. In fact, the exposure trends are almost identical to those exhibited by child fatalities. From that it reasons that the fatality risk or relative risk for cars to LTV's is close to one, indicating that one vehicle type (as examined) does not provide a marked safety advantage over another.

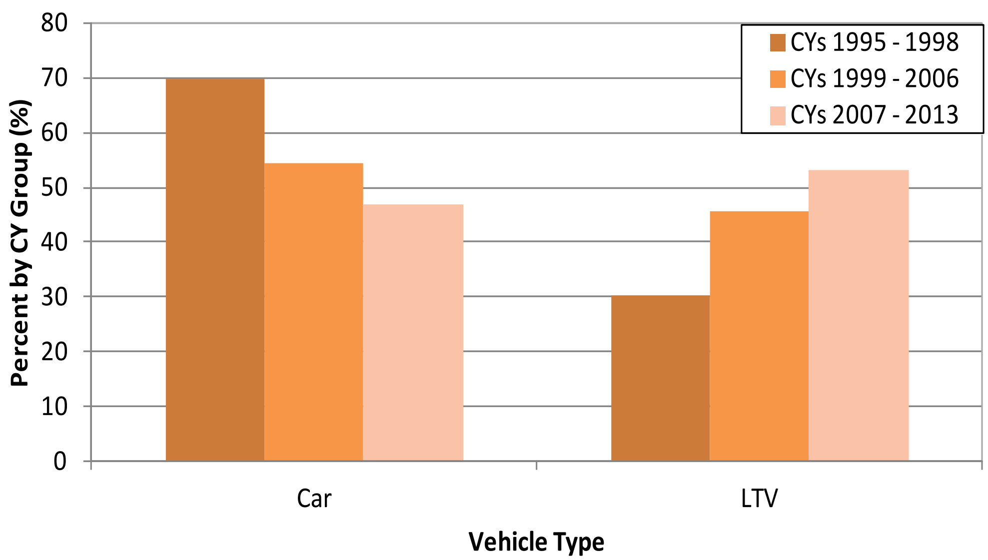

Figure 32. NASS-GES Vehicle Type Exposure for Children 12 & Under

To examine whether this trend was exclusive to children, the same analysis was performed for adults aged 25 to 65 years of age (Figure 32 & Figure 34). Both the adult fatalities and exposure were found to almost identical as well, indicating that the trends seen in the child fatalities and exposures are trends overall amongst all vehicle passengers.

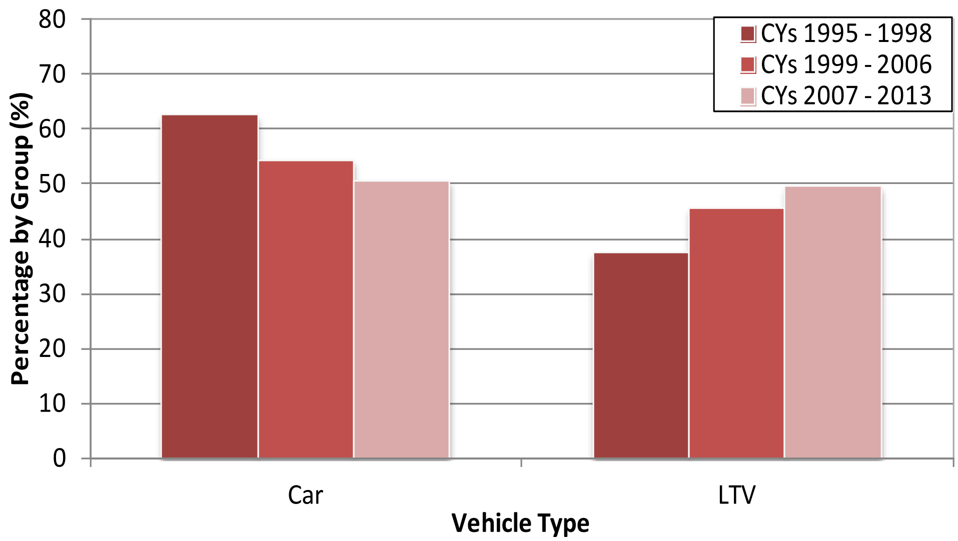

Figure 33. FARS 1995 – 2013 Fatalities by Vehicle Type for Adults Aged 25 – 65 Years Old

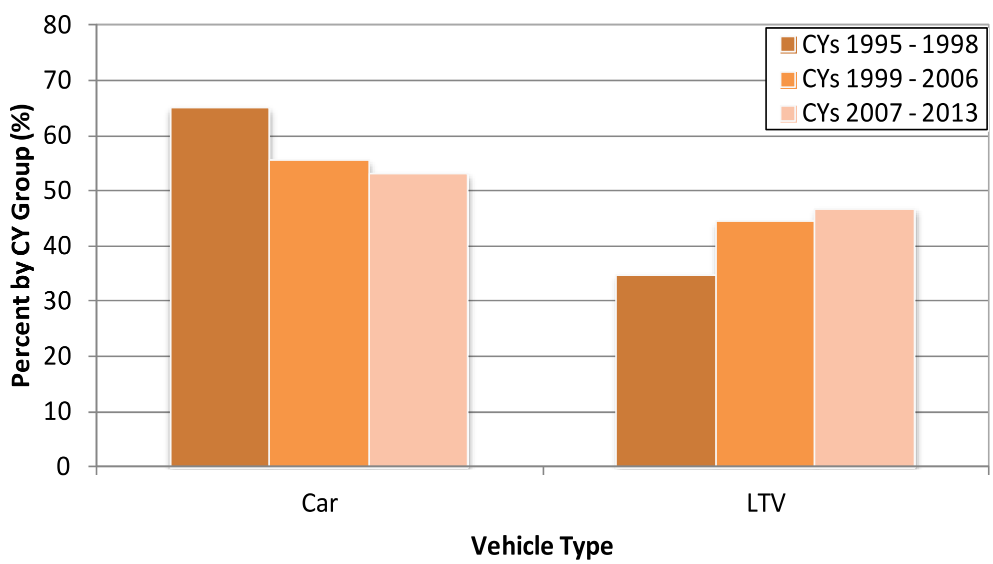

Figure 34. NASS – GES 1995 – 2013 Vehicle Type Exposure for Adults Aged 25 – 65 Years Old

Different trends were noted when the same analysis was performed by model year generation for both FARS and NASS-GES (Figure 35 & Figure 36). Though the trends are similar for both fatalities and exposures, it appears that later model year cars present a greater fatality risk to children as fatalities from this group represent nearly 70% of the children fatally injured in a later model year vehicle (Figure 35), but exposure estimates indicate that the exposure to cars and LTVs were nearly equivalent (Figure 36).

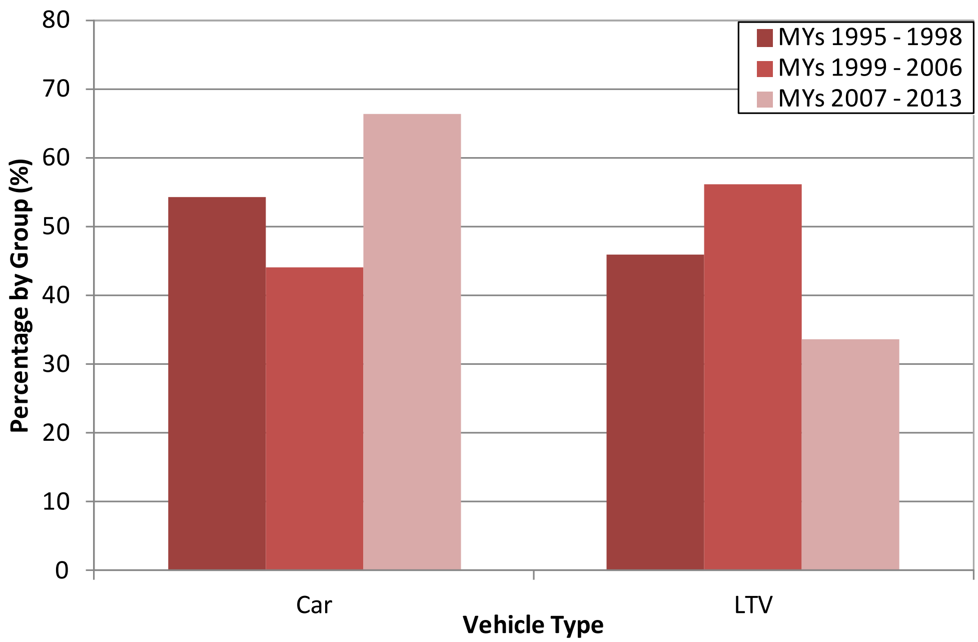

Figure 35. FARS 1995 – 2013 Fatalities by Vehicle Type for Children 12 & Under Limited to Model Years 1995 - 2013

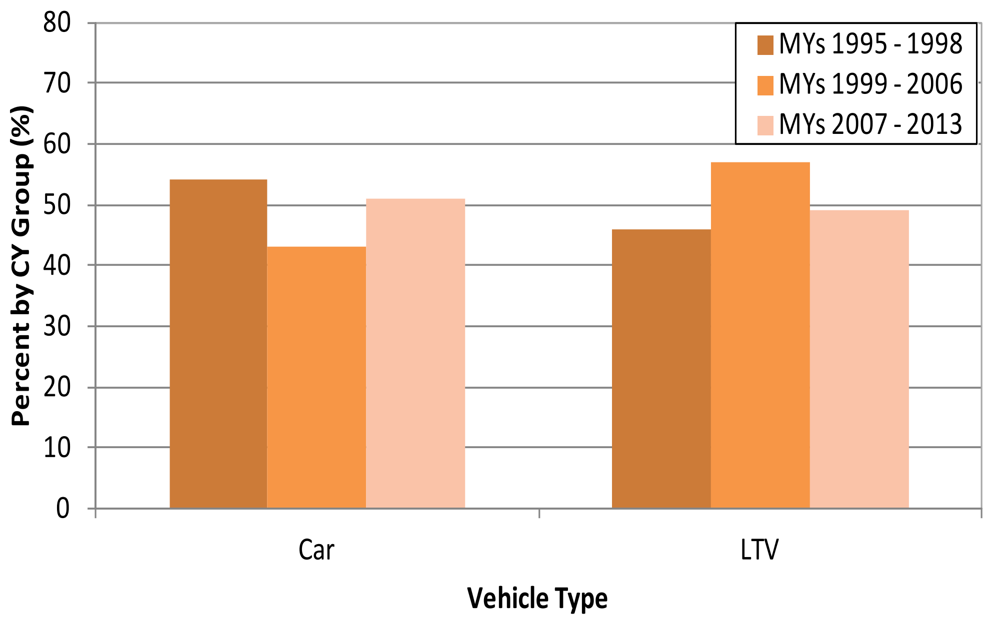

Figure 36. NASS-GES Vehicle Type Exposure for Children 12 & Under Limited to Model Years 1995- 2013

When analyzed with respect to time, the fatality risk to children as a result of riding in a car or an LTV reveals the same trend (Figure 37). In 1999, the fatality risk for children riding in a passenger car surpassed the fatality risk of riding in an LTV. As a result the relative risk for children riding in LTVs with respect to children riding in a passenger car is less than one throughout a majority of the time analyzed. This could be a result of a number of things including crash compatibility between cars and LTVs.

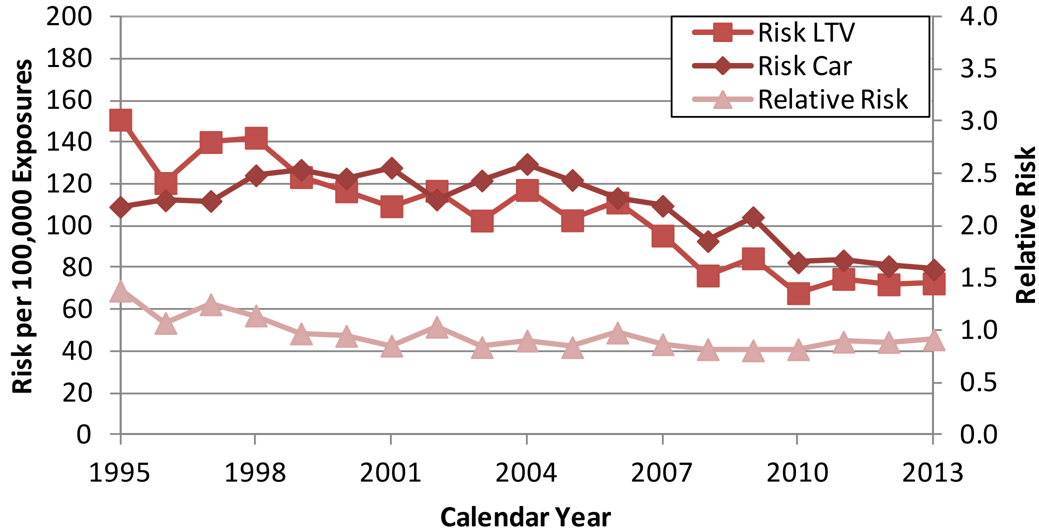

Figure 37. Risk and Relative Risk as a Function of Time for Vehicle Type, Relative Risk Presented is LTVs with Respect to Cars

3.5 Conclusions

In the US, child fatalities in traffic crashes decreased during the period from 1995 to 2013. These fatalities declined by 57% overall during the period of analysis. The number of fatalities for children 12 and under fell from 2,201 in 1995 to 939 in 2013. The percentage of fatally injured children decreased significantly from 8.8% during the years 1995 to 1999 to 6.1% for the years 2006 through 2013 – a positive trend. The number of children exposed to traffic crashes also declined during this period. To compare the fatalities and exposure, fatality risks were calculated for each of the 19 years examined. The fatality risks exhibited a downward trend as well; the fatality risk for all children decreased from 188 to 105 per 100,000 exposures over the 19 year period.

3.5.1 Effect of Crash Mode

Rollovers appear to present a very high risk of fatality to child passengers as the fatality frequency is close to 35% of all crash modes, but the exposure is much less than 5%. The relative risk for rollovers to frontal crashes between 1995 and 2007 was 16; meaning rollovers were about

16 times more deadly than frontal crashes during that period. During the period 2008 to 2013, the relative fatality risk for children involved in rollovers as compared to frontal crashes was 140, a significant increase. The crash mode fatality and exposure distributions for adults are nearly the same as for children. The increased rollover fatality risk due to rollovers is not restricted to children only; the relative risk for adults between 1995 and 2005 was 32 and it increased to 85 for the period between 2005 and 2013. This is understandable as there were few, if any, safety measures designed specifically for rollovers until recently and later model year vehicles were shown to have a lower fatality proportion as a result of rollover than previous model year groups. The second most fatal crash mode for children and adults was the frontal crash mode, which is the crash mode that frontal airbags are designed to provide protection from.

3.5.2 Effect of Seating Position

By comparing the FARS seating position data to the NASS-GES data, it is clear that children are more frequently fatally injured in the front seat than are exposed to the front seat. However, for the back seat the contrary is true. This indicates that the front seat presents a higher fatality risk than the back seat. While the front seat fatality risk for children has decreased considerably over the 19 year time period, the relative risk has consistently remained greater than one. The back seat fatality risk for children has remained relatively constant over the period examined, with a general downward trend.

More than 10% of the children who died in the front seat in the years between 1995 and 1999 were infants (age 0). During this time more infants sustained fatal injuries in the front seat than any other child age group. NASS-GES estimates show that 5% of the children riding in the front seat from 1995 to 1999 were infants (age 0). The fatality risk for this group was higher than all other examined ages (1 – 12 years) during the same time frame. The relative risk for infants sitting in the front seat to the back seat over the 19 year period analyzed was consistently above unity, indicating that the front seat presents a higher fatality risk than the back seat. While there is no clear trend for this relative risk over time the average relative risk between 1995 and 2013 is 3 – infants were 3 times more likely to be fatally injured in the front seat than the back seat.

Overall, it appears that younger children are more frequently fatally injured in the back seat; as age increases the risk of fatality decreases. But, as could be expected more of the younger children are seated in the back seat than older children. However, it appears that the back seat exposure for infants, while increasing over time, is particularly low; this would indicate relatively high fatality risk in the back seat for infants as well.

3.5.3 Effect of Age

Alarmingly, regardless of seating position, the infant fatality frequency exceeds that of all other ages examined from 1 to 12 years old. This could be due to their lower injury tolerance. To further examine the infant fatalities specifically, Figure 38 shows the restraint use among infants (age 0) fatally injured during the 19 year period. Infant fatalities resulting while restrained in a CSS and unrestrained have both decreased over time. Notably at the start of the analysis in 1995, fatalities among infants restrained in CSS and unrestrained were roughly equal, the unrestrained group of fatally injured infants decreased fairly consistently over time, this may be due to decreased exposure resulting from increased awareness following safety campaigns. However, the CSS group of fatally injured infants appears to have waxed and waned between 1995 and 2005, after which a general downward trend can be noted, though these are calendar years.

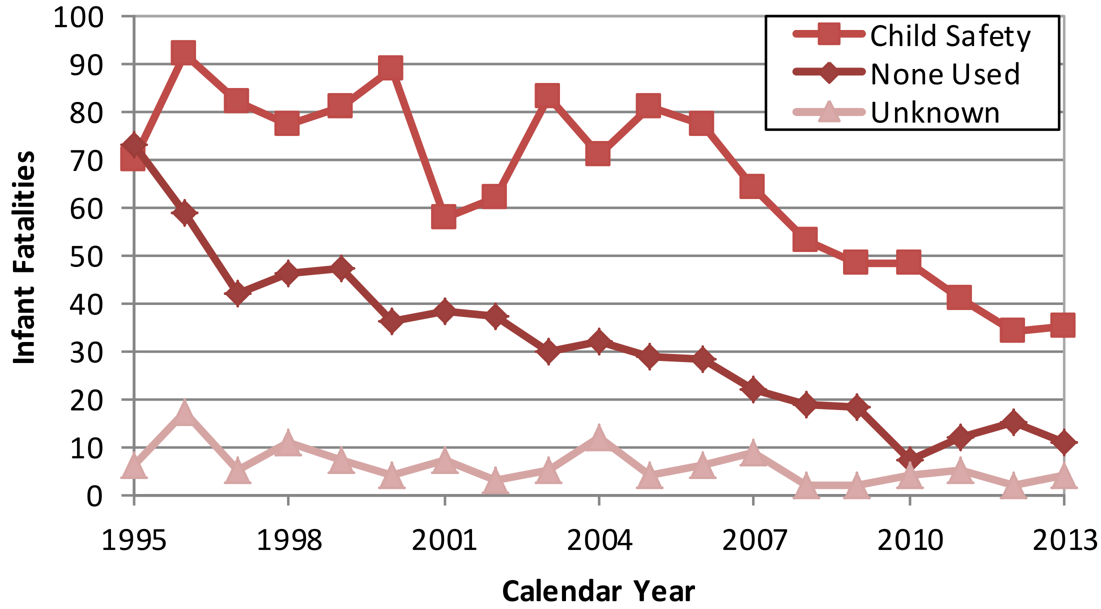

Figure 38. FARS Fatalities by Restraint Use for Infants (Age 0)

Yet another analysis performed to examine the FARS data for trends roughly correlated with the implementation of depowered airbags and advanced airbags looked at fatally injured infants by seating location (Figure 38). Infants fatally injured in the front seat sharply decreased after 1996 after which these numbers generally continued declining and have remained at or under 10 per year since 2008 again this is likely due to the decrease in exposure but could also have been impacted by the introduction of advanced airbags.

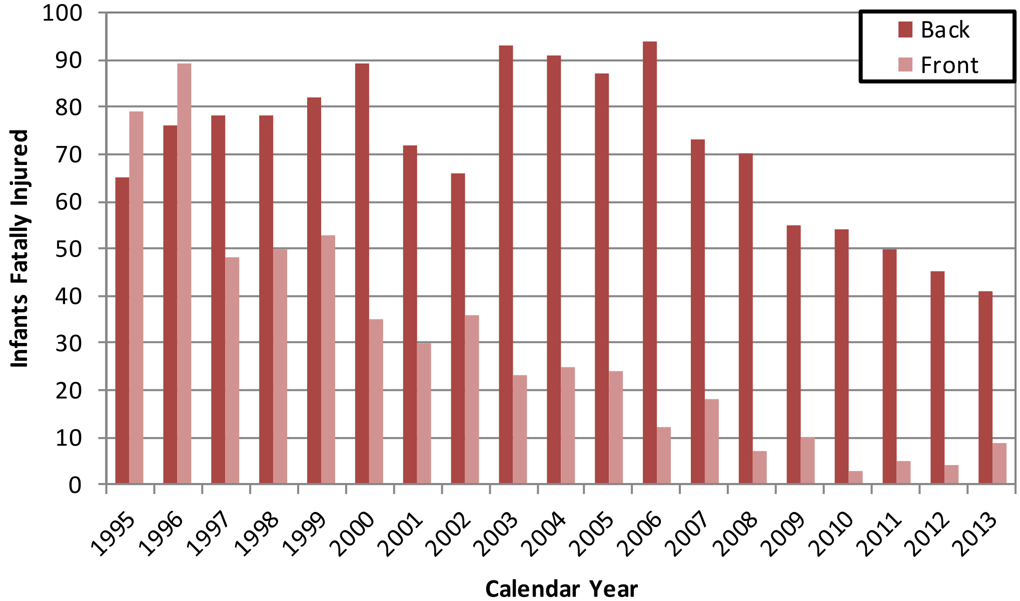

Figure 39. FARS Fatalities by Seating Position for Infants (Age 0)

3.5.4 *Effect of Restraint Use*

Most children who were fatally injured were unrestrained. However, it is encouraging that the frequency of child fatalities occurring while unrestrained has decreased over time. NASS-GES exposure estimates for children by restraint type indicate that there are fewer children riding unrestrained – implying that it is considerably more likely that a child will sustain a fatal injury if travelling unrestrained. Conversely, there are more children riding in CSS and wearing seat belts than in the past which indicates that restraint use is increasing.

3.5.5 *Effect of Vehicle Type*

Vehicle type does not seem to have a substantial influence on child fatality risk. Exposure estimates from NASS-GES also show similar trends over the 19 years for cars and LTVs. In fact, the exposure trends are almost identical to those exhibited by child fatalities. However, when analyzed with respect to model year generations and calendar year generations it was found that cars presented a higher risk of fatality than LTVs.

In conclusion, rollovers present a very large fatality risk to all occupants not just children, children riding in the front seat are at increased risk for fatality especially infants, infants regardless of seating position are at the highest risk of fatality of all children and finally, children riding unrestrained are at considerable risk of fatality. Overall fatality trends are decreasing among the child population despite the fact that adult fatalities have remained nearly constant over the 19 year period. This downward trend is encouraging, but the socio-economic burden of child fatalities as a result of an MVC is still large.

4 ARE ADVANCED AIRBAGS SAFER FOR CHILDREN IN THE RIGHT FRONT SEAT?

4.1 INTRODUCTION

This study examines the field crash performance of advanced airbags when children are seated in the front seat and the resulting injury outcomes.

4.2 METHODS

This study utilized the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) from 1995 to 2013 for children in the front seat of an airbag equipped vehicle involved in a frontal crash. NASS-CDS was used to compare injuries sustained in vehicles equipped with advanced airbag systems with injuries sustained in vehicles not equipped with advanced airbag systems.

Started in 1979, NASS-CDS is a stratified sample of crashes in the US wherein at least one passenger vehicle was towed. NASS-CDS investigates crashes at 24 primary sampling units (PSU) are located in different geographic regions within the US. Approximately 5,000 cases are selected each year from crashes involving at least one passenger vehicle wherein a vehicle was towed from the scene of the crash due to damage to the vehicle. Accidents involving late model year vehicles (the five most recent model years) are oversampled. NASS-CDS provides a weight for each crash selected to provide a nationally representative estimate of the number of similar crashes within the US each year.

Following selection of a case, NASS crash investigators examine the site of the crash for physical evidence such as skid marks or damage to roadside objects, the vehicle(s) as well as the occupants involved in the crash. From measurements of the physical damage to the vehicle, NASS investigators use an algorithm called WinSmash to compute or estimate the vehicle's change in velocity (delta-V) during the crash. Though the accuracy and effectiveness of WinSmash in certain trajectories have been called into question [49], [50], the estimates have been uniformly calculated and are sufficient for this analysis. NASS investigators also interview and review medical records of, the occupants involved in the crash to examine the nature and severity of the injuries sustained.

Injuries are described within NASS-CDS via the Abbreviated Injury Scale (AIS). The AIS is a method used to rank the threat to life for an injury on a scale from 1 (minor) to 6 (unsurvivable) as outlined in Table 8 in nine anatomical body regions. The AIS is widely used in trauma registries and provides standardized vocabulary and numerical methods for injury scoring. For this analysis, injury severity was classified using the maximum AIS (MAIS) injury score sustained by each occupant. Further, the MAIS was adjusted so that occupants fatally injured received an MAIS of 6 regardless of the MAIS of their individual injuries. Additionally, injuries were classified by body region, i.e. head, neck, face, spine, abdomen, upper extremities, and lower extremities.

Table 8. Abbreviated Injury Scale

AIS Level	***Threat to Life***
0	No Injury
1	Minor Injury
2	Moderate Injury
3	Serious Injury
4	Severe Injury
5	Critical Injury
6	Fatal (Unsurvivable) Injury

To examine crashes involving children in the right front passenger (RFP) seat who may be exposed to a deploying airbag, NASS-CDS cases were selected which met the following conditions:

- Child (Age < 13) passengers in the right front passenger seat,
- Passenger car or light trucks/vans,
- Frontal crashes,
- Excluding rollover crashes,
- Known injury severity,
- Model year ≥ 1980,

Frontal crashes were selected via the general area of damage (GAD1) variable. Since rollovers are complex and present a high risk of injury (as evidenced by the high fatality risk associated with rollover accidents noted within the characteristics analysis) cases where a rollover occurred were excluded. Only cases with known injury severity were included as this was the primary metric of interest. Further, because the availability of automobile safety equipment varies by model year, vehicles older than 1980 were excluded from the dataset. Weighting was applied to provide a nationally representative sample.

4.2.1 Statistical Analysis Methods

A comparison between airbag generations was based upon the odds of injury, as shown in Equation 3, where the probability (P) of injury for a given body region was expressed as the percentage of injured cases in a total number of known cases, as calculated in Equation 4. The odds ratios were used to compare the odds of injury during a critical event to a reference event, as shown in Equation 5.

In order to include the effect of several covariates, odds ratios were calculated using a logistic regression model within SAS called SurveyLogistic which calculated the odds ratios and their associated confidence limits.

$$Odds = \frac{P}{1-P}$$ **Equation 3**

$$P = \frac{Number\ of\ cases\ at\ a\ certain\ severity}{Total\ number\ of\ known\ cases}$$ **Equation 4**

$$Odds\ Ratio = \frac{Odds\ of\ Injury\ for\ Critical\ Event}{Odds\ of\ Injury\ for\ Reference\ Event}$$ **Equation 5**

The probability of an event occurring can be estimated using a logistic regression model. Given a dependent variable, a logistic regression predicts the outcome of a categorical variable, such as injury severity (MAIS 2+ or not), as shown in Equation 6 where β_N is the coefficient estimate which describes the effect of factors, such as passenger restraint use, occupant weight and vehicle delta-V, upon odds of injury. Similar to the calculation of odds, β_N is the coefficient estimate which describes the effect of the relevant covariates.

$$Probability\ of\ Occurence = \frac{1}{1 + e^{-(\beta 0 + \beta 1 * Factor1 + \ldots \beta N * FactorN)}} \qquad \textbf{Equation 6}$$

4.2.2 *ADVANCED AIRBAG STRATEGIES*

With data provided by manufacturers to and made publicly available by NHTSA, the certified deployment strategies for make and models between model year 2005 and 2012 were classified using the MAKMOD variable which specifically identifies a vehicles make and model in NASS-CDS. The strategies for all vehicles included are included in the Appendices in Table 19. Since the manufacturer's had to certify a strategy, either suppression or low risk deployment (LRD) for each of three occupant classes, the 1, 3 and 6 year old, the strategies are described by 'S' or 'L' for suppression and low risk deployment respectively. The 'S' and 'L' were then concatenated such that the first letter represents the strategy for the one year old and the final letter in the string represents the strategy for the six year old. For example, a vehicle whose deployment strategy is suppression for all certifying occupant classes, the strategy was noted as SSS. In cases where the deployment strategy was reported for one model year and not reported for a subsequent year, the deployment strategy was assumed to be the same as the prior year. In total, strategies were identified for 357 different make-model combinations. On average each model year included 213 unique vehicles.

Within the 2005 model year, Mercedes Benz employed a technology called "Babysmart," in lieu of suppression or low risk deployment, which is denoted with a 'B.' The Babysmart technology consisted of an antenna within the RFP seat that could detect Mercedes Benz Babysmart child safety seats (CSS). The Mercedes Benz Babysmart CSS also contained electronics within the base that would indicate to the receiver in the RFP seat that a Babysmart child seat was installed and as a result suppress the airbag. If a non-Babysmart CSS was placed on the RFP seat of a Babysmart equipped vehicle, the driver could manually switch the airbag off and thus suppress the airbag; however, a problem with this method is that it is not automatic and is susceptible to human error.

Further, due to the MAKMOD variable not having the resolution to discern between engine or trim types, cases where the deployment strategy varied by engine or trim level were excluded to prevent misclassification, these vehicles are listed in the table as having conflicting strategies. In particular, all model years of the Chevrolet C/K-series (Silverado) and GMC C/K-series (Savanna) pickup trucks were excluded since their strategy varied by engine type. Also excluded were the Hyundai Elantra (MYs 2011-2012) and Hyundai Genesis (MYs 2010 - 2012) as their deployment strategies varied by trim/vehicle configuration. Finally, though several Bentley models reported a deployment strategy to NHTSA in 2007, the MAKMOD variable did not allow enough resolution alone to differentiate between the different models and the deployment strategy varied between all suppression and mixed methods (suppression and LRD). As a result these vehicles were also considered conflicting in the table for model years 2007 - 2011, when all Bentley models reported having SLL strategy.

4.2.3 Airbag Generation Classification

Right front passenger airbags were classified into generations by the model year, make and model of each vehicle included in the study. The vehicle identification number (VIN) was used to determine whether a vehicle was equipped with a first generation airbag or not via a VIN decoding algorithm developed by C. Kahane of NHTSA to determine the restraints in vehicles model year 2006 and earlier. Vehicles were classified as having first generation airbags if they had “dual airbags,” meaning that they were equipped with both driver and passenger airbags. Since passenger (frontal) airbags were still being phased-in when FMVSS 208 was revised to include depowered (second generation) and subsequently advanced airbags, some vehicles in the dataset were equipped with driver airbags, but not passenger airbags, these cases were classified in the 'None' category; hence 'None' indicates that the vehicle was not equipped with an airbag for the RFP. For model years 1999 through 2006, all vehicles were assumed to have second generation airbags unless they were classified as having advanced airbags. Some vehicles were equipped with advanced airbags as early as 2003. Thus, between 2003 and 2006 model years, advanced airbags were determined via an IIHS report [51] and NHTSA's safety equipment list [52]. The list of all vehicles with advanced airbags and the year they were certified advanced are presented in the Appendices in Table 20. Vehicles manufactured after model year 2007 (on or after September 1, 2006) were automatically classified as being equipped with advanced airbags. The number of cases in each generation and a summary of how generations were determined are outlined in Table 9.

Table 9. Distribution of NASS/CDS Cases by Airbag Generation Outlining How Each Designation was Determined

RFP Airbag Generation	Model Years	Determined By	Cases
None	Before 1998	VIN	496
1st	Before 1999	VIN	221
2nd	1999 - 2003+	Assumed from 1999 Until Advanced	220
Advanced	2003 - 2013+	Make & Model Data	98

4.3 RESULTS

An overview of the resultant NASS-CDS dataset is presented in Table 10 which provides the raw number of cases (not weighted) and weighted number of cases by injury, sex, deployment, restraint usage, and vehicle type. Promisingly, though there were 98 unweighted cases involving an advanced airbag in the study, a large proportion of those cases presented without injury, further, there were no serious injuries (AIS 3+) in that group. It should be noted that because the two injury levels listed are inclusive, the AIS 2+ category includes all AIS 3+ injuries and as a result the sum of the injury levels will exceed the total number of cases in each group. The odds of a child being moderately injured (AIS 2+) in a crash were lower in vehicles equipped with advanced airbags

(0.0165) compared to: second generation (0.0271), first generation (0.0525) and those not equipped with passenger airbags (0.0410). This does not control for seat belt or child seat use or deployment and it is likely that increased restraint use, increased safety features in newer vehicles and the trend for older children being seated in the RFP seat all have an effect on the decrease in moderate injury odds. For all airbag groups the number of males and females were roughly equal.

Within the first and second generation airbag groups, there were cases where the only the driver bag deployed, in these cases the airbag was switched off. Interestingly, for the advanced airbag group, the driver airbag solely deployed in roughly one quarter of the cases and both airbags deployed in roughly half of the cases. As airbags advanced from one generation to the next, the number of unrestrained children also decreased, as noted earlier we know that this is likely an attribute of cultural changes in the US, not an indication of cause and effect on children in crashes.

Finally, for the period of analysis, the proportion of children in cars and LTVs has varied by airbag generation as shown in Table 11 showing a decline from mostly passenger cars in vehicles not equipped with passenger airbags to 50/50 for vehicles with advanced airbags. However, as described earlier in Chapter 3 the exposures (by model year thus aligning with airbag generations) were nearly 50/50 for cars and LTVs for all generations. This may indicate that cars were more likely to be involved in tow-away crashes.

Table 10. Overview of NASS/CDS Cases Showing Unweighted & Weighted Case Counts by Airbag Generation & Varying Demographics

	No Airbag		***1st Gen***		***2nd Gen***		***Advanced***		***Total***	
	Not Weighted	***Weighted***	***Not Weighted***	***Weighted***	***Not Weighted***	***Weighted***	***Not Weighted***	***Weighted***	***Not Weighted***	***Weighted***
Exposed	**496**	***272,583***	**221**	***102,058***	**220**	***88,016***	**98**	***35,396***	**1,035**	***498,054***
No Injury	404	*261,858*	177	*96,965*	198	*85,686*	95	*34,821*	874	*479,330*
AIS2+	92	*10,725*	44	*5,093*	22	*2,330*	3	*575*	161	*18,723*
AIS3+	46	*5,320*	21	*2,559*	9	*565*	0	*0*	76	*8,443*
Sex	**496**	***272,583***	**221**	***102,058***	**220**	***88,016***	**98**	***35,396***	**1,035**	***498,054***
Male	247	*128,959*	120	*46,773*	111	*44,115*	42	*18,923*	520	*238,771*
Female	248	*137,881*	101	*55,285*	109	*43,901*	56	*16,473*	514	*253,540*
Deployment	**496**	***272,583***	**221**	***102,058***	**220**	***88,016***	**98**	***35,396***	**1,035**	***498,054***
No Bags	384	*182,525*	35	*45,538*	75	*50,554*	28	*11,108*	522	*289,725*
Both Bags	0	*0*	180	*56,334*	143	*37,311*	47	*15,035*	370	*108,680*
Just Driver	112	*90,059*	3	*93*	1	*13*	23	*9,253*	139	*99,418*
Restraint Use	**496**	***272,583***	**221**	***102,058***	**220**	***88,016***	**98**	***35,396***	**1,035**	***498,054***
Belt Use	277	155,131	176	86,754	187	71,040	87	32,906	727	*345,831*
CSS	54	46,791	16	8,846	7	12,393	3	1,490	80	*69,521*
None Used	161	70,412	26	6,395	22	4,116	7	570	216	*81,493*
Vehicle Type	**496**	**272,583**	**221**	**102,058**	**220**	**88,016**	**98**	**35,396**	**1,035**	***498,054***
Car	320	208,729	161	65,989	126	49,409	52	20,264	659	*344,391*
LTV	176	63,855	60	36,069	94	38,607	46	15,132	376	*153,663*

Further characteristics of the cases included in the dataset are shown in Table 11 by airbag generation. The average age and weight of a child in front of an airbag has increased between the airbag generations while the mode has remained constant for all airbag generations. Interestingly, the most common age of a child in the RFP seat in vehicles not equipped with airbags was considerably lower (roughly 50%) than the most common age of a child seated in the same location within a vehicle equipped with any airbag. Additionally, along those same lines, the most common weight of a child seated in the RFP in a vehicle not equipped with an airbag was roughly one-third lighter than the most common weight of a child seated in the same location in a vehicle with equipped with any generation airbag. Importantly, the children seated in the RFP seat for all airbag generations most commonly weighed 45 kilograms (nearly 100 pounds), for reference, a 5^{th} percentile female adult weighs 48.9 kilograms (~108 pounds).

Most vehicles included in the study which were not equipped with an airbag were involved in crashes occurring in calendar year 1995. As the US fleet changed to include the current generation of airbags, most of the crashes involving cars equipped with first generation airbags occurred in 1998, the second generation group peaked in 2004 and for the advanced airbag group was 2011 (within the period evaluated). It should be noted that these statistics are true for the dataset evaluated, that is, in cases where there was a child in the RFP seat and was involved in a frontal crash. The average and mode of the model year is also outlined for the different airbag generations (Table 11). As time goes on the fleet will have proportionally more vehicles equipped with advanced airbags and the average model year for that group is expected to increase.

Table 11. Descriptive Demographics of Occupants/Vehicles in the NASS/CDS Dataset (Not Weighted)

	No Airbag	*1st Gen*	*2nd Gen*	*Advanced*
Age	*Years Old*			
Mean	7.2	7.9	9.3	9.9
Mode	6	12	12	12
Weight	*Kilograms*			
Mean	31.2	34.6	39.4	42.0
Mode	27	45	45	45
Case Year	*Calendar Year*			
Mode	1995	1998	2004	2011
Model	*Year*			
Mean	1990	1996	2002	2008
Mode	1993	1995	2002	2007

To better visualize the proportional differences of injuries by airbag generation, a stacked bar plot is presented in Figure 40. Again, the first generation airbag group has the lowest proportion without injury. The advanced airbag group is the only group without any MAIS 3+ injuries.

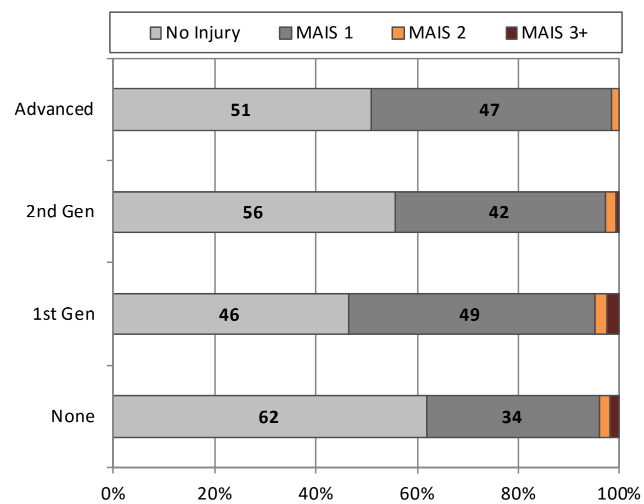

Figure 40. Stacked Bar Plot of Weighted MAIS Injuries by Airbag Generation

Weighting the data provides a nationally representative sample, but does not necessarily increase the proportions equally as noted earlier with the airbag generation. The weighted distribution of each MAIS by airbag generation is provided in Figure 41.

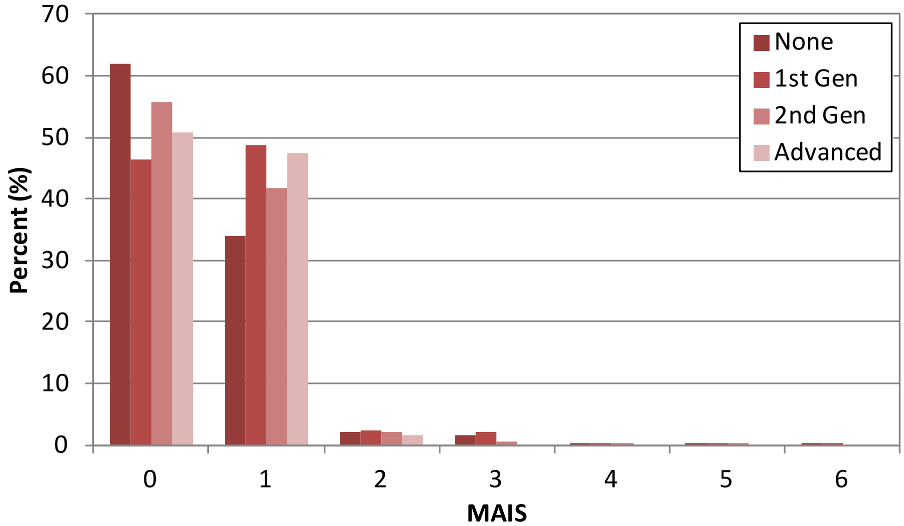

Figure 41. Distribution of MAIS by Airbag Generation (Weighted)

When weighted, deployment frequency changed dramatically for first and second generation airbags trending toward a 50/50 split (Figure 42). This seems reasonable as a nationally representative sample as less severe crashes are more prevalent than NASS-CDS would indicate given the cases within NASS-CDS are limited to those where at least one vehicle was towed due to damage from the crash. This distribution does not control for belt use or delta-V.

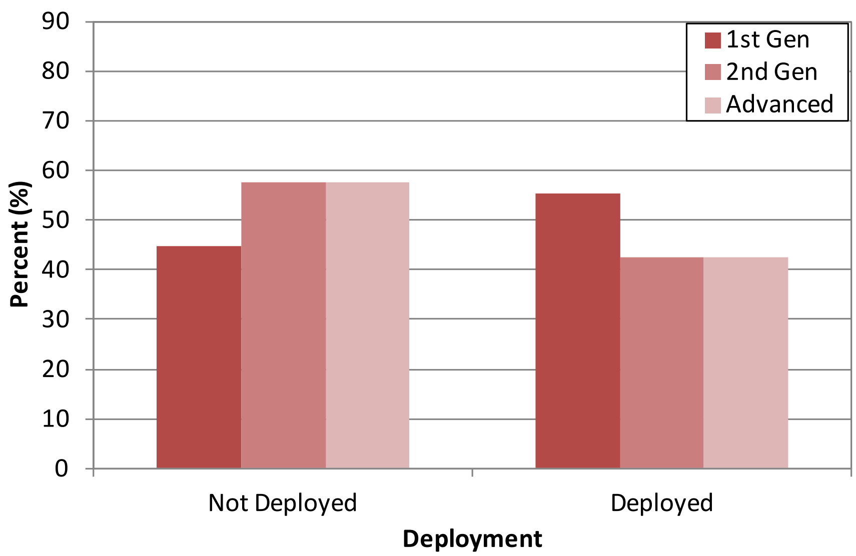

Figure 42. Distribution of Passenger Airbag Deployments by Airbag Generation (Weighted)

To examine whether the airbag deployments varied for passengers compared to that for the driver, the distribution of passenger and driver deployments were analyzed (Figure 43). Because the airbag generation was determined by the passenger airbag, there were cases where there was a driver airbag which deployed in the accident, but the passenger side was not equipped with an airbag. When weighted, this was true for nearly 30% of the cases categorized as not having an airbag as shown in Figure 43. First generation airbags were estimated to deploy more often than they did not; this aligns with cases examined by Special Crash Investigations (SCI) as outlined in the introduction chapter of this work where first generation bags were found to deploy during low-severity crashes. Second generation bags are estimated to more frequently not deploy than deploy in a crash. But this does not control for delta-V, so it is possible that as a result of the changes made in developing second generation airbags that airbags were less likely to deploy during lower severity crashes. Similarly, in roughly 30% of the weighted advanced airbag crashes included in the study the airbag did not deploy for either the driver or passenger; however when the driver airbag did deploy (~70% of the cases), the airbag was estimated to suppress for the passenger in roughly 25% of the cases.

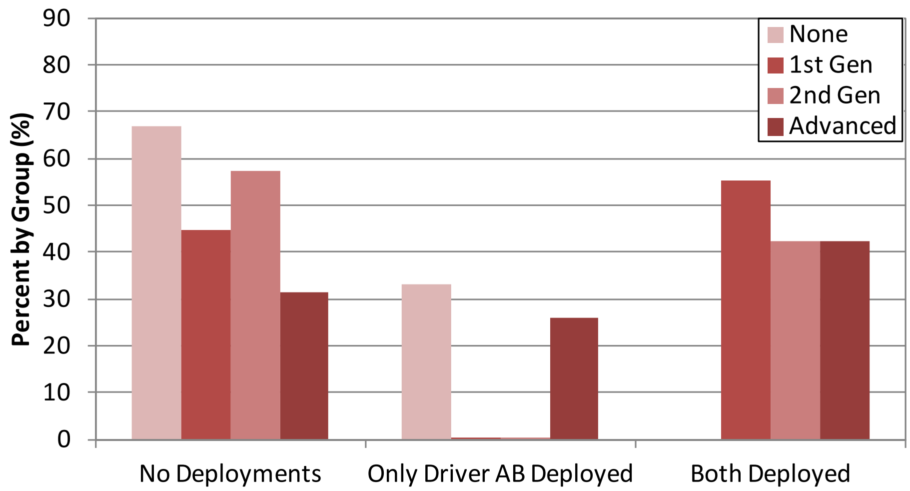

Figure 43. Passenger & Driver Airbag Deployments by Airbag Generation (Weighted)

When weighted and analyzed by airbag generation, it is estimated that children in front of an advanced airbag during a crash are less likely to be in a CSS or unbelted than other those seated in front of first or second generation bags (Figure 44). This trend could be part of the reason that there are fewer injuries in the advanced airbag group.

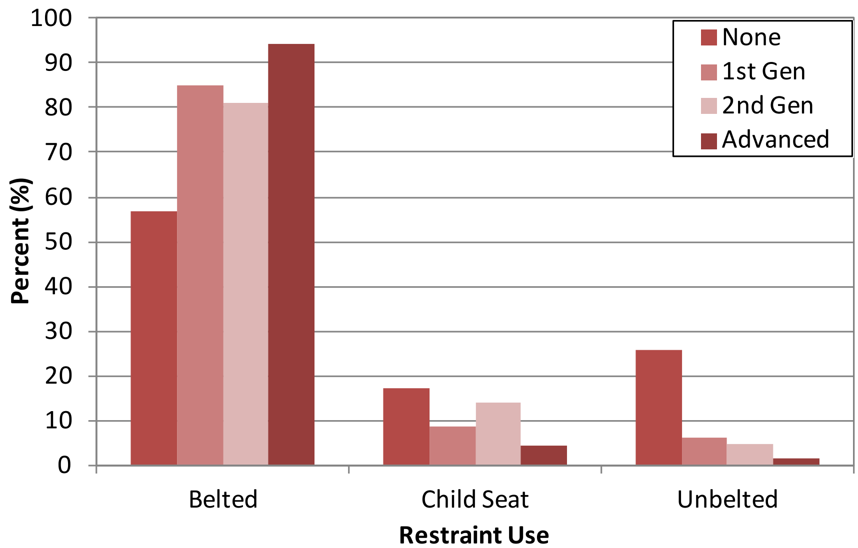

Figure 44. Passenger Restraint Use by Airbag Generation (Weighted)

The distribution of weighted cases by vehicle type and airbag generation is presented in Figure 45. When the cases are weighted the no airbag group is estimated to have many more cars by proportion than the unweighted case distribution would indicate. Conversely, the first generation and second generation airbag groups are closer to a 60/40 split in favor of cars than indicated by the unweighted case data. Again, because the exposure data indicates that children are exposed equally between cars and LTVs, it appears that cars may be more likely than LTVs to be involved in tow-away crashes. This can likely be attributed to the US fleet composition changing from mostly cars to an even mix of cars and LTVs over time.

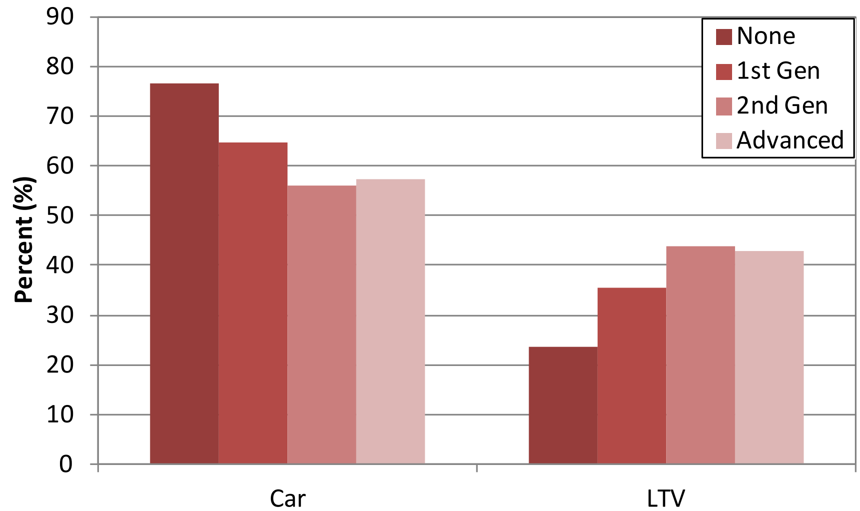

Figure 45. Passenger Vehicle Type by Airbag Generation (Weighted)

The weighted advanced airbag group indicates that the majority of children involved in tow-away crashes seated in the RFP seat are mostly between 10 and 12 years old (Figure 46). The age distribution within the advanced airbag group is notably different from the other airbag groups. Because older children are heavier and have more developed muscles by comparison to younger children, they also have a higher injury tolerance. While this is encouraging since it is known that the RFP seat presents a higher injury risk than the back seat, it may be confounding factor in the reduction in injuries noted in the advanced airbag group.

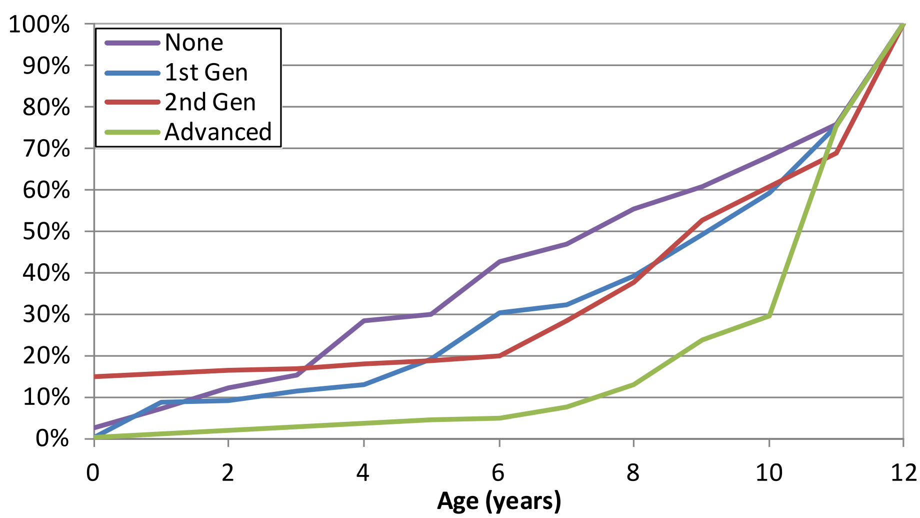

Figure 46. Distribution of Age by Airbag Generation (Weighted)

The cumulative distribution of weighted RFP weights is presented in (Figure 47). One case was considered an outlier and was excluded from the injury analysis as the weight of the child was 132 kilograms (291 pounds). The minimum weight in the dataset was 3 kilograms (~ 7 pounds) and with the outlier excluded the highest weight was 82 kilograms (~182 pounds).

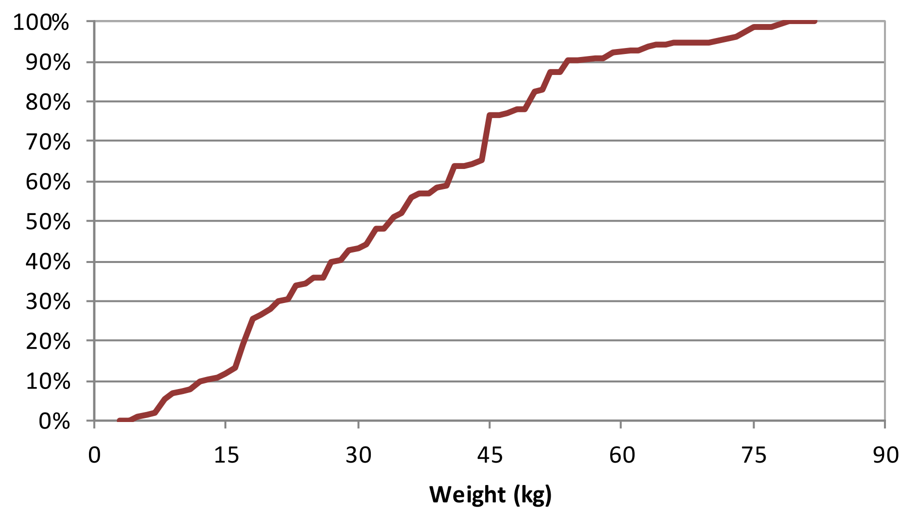

Figure 47. Cumulative Distribution of Weighted Child Occupant RFP Weights

4.3.1 Probability of Moderate Injury

Though the advanced airbag dataset had very few moderate injuries especially compared to the other airbag generation groups, we were interested to examine how the probability of moderate injury varied from previous generation airbags and whether the reduction in moderate injuries was significant statistically. To do this a logistic regression was performed using SAS 9.3 (SAS Institute Inc., Cary, NC). In order to account for the stratified sampling scheme used by NASS-CDS, the SurveyLogistic function within SAS was used to test the effect of each of the independent variables in a Wald test. Moderate injury (AIS2+) was used as the binary response. The age and weight of the occupant, as well as the longitudinal and total delta-V were included as continuous covariates. The occupant's sex, restraint use, type of airbag, vehicle class and the passenger airbag deployment were included in the analysis as categorical covariates. All of the variables initially included in the logistic regression are outlined in Table 12. Importantly, because this study analyzes children, restraints used vary between seat belt and child safety seat (CSS); however, to test for the effect of restraints on likelihood of injury restraints were forced into a binary covariate where restrained (including seat belt and CSS) was set to 1 and unrestrained was set 0.

Table 12. Variables Initially Included in Logistic Regression for Effects Analysis

Variable	Continuous/Categorical
Age	Continuous
Weight	
Longitudinal Delta-V	
Total Delta-V	
Sex	Categorical
Restraint Use	
Airbag Generation	
Vehicle Class	
Passenger Airbag Deployment	

In order to avoid bias by overfitting the data, non-significant factors were removed from the analysis and the analysis was run again with factors that were statistically significant. The final logistic model included three variables: longitudinal delta-V, airbag generation and passenger airbag deployment. The estimate coefficient and its respective 95% confidence interval are presented in Table 13.

Table 13. Statistically Significant Logistic Regression Parameter Estimates

Variable	Coefficient Estimate	95% Confidence Limits	
Intercept	-13.1011	1.5560	70.8948
Longitudinal Delta-V	0.0705	0.0228	9.5278
No Airbag	8.5794	1.5333	31.3084
1st Gen Airbag	3.2526	0.9864	10.8732
2nd Gen Airbag	2.9429	1.0355	8.0780
Airbag Deployment	6.0961	1.1951	26.019

The results of the Chi-Square test or global null hypothesis test which tests whether any of the coefficient estimates may be equal to zero are presented in Table 14. Based on the Chi-Square values and their associated probabilities the null hypothesis can be rejected.

Table 14. Chi-Square Test Results which Test the Global Null Hypothesis

Test	Chi-Square	DF	Pr > Chi-Square
Likelihood Ratio	16,485.6	5	<0.0001
Score	16,294.3	5	<0.0001
Wald	52.7	5	<0.0001

Using the parameter estimates in Table 13 and the logarithmic regression equation in Equation 6, the probability of moderate injury for a deployment event are shown in Figure 48.

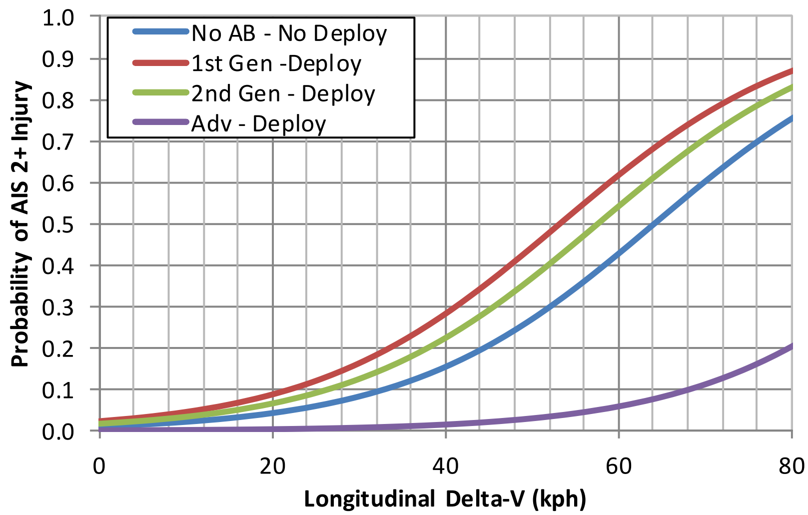

Figure 48. Probability of moderate injury for restrained children seated in RFP seat of a passenger car with a deployment for all airbag generations as a function of delta-V

Odds ratios were calculated for each airbag type where advanced airbags were used as the reference in order to compare the influence of other airbag generations on moderate injury to advanced airbags. They were calculated using a logistic regression model in order to control for longitudinal delta-V and airbag deployment. By using the SurveyLogistic method within SAS the potential difference in the odds of moderate injury by comparing crashes with a similar crash severity and airbag deployment. An odds ratio greater than one suggests the reference event had a smaller odds of injury, while an odds ratio less than one suggests that the reference event have a greater odds of injury. A confidence interval which included odds ratio of one indicates no statistically significant difference in the odds of injury. The odds ratios of moderate injury for no airbag, first and second generation airbags are presented in Table 15. As shown, the odds of moderate injury are higher for all airbag types than advanced airbags. Specifically, first generation airbags are estimated to present roughly 26 times greater odds of moderate injury than advanced airbags and similarly second generation airbags present 19 times higher odds of moderate injury for children seated in front of these bags during a crash.

Table 15. Odds Ratio of Moderate Injury Adjusted for Longitudinal Delta-V and Airbag Deployment

Airbag Type	Coefficient Estimate	95% Confidence Limits	
No Airbag	>999.999	263.532	>999.999
1st Gen Airbag	25.857	3.741	178.733
2nd Gen Airbag	18.971	2.493	144.370

Reference: Advanced Airbags

4.3.2 Factors Influencing Moderate Injuries

As shown in Table 16, factors that are associated with an increase in the probability of a child in the RFP sustaining a moderate injury include: longitudinal delta-V, airbag generation and airbag deployment. These factors were all significant at the alpha=0.05 level. However, age, weight, sex, restraint use and vehicle type did not have a statistically significant effect on probability of moderate injury and thus were excluded from the model effects analysis. It should be noted that although for the dataset as a whole, airbag deployment influenced whether a child was injured or not, there was no such statistical correlation for the advanced airbag group alone.

Table 16. P-Values Resulting from Model Effects Analysis Examining Factors Influencing Moderate Injuries

Variable	P-Value
Longitudinal Delta-V	0.002
No Airbag	<0.0001
1st Gen Airbag	0.001
2nd Gen Airbag	0.0045
Airbag Deployment	<0.0001

4.3.3 *Injuries by Body Region*

In order to evaluate which injuries occur most frequently as a function of airbag generation and deployment status, the weighted cases where at least one injury was reported were analyzed by body region (Figure 49). The injuries presented included any injury including minor which could be a laceration (cut) or hematoma (bruise) and does not control for restraint use. Not surprisingly, the highest prevalence of head and neck injuries occurred when children were seated in front of deploying first generation airbags.

In general, the proportions of injuries while seated in front of an advanced airbag regardless of whether it deployed were lower, with a few exceptions. Children injured in a crash while in front of an advanced airbag appeared to sustain head injuries as frequently as those seated in front of second generation airbags. Further, there were proportionally more injured children seated in front of an advanced airbag that did not deploy who sustained head injuries than those in front of first or second generation airbags. However, the head injuries in the advanced airbag group ranged from minor to moderate. Also, though minor (AIS 1) in severity, proportionally more children sustain neck injuries seated in front of an advanced airbag that did not deploy than those who were seated in front of advanced airbags that did deploy. Proportionally more children sustained minor chest injuries when seated in front of an advanced airbag which did not deploy than those in front of advanced airbags that did deploy. Finally, a large proportion of children injured as a result of a crash while seated in front of an advanced airbag which did not deploy sustained minor lower extremity injuries. The majority of the children sustaining lower extremity injuries were restrained. This injury modality could be the result of poor belt fit resulting in "submarining" where the child occupant's hips slide under the belt during the event and make contact with the instrument panel or could be a result of seat track location.

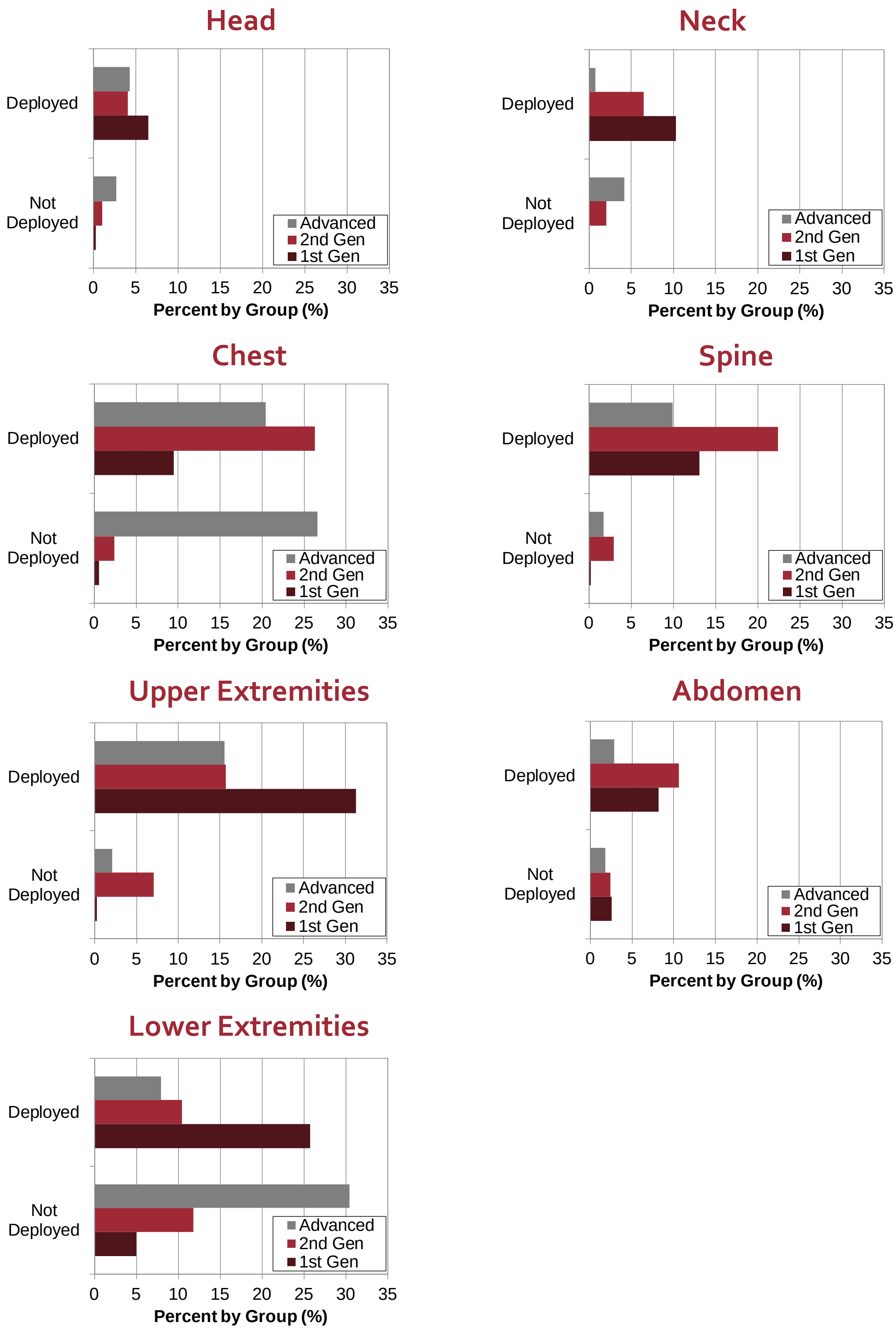

Figure 49. Frequency of any injury sustained by children seated in the RFP during a crash by body region resulting from deployed and non-deployed airbags.

4.4 CONCLUSIONS

NASS-CDS was used to extract real-world crashes involving children seated in the RFP. The analysis used the NASS-CDS sampling weights to provide a nationally representative sample of children seated in front of airbags. Advanced airbags were classified using a number of data sources. A logistic regression analysis was performed on the resulting data to compare previous airbag generations to advanced airbags; there was a statistically significant difference in the probability of moderate injury between advanced airbags and all other airbag generations. First generation airbags were estimated to present roughly 26 times greater odds of moderate injury than advanced airbags and similarly second generation airbags present 19 times higher odds of moderate injury for children seated in front of these bags during a crash.

It is interesting that there is a difference between no airbag and advanced airbags considering that for many occupant sizes the advanced airbags can suppress essentially rendering that occupant without an airbag. This suggests that other vehicle safety features may also be providing some of the protective benefit to children in the front seat. Encouragingly, the most injurious cases within the advanced airbag group were moderate (AIS 2) and further there were only three cases at that severity, the remainder of the injuries were minor (AIS 1). The factors affecting the probability of moderate injury were longitudinal delta-V, airbag generation and airbag deployment. However, airbag deployment was not an indicator of the probability of moderate injury amongst the advanced airbag group.

Injuries sustained by children in all four airbag groups were further analyzed by body region for children sustaining any injury including minor (AIS 1) injuries. In general, the proportions of injuries while seated in front of an advanced airbag regardless of whether it deployed were lower, with a few exceptions. Children injured in a crash while in front of an advanced airbag appear to sustain head injuries equally as frequently as those seated in front of second generation airbags. Further, there were proportionally more injured children seated in front of an advanced airbag that did not deploy who sustained head injuries than those in front of first or second generation airbags. However, the head injuries in the advanced airbag group ranged from minor to moderate. Also, though minor (AIS 1) in severity, proportionally more children sustain neck injuries seated in front of an advanced airbag that did not deploy than those who were seated in front of advanced airbags that did deploy. Proportionally more children sustained minor chest injuries when seated in front of an advanced airbag which did not deploy than those in front of advanced airbags that did deploy. Finally, a large proportion of children injured as a result of a crash while seated in front of an advanced airbag which did not deploy sustained minor lower extremity injuries.

5 Case Study of Advanced Airbags in the Field

5.1 Introduction

The performance of advanced airbags has been extensively tested under laboratory conditions; however, little is known about the field crash performance of these airbags in the presence of children. This study evaluates the performance of advanced airbags when children are seated in the front seat in the field.

5.2 Methods

The first part of this analysis evaluates the behavior of advanced airbags in comparison with the certified deployment strategy for that particular vehicle make and model. In conjunction with NASS-CDS the second part of this study employs our event data recorder (EDR) database, examining cases where children were in the right front passenger seat during a crash. EDRs are the computer devices that record information about the vehicle and control the airbags in the event of a crash [55]. EDRs have been validated and ruggedized to survive a multitude of crashes since a failure of this system can be catastrophic [56]. EDRs have been used previously to evaluate the performance of advanced airbags for all occupants before [57], [58]. However, this analysis did not focus on the performance in the presence of children. Since EDRs record the last 5 seconds of vehicle speed, throttle and braking prior to a crash and/or deployment, they have been used to analyze crash severity estimates obtained via crash reconstructions and WinSmash algorithms [59], [60], [61], [62], [63].

The EDR database provides key details about the airbag deployment that NASS-CDS does not provide such as if a child was detected, when and if the airbag deployed and if deployed the firing time of the airbag stages. The EDR database provides better insight on the design and performance of advanced airbags but, does not provide passenger or injury information. By combining the EDR database information with NASS-CDS, a complete picture can be provided for anecdotal evidence regarding the operation of advanced airbags.

5.2.1 WEIGHT CLASSIFICATION

Since weight is the predominant factor available to airbag and vehicle manufacturers to decide whether the occupant in the front seat is a child or not, this study classified children into the following categories: newborn, 1-, 3-, 6- and 12-year old. Children were classified using the CDC growth charts for boys and girls from newborn through 20 years old [53], [54]. Weights selected for the upper bounds of each occupant group represent 75th-percentile boys since boys are heavier, while the lower threshold were designed to retain 50th – percentile girls for that same age group. The range for each occupant class is presented in Table 14. For reference the weights of the anthropomorphic test devices (ATD) used in testing are listed as well. The advanced airbag ruling requires that airbags are suppressed for newborns (age 0) but allows the manufacturer to choose to either suppress or deploy in a low risk manner for 1, 3 and 6 year olds; the technique can vary between occupant classes.

Table 17. Weight ranges used to classify a child's age by their weight & the weight of the applicable ATD in kg

Age	Lower Weight (kg)	Upper Weight (kg)	ATD Weight (kg)
0	0	9	7.7
1	9	14	10.0
3	14	19	15.5
6	19	28	23.4
12	28	--*	N/A

* 5th % Female weighs 48.9kg (108 lbs.)

To evaluate how well the age prediction by weight correlated with the actual age of the children in the study, the distribution of each predicted occupant class group is presented in Figure 50 as a function of the occupant's actual age. The predicted infant group is nearly 80% children whose actual age was < 1 year old. The predicted 1 year old group peaked for children who were actually 2 years old, but roughly 25% of the group was actually 1 year old. The distribution of predicted 3 year olds, 6 year olds and 12 year olds all peaked at an actual age corresponding to their predicted age.

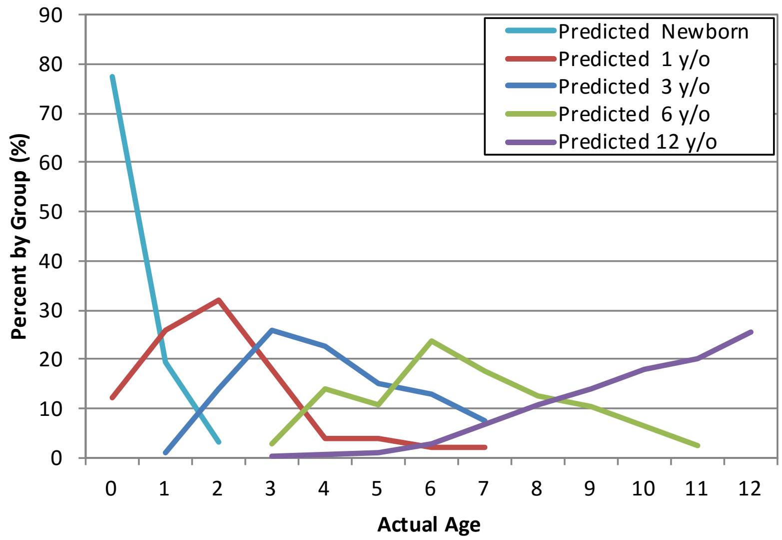

Figure 50. Distribution of Predicted Newborns, 1-, 3- and 6-year olds by Actual Age

5.3 Advanced Airbag Algorithm Analysis

The distribution of known advanced airbag strategies for the entire NASS-CDS advanced airbag group is presented in Figure 51. Most frequently airbags were certified to suppress for ALL occupants 0 – 6 years old (SSS), followed by a mixed deployment technique (SSL, SLL). The least common was low risk deployment for all occupants 0 – 6 years old (LLL).

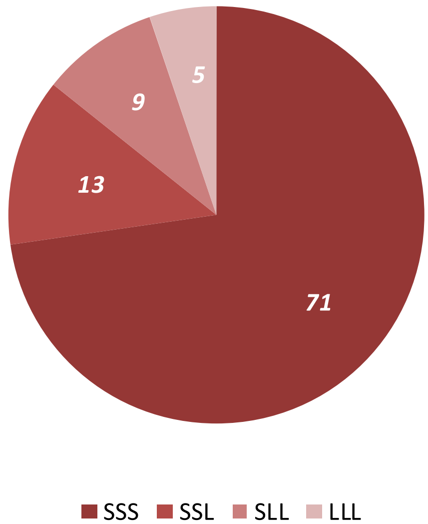

Figure 51. Distribution of Known Advanced Airbag Strategies for the NASS-CDS Dataset

To evaluate whether the airbags were working as designed, the responses in the field (Table 18) were compared with the respective airbag's certified deployment or suppression strategy. Since it is impossible to tell if an airbag would have suppressed in an accident where a deployment for the adult was not warranted, cases where the airbag did not deploy for both the driver and passenger were categorized as not deployed. However, cases where the driver bag did deploy and the passenger bag did not were categorized as suppressing. Furthermore, it is not possible to evaluate whether the airbag behaved as designed for occupants classified as twelve year olds; however, it is interesting to evaluate whether the airbags in these crashes behaved in accordance with the certified strategy for the six year old occupant class or not.

Table 18. Actual Responses for All Advanced Airbag Cases by Occupant Classification

Occupant Classification	No Deployment	Suppressed	Deployed	Total
Newborn	0	2	0	2
6 Year Old	3	8	2	13
12 Year Old	26	13	47	86
All	***29***	***23***	***49***	***101***

Actual airbag responses for cases with known airbag deployment strategies are presented in Figure 52. In 10 of the cases an advanced airbag suppressed in agreement with the certified strategy. That is, for children classified by weight as being in a particular occupant class, the airbag suppressed which aligned with the certified strategy for that vehicle make and model. Two of the ten cases that suppressed as certified, suppressed for occupants that were classified as newborns. One of the newborns was an unrestrained riding in a 2008 Suzuki Forenza, wherein an occupant within the vehicle sustained a serious (MAIS 2) injury. With the exception of that same newborn, the children in cases where the airbag suppressed as certified were all restrained. In 8 of the 10 cases that were described as suppressing as designed, the occupants were classified as a six year old occupant, one of which was restrained in a child seat. Their actual ages ranged from 5 to 10 years old, where the average age was 9 years old and children were most frequently 9 years old. Six of eight six year olds sustained minor injuries (MAIS 1), the remaining two were not injured (MAIS 0). In four of the cases the driver of the vehicle sustained an MAIS 2+ injury. A majority of the cases where the child was classified as a six year old occurred in cars.

There was one case where an advanced airbag was classified as deploying as certified for an occupant classified as a six year old. In this case, the vehicle was a 2011 Buick Enclave whose certified deployment strategy was suppression for the 1 year old occupant class and low risk deployment for the 3- and 6-year old occupant classes. The child was restrained, the airbag deployed and the child was not injured during the crash; however, an occupant in the vehicle sustained a minor injury (MAIS 1). The driver airbag also deployed.

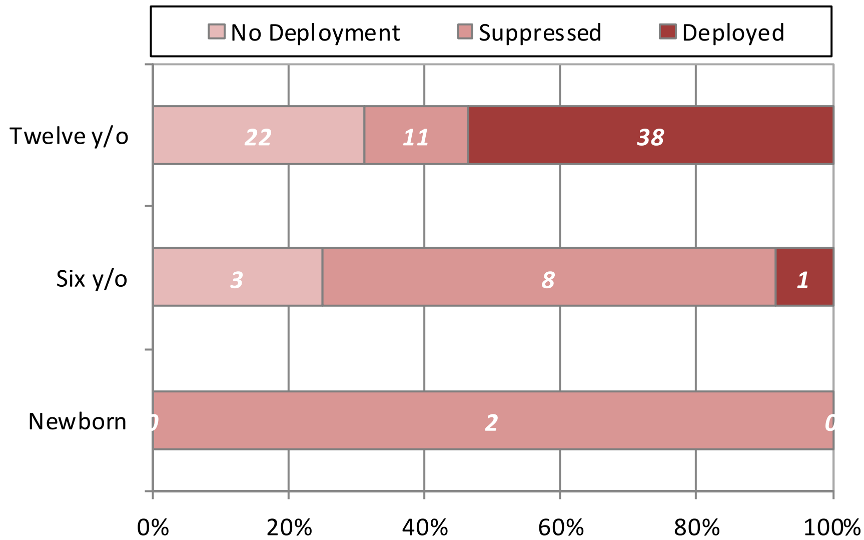

Figure 52. Distribution of Airbag Responses for Cases with Known Deployment Strategies by Child Occupant Classification

Since deployment techniques for older children are not required to be certified by law, it would be impossible to tell if the advanced airbag was not working as intended. However, the response of advanced airbags in the presence of child occupants classified as twelve year olds was interesting. As shown in the pie chart in Figure 53, 22 cases did not result in deployment and eight airbags suppressed matching the certified deployment strategy for the 6 year old occupant class. Interestingly, three airbags suppressed for a child classified as a 12 year old even though the deployment strategy for the 6 year old was low risk deployment. Another 17 airbags deployed during a crash in the presence of a child classified as a 12 year old matching the deployment strategy for the 6 year old occupant class. Another 21 airbags as might be expected deployed when the driver's bag deployed though the deployment strategy for the 6 year old was suppression. This would suggest as might be expected that when older children are seated in front of advanced airbags in a frontal crash, the deployment is dictated more by crash severity and older children for the most part are treated like small adults. In fact, one vehicle from the group of 21 airbags that deployed for the twelve year old occupant class had been tested for low risk deployment with a 5th percentile female in NHTSA's test database.

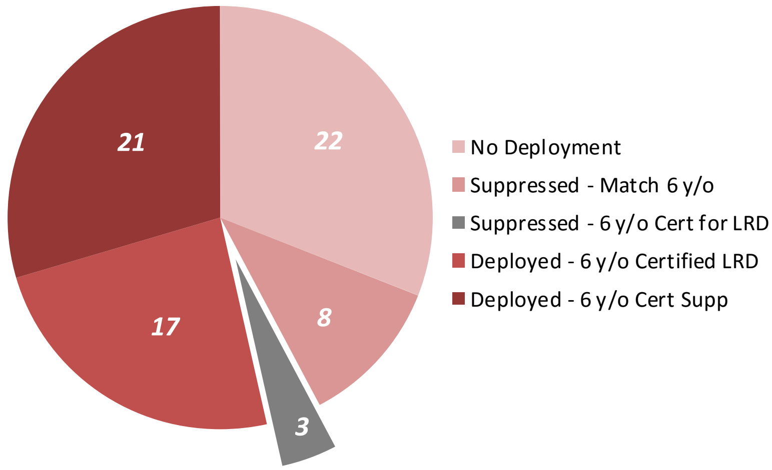

Figure 53. Deployment Status of Advanced Airbags for Occupants Classified as 12 Year Olds Grouped by Certification Strategy for 6 Year Old Occupants; Surprisingly 3 Airbags Suppressed When Certified to Deploy for the 6 Year Old Occupant Class

From the data available it appears that advanced airbags are working as designed during real-world crashes when children are seated in front of the airbags. There are three interesting cases where the airbag suppressed for an older child when the airbag was certified to low risk deployment for a smaller child class. The author has no explanation for this and since there is no certified strategy for this occupant class it is impossible to know whether this behavior was intended or not.

5.3.1 Predicted Strategies For Cases Without Strategy Data

Since the information to classify deployment strategies was only available starting in model year 2005, but vehicle manufacturers started certifying advanced airbags in 2003, there were some cases whose deployment strategies were not defined. In addition, within the deployment strategy data there were a few instances where 2013 model year data was available, but for the majority of the vehicles data was only available through model year 2012. As a result there were 16 cases whose deployment strategies were not defined; however, in these cases it was possible to predict or guess what strategy was present in the vehicle by looking at the following or previous model year strategy, the responses of the advanced airbags in these cases are presented in Figure 54 by predicted child occupant class. There was one airbag that deployed for a six year old, but the predicted deployment strategy for that airbag was low risk deployment. Since the deployment strategy was predicted, not certified, it is impossible to know with certainty whether this deployment was an anomaly. The responses of the children classified as 12 years old are further analyzed in Figure 55.

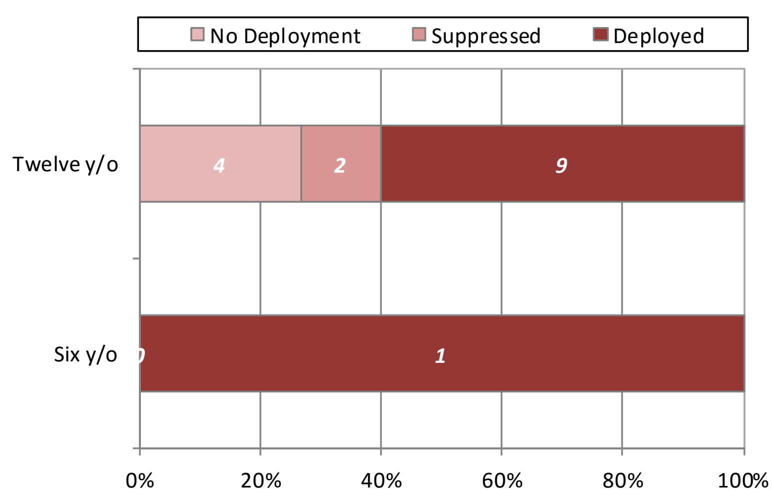

Figure 54. Deployment Distribution by Occupant Class

Again, since a deployment strategy is not required by FMVSS 208, it would be impossible to tell if the advanced airbags are working as intended in cases involving children classified as 12 year olds. Regardless, it is interesting to see how the airbags are responding in comparison to their predicted deployment strategy for the younger occupant class. As shown in the pie chart in Figure 55, in four cases there was no deployment of either the driver or passenger airbag. In two cases the airbag suppressed which matched the predicted strategy for a 6 year old occupant and similarly in five cases the airbag deployed again matching the predicted strategy for a 6 year old occupant. In another 4 cases, the airbag deployed when the predicted strategy for the 6 year old occupant was suppression. Again, overall this suggests that advanced airbags are treating the older child occupants like a small adult as would be expected. However, it is surprising that some airbags would suppress for the older children.

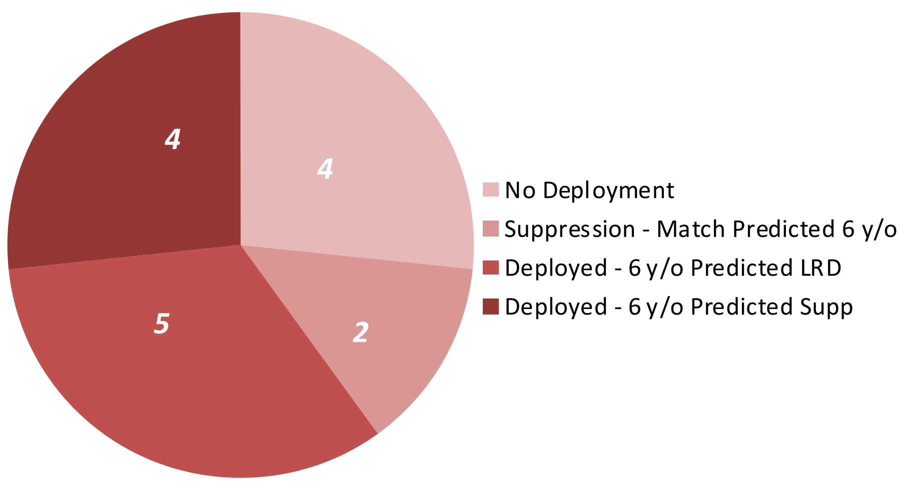

Figure 55. Deployment for Occupants Classified as 12 Year Olds Compared to the Predicted Certification Technique for the 6 Year Old Occupant Class

5.4 A Look at Moderate Injuries in Cases with Advanced Airbags

Since there were only three moderate injury cases within the advanced airbag case group, this section will briefly review the crashes involving advanced airbags and moderate injuries in children. The three cases involve a Mazda 6, a Nissan Sentra and a Toyota Highlander. Since the Highlander is in the EDR database, EDR data is also provided for this case.

5.4.1 2006 Mazda 6

In November 2006, a 2006 Mazda 6 traveling north on a six lane divided highway departed the highway, crossed a parking lot and came to a stop after striking a house as shown in the scene diagram presented in Figure 56 (NASS Case No. 2006-50-135). The vehicle was towed due to damage. The majority of the damage to the front was on the driver's side as shown in Figure 57-*left*. The driver and RFP were transported and released. The driver suffered from an open fibula fracture believed to have been caused by the floor pan. The passenger, a 12 year old female weighing 64 kilograms was belted at the time of the crash and suffered a thoracic spine (superior/upper T12) fracture without cord involvement and minor disk compression. The injury was determined to have been caused by direct contact with the seat belt. The top-mounted front airbag deployed (Figure 57-*right*) and the seatbelt pre-tensioners fired. However, no other passenger airbags fired (i.e. seat back or roof rail). The RFP seat was upright and located between the middle and rear most seat track position at the time of the investigation. The seat was determined to have been in that position prior to and following the crash. Further, it was determined that the injuries sustained were not airbag related.

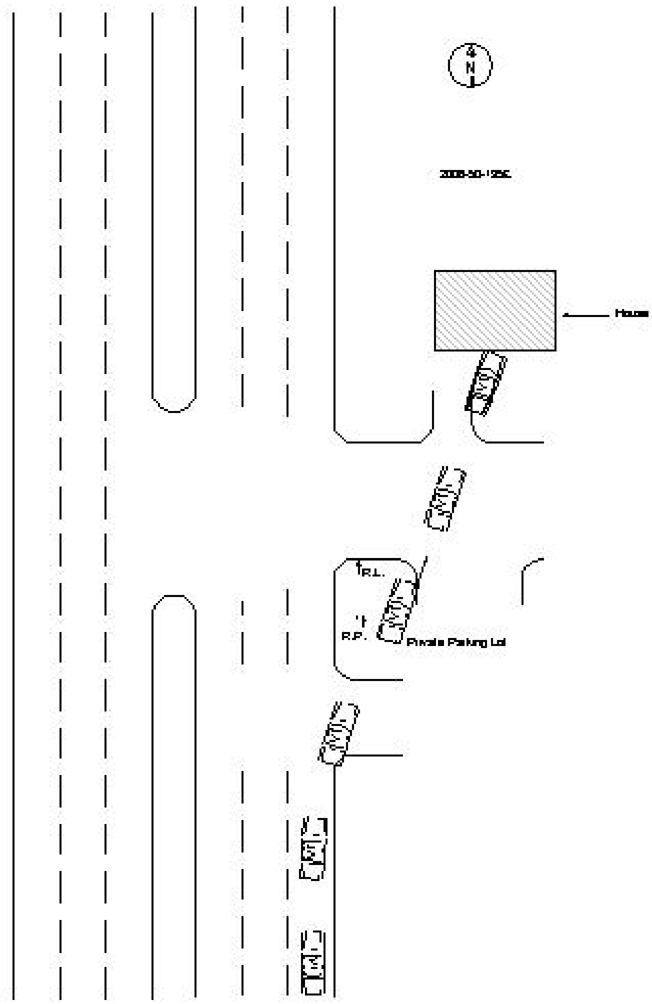

Figure 56. NASS Case Number 2006-50-135 Scene Diagram Showing the Vehicle Departing the Road and Striking the House

Figure 57. NASS Case Number 2006-50-135 Vehicle 1, Mazda 6 During Investigation Showing More Damage to the Driver's Side (*left*) and the Passenger Airbag (*right*)

5.4.2 2007 Nissan Sentra

In March 2010, a 2007 Nissan Sentra (V2) was heading eastbound on an intersecting two-way undivided roadway (NASS Case No. 2010-72-027). Both the Sentra and a 2008 Honda Accord (V1) heading southbound entered the intersection in straight paths and the right plane of the Accord contacted the front plane of the Sentra. After the initial impact, the two vehicles side-slapped, the left plane of the Sentra impacted the right plane of the Accord as shown in the scene diagram shown in Figure 58. Both vehicles were towed due to damage; the majority of the damage sustained by the Nissan was on front of the vehicle as shown in Figure 59-*left*.

The driver and RFP of the Sentra were treated and released. The driver airbag deployed, however, the passenger airbag did not (Figure 59-*right*). The vehicle was equipped with pretensioners but their firing status was undetermined. The driver was treated for a facial hematoma determined to be caused by the airbag. The passenger, an 11 year old female weighing 41 kilograms was treated for a cerebral concussion with loss of consciousness for less than 30 minutes and a facial hematoma. The probable cause of both injuries was determined to be the instrument panel. The RFP was unrestrained during the crash and the RFP seat was upright and in a full forward position prior to, during and at the time of investigation (Figure 59-*right*).

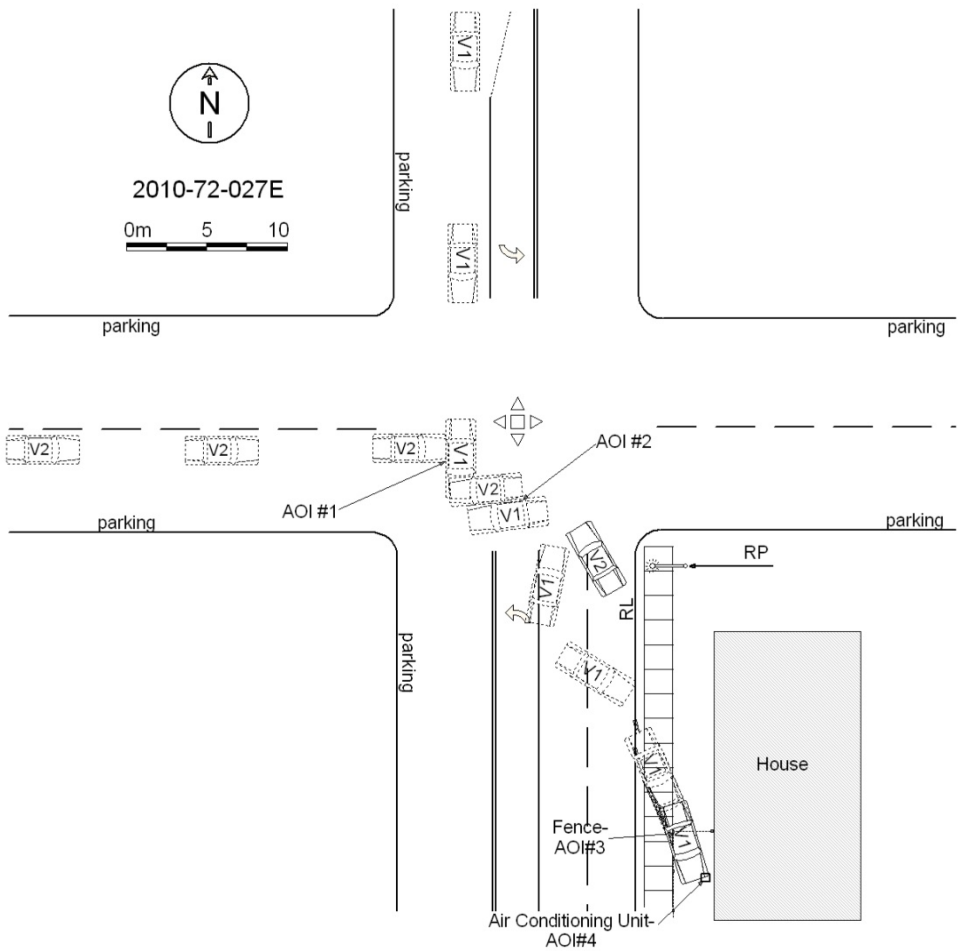

Figure 58. NASS Case Number 2010-72-027 Scene Diagram Showing the Vehicles Colliding in the Intersection Prior to Striking Inanimate Objects on the Roadside

Figure 59. NASS Case Number 2010-72-027 Vehicle 2 Showing the Damage to the Front of the Vehicle (*left*) and the RFP Seat Fully Forward, No Airbag Deployment (*right*)

5.4.3 2007 Toyota Highlander

In May 2012, a 2007 Toyota Highlander heading eastbound on a two-lane roadway struck a 1993 Mercury Grand Marquis (travelling westbound) head on as shown in Figure 60. Both vehicles were towed due to damage; the Highlander sustained damage to the front of the vehicle as shown in Figure 61-*left*. Both occupants in the Highlander were restrained. Further, both the driver and the (top mounted) passenger airbags deployed (Figure 61-*right*) along with the seat belt pre-tensioners which fired for both occupants as well.

The driver sustained a multitude of injuries resulting from the seat belt, steering wheel and airbag and was hospitalized for three days. The 12 year old female, passenger, weighing 50 kilograms was seated in an upright position at the rear-most seat track position. She sustained left distal radius and ulna fractures which were attributed to the center mounted transmission lever and a variety of other injuries resulting from the seat belt (e.g. abdominal hematoma, skin lacerations). The 12 year old passenger was hospitalized for two days; however, none of her injuries were associated with the deployment of the airbag.

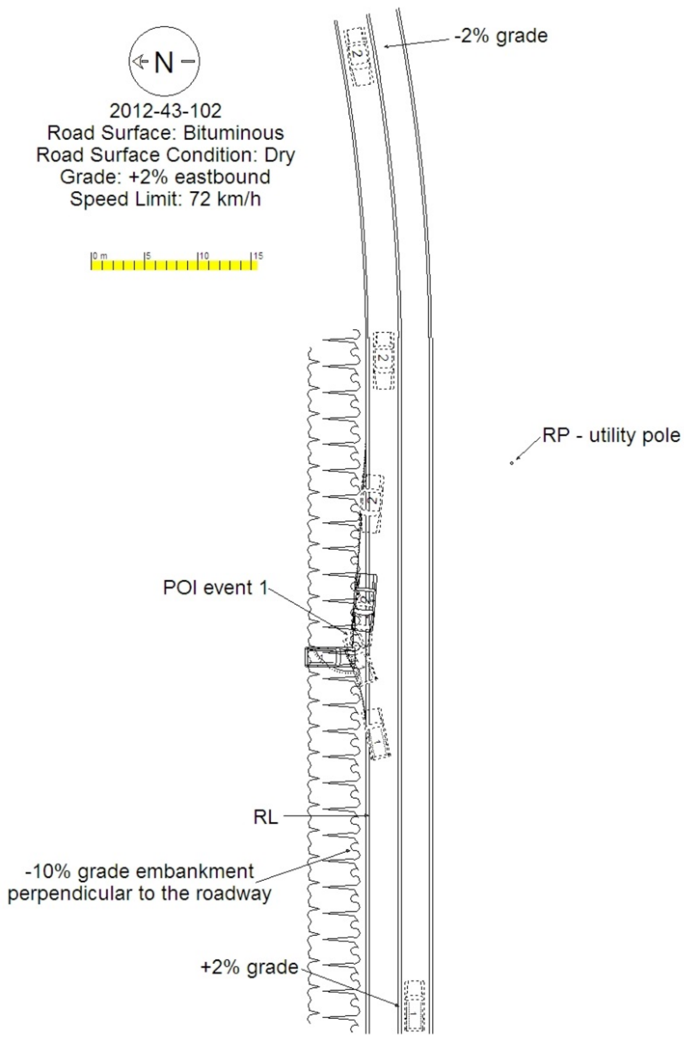

Figure 60. NASS Case Number 2012-43-102 Scene Diagram Showing the Vehicles Colliding in a Head On Crash

Figure 61. NASS Case Number 2012-43-102 Vehicle 1, Showing Damage to Front of Toyota Highlander (*left*) and Top-Mounted Passenger Airbag (*right*)

5.4.3.1 EDR Information

The Highlander was one of the vehicles in our EDR database, this subsection will identify parameters sensed, identified and recorded by the EDR. The EDR expressly sensed the 12 year old and classified the child as a small statured adult (5th percentile female). The EDR fired the passenger at 8ms and only fired one stage. The driver's seat position was sensed as rearward and the driver's bag also only deployed one stage. The EDR also indicated that both the driver and passenger were belted. The airbag warning lamp was not illuminated meaning that the airbag system was not in error prior to the event/crash. No information was provided regarding the seat belt pretensioners from the EDR.

5.4.4 Summary of Moderate Injury Cases

Three NASS-CDS cases were presented involving children sustaining moderate (AIS 2) injuries while seated in front of an advanced airbag. One of the three children required hospitalization which was likely due to the number of injuries sustained most of which were identified as being caused by the seat belt. None of the three cases presented injuries were associated with the airbag. One of the airbags suppressed, the other two deployed. The child seated in front of the airbag that suppressed weighed 48.9 kilograms (classified as a 12 year old by standards defined herein) was seated in close proximity to the instrument panel this occupant sustained a cerebral concussion with loss of consciousness for less than 30 minutes and a facial hematoma. The suspected cause of this injury was the instrument panel which may have been prevented if the airbag deployed. On the other hand the child could have been more seriously injured if the airbag had deployed. Additionally, one child was unrestrained, the remaining two were restrained. All of the airbags included in this section were certified for suppression for the 1, 3 and 6 year old occupants. However, the occupants involved in the crashes examined were all older (11 and 12 years old).

5.5 Select EDR Cases

A total of 30 NASS-CDS cases with children seated in front of advanced airbags were included in the EDR database, a subset of those cases were selected and presented within this section to serve as anecdotal evidence that advanced airbags appear to be working as intended during real world crashes. Specifically, this section will outline advanced airbag cases where: (1) the child was seated in a child safety seat, (2) the child was unrestrained, (3) the vehicle expressly classified the passenger as a child, (4) the airbag suppressed, and finally, (5) the airbag deployed.

5.5.1 Child Safety Seats & Advanced Airbags

This subsection examines two cases within the EDR database where a child was seated in front of an advanced airbag while restrained in a child safety seat as this was a particular concern for earlier airbags. The two cases involve a Chevrolet HHR (NASS Case No. 2010-75-160) and a Ford Escape (NASS Case No. 2011-48-111). In both cases the child safety seat was a belt positioning booster seat, in one of the cases, pictures of the safety seat were available.

5.5.1.1 2008 Chevrolet HHR

In July 2010, a 2008 Chevrolet HHR was heading northbound, stopped at an intersection. A 1997 GMC Envoy was heading eastbound, approaching the intersection. The HHR turned left and the front struck the right side of the Envoy. The Envoy rotated clockwise and rolled over to the left three quarter turns, then one additional quarter turn back to the top (NASS Case No. 2010-75-160). Both vehicles were towed due to the damage sustained; the HHR is pictured in Figure 62-*left*. The top-mounted passenger airbag suppressed (Figure 62-*right*), however, the driver's airbag deployed. The seat belt pretensioners fired for both occupants. No other airbags deployed (knee, curtain, etc.). Neither the driver nor the passenger was treated for injuries. The driver who was restrained, sustained minor injuries reported to be caused by the airbag. Namely, the driver sustained bruising to the chest and abdomen. The 7 year old male passenger weighing 33 kilograms (predicted in the 12 year old child class) was restrained in a Cosco Ambassador belt positioning booster seat as shown in Figure 63 and the passenger was not injured. The seat track location was between the forward most and middle seat track location.

Figure 62. NASS Case Number 2010-75-160, Chevrolet HHR During Inspection Showing Damage to the Right Front of the Vehicle (*left*) and Instrument Panel Showing the Airbag Did Not Deploy (*right*)

Figure 63. Cosco Ambassador Belt Positioning Booster Seat Used in NASS Case Number 2010-75-160 by a 7 year old RFP in Front of an Advanced Airbag that Suppressed

In this case, the EDR confirmed that both passengers were restrained and that the pretensioners fired for both the driver and passenger. Further, the EDR reported that only the driver's first stage deployed at 40 milliseconds. Finally the SIR warning lamp was off indicating that the supplemental restraint system was not in error prior to the crash.

5.5.1.2 2011 Ford Escape

In June 2011, a 2011 Ford Escape was traveling west on a two lane road, a medium-heavy truck, was traveling east on the same road. The Escape crossed the center line and the front contacted the front plane of the medium-heavy truck. The Escape rotated counter-clockwise and departed the north road edge. The Escape came to final rest facing east on the grassy roadside. The truck came to final rest facing east a short distance from the area of impact. Both vehicles were towed due to disabling damage, the Escape is shown at the scene of the crash in Figure 64-*left* (NASS-CDS Case No. 2011-48-111). The driver's front, roof rail and seatback airbags all deployed. The passenger's mid-panel (frontal) airbag suppressed (Figure 64-*right*), but the roof rail airbag did deploy for the right front passenger.

The belted driver of the Escape sustained a total of 25 injuries including multiple severe injuries (MAIS 4). The severe injuries included a diaphragm rupture with herniation, rib fractures with unilateral flail chest, spleen and liver lacerations. In addition, the driver sustained multiple lower and upper extremity fractures. None of the injuries were considered airbag related. The driver was treated in the hospital for 17 days.

The right front passenger, a 5 year old female weighing 20 kilograms (predicted 6 year old occupant), was restrained in a forward facing child safety seat which appears to have been a belt positioning booster seat. The make and model of the CSS was unknown and a picture was not available. The child only sustained multiple minor injuries despite the driver's condition. Namely, the child received abdominal abrasions/bruising and a cervical spine strain which were considered to be caused by the child safety seat harness system with a probable confidence level. The passenger was transported to the hospital and released the same day.

Figure 64. NASS Case Number 2011-48-111, Ford Escape at the Scene Showing Damage to the Front of the Vehicle (*left*) and the Instrument Panel for the Suppressed Passenger Airbag (*right*)

The EDR reported that both stages deployed for the driver at 20.5 and 30.5 milliseconds respectively. The roof rail airbags fired at 27.5 milliseconds. In addition, the EDR recorded the seat track position of the driver as being 'not forward,' the NASS investigator reported it being in the rear seat track position. Further, the EDR expressly detected the child and suppressed the mid-panel mounted front airbag, but deployed the roof rail bag as a result of the crash. Two events were recorded and both pretensioners were fired according to the EDR. The NASS investigators noted that there were previous crashes without deployments, but this may have been due to the two events recorded.

5.5.2 *Unrestrained Children & Advanced Airbags*

Also of interest were children who were riding in front of an advanced airbag while unrestrained during a frontal crash. Of the 30 advanced cases in the EDR database, two cases involved unrestrained children, one in a Chevrolet C/K Series Pickup (NASS Case No. 2009-49-161) and a Hummer H3 (NASS Case No. 2010-75-081). This subsection will outline these two cases.

5.5.2.1 2006 Chevrolet C/K Series Pickup

A 2006 Chevrolet C/K-series pickup was traveling eastbound and veered to the left. The vehicle departed the left side of the roadway and impacted a metal fence with its front end. The vehicle then impacted the corner of a house with its front left end. The truck continued eastward and impacted the house with its left back side. Finally, the vehicle continued eastward and impacted another metal fence, then the left side of a parked vehicle, with its front end as shown in Figure 65-*left* (NASS-CDS Case No. 2009-49-161). The vehicle was towed due to damage. The airbag deployed for the driver but the mid-instrument panel mounted airbag suppressed for the passenger (Figure 65-*right*).

In this case it was found that the driver was driving under the influence of drugs or alcohol and was unconscious following the final crash for less than one hour. The driver was transported to the hospital and released. The passenger, a female newborn (4 months old) weighing 6 kilograms (predicted as a newborn) was not injured, but was transported to the hospital and released regardless.

During an interview following the crash, during the investigation, the newborn was reportedly in an Evenflo car seat during the crash. The police reported that restraints use were not used, but the seatbelt was still buckled upon investigation. It would appear that the car seat, if used, was either restrained with the belt in such a way that the child safety seat could be removed without unlatching the seatbelt or another scenario that fits the data would be that the seat belt was buckled on the passenger side (perhaps to silence an alarm) and the child safety seat was placed on the seat unrestrained.

Figure 65. NASS Case Number 2009-49-161, Chevrolet C/K-Series Pickup During Investigation Showing More Damage to the Driver's Side (*left*) and the Instrument Panel Showing a Suppressed Passenger Airbag (*right*)

Both events were recorded by the EDR and the EDR report confirms that that seat belt was engaged during the crash. The EDR also reported that the driver airbag fired one stage at 45 milliseconds. Further, the SIR warning lamp was not illuminated indicating that the supplemental restraint system was not faulting prior to or during the crash.

5.5.2.2 2007 Hummer H3

In April 2010, a 1999 Chevrolet Malibu was traveling southbound on a state highway approaching a four-way traffic controlled intersection. A 2007 Hummer H3 was traveling northbound on the same highway approaching the same intersection. A 1996 Ford F-Series Pickup was traveling westbound approaching the same intersection. The Malibu entered the intersection intending to turn left. The front of the Hummer struck the right side of the Malibu. The impact forced the Malibu to the northeast where the front of the Malibu struck the left side of the pickup truck (NASS Case No. 2010-75-081). The Malibu and Hummer were towed from the scene, Figure 66 shows the Hummer H3 during repair.

This crash resulted in several airbag deployments, the driver's steering wheel mounted airbag and roof rail airbag deployed. In addition, the passenger's mid-instrument panel mounted frontal airbag deployed (Figure 67-*left*). In addition the roof rail airbag deployed for the front and rear passengers (Figure 67-*right*).

There were no injuries reported for the driver or the 12 year old female passenger (weight unknown). Neither were transported to the hospital or treated despite the fact that both were unrestrained. Impact points were noted on the knee bolster by the investigator on the passenger side (Figure 68) in addition to toe pan intrusions.

Figure 66. NASS Case Number 2010-75-081, Hummer H3 The Investigation Occurred After Repairs Began

Figure 67. NASS Case Number 2010-75-081, Hummer H3 Interior Showing Passenger Airbag (*left*) and Roof Rail Airbags for the Front & Rear Passengers (*right*)

Figure 68. NASS Case Number 2010-75-081, Hummer H3 Glove Compartment Showing Contact Marks

Despite all of the airbag deployments during this crash it appears that the EDR perhaps did not complete recording of the crash; however, no events recorded by EDR. This may be because GM EDRs can only record a limited number of events. Interestingly, it seems that the pretensioners may have fired even though NASS reported the occupants were unrestrained, as the NASS investigator noted that the seat belts were locked in their retracted position.

5.5.3 Advanced Airbag Systems That Detected a Child

Since advanced airbags were specifically designed to protect children and small adults, it was interesting to evaluate cases where a child was expressly detected. There were two cases in the set that reportedly detected a child in the front seat, one of those cases involved a Ford Escape (NASS Case No. 2011-48-111) and is detailed in the subsection focusing on child safety seats and advanced airbags. The other case involves a Ford F Series pickup truck (NASS Case No. 2012-48-80) and is outlined in the following subsection.

5.5.3.1 2010 Ford F-Series Pickup

A 2004 Toyota Camry was traveling east approaching a "T intersection" controlled by a stop sign. The 2010 Ford F-150 pickup was traveling south on the intersecting three lane road in lane one. As the Camry turned left at the intersection, the driver of the F-150 steered left to try to avoid contact but the front of the Camry contacted the front of the F-150. The Camry rotated clockwise to final rest facing southwest in the intersection. The F-150 came to final rest facing south in the intersection (NASS Case No. 2012-48-80). The pickup was partially repaired prior to inspection as shown in Figure 69-*left*.

Neither the driver's or passenger's airbag or pretensioners fired. The driver was unrestrained during the crash. The passenger's mid-instrument panel mounted airbag is shown in Figure 69-*right*. The 9 year old male weighing 27 kilograms (classified as a 6 year old) was restrained and not injured or treated.

Figure 69. NASS Case Number 2012-48-80, Ford F-150 Pickup during Investigation which Occurred After Repairs Began (*left*) and the Passenger Mid-Instrument Panel Mounted Airbag (*right*)

The EDR recorded the event and classified the driver's seat as "not forward." The EDR expressly identified the passenger as a child. The certified strategy for the Ford F-Series pickups was suppression for all of the child occupant classes. Further, the EDR recorded the belt status of the driver and passenger. The information from this EDR verifies that these systems are working properly in the field.

5.5.4 Select Advanced Airbags That Suppressed

With the special cases of child safety seats, unrestrained children and airbags that detected children examined, cases where the airbag suppressed were of interest. In total there were 10 cases identified where the airbag suppressed. However, for brevity, this section will outline two. Particularly this section will review one case involving a Chevrolet Malibu (NASS Case No. 2012-4-92) and another case involving a Chevy Impala (NASS Case No. 2010-45-166).

5.5.4.1 2010 Chevrolet Malibu

A 2010 Chevrolet Malibu and a 2011 Honda Ridgeline were traveling northbound in the right lane. The Ridgeline slowed down to turn right when the front of the Malibu impacted the rear of the Ridgeline (NASS Case No. 2012-4-92). The Malibu (Figure 70-*left*) was towed due to damage.

The driver's frontal airbag deployed and the passenger's mid-panel mounted frontal airbag suppressed (Figure 70-*left*). The driver was not belted at the time of the crash and was treated sometime after the crash for injuries not related to the airbag but related to direct impact with the vehicle. The passenger a 12 year old male, weighing 41 kilograms (classified as 12 year old) suffered from a minor thoracic contusion or hematoma. The injury was determined to be caused by the seat belt with probable confidence.

Figure 70. NASS Case Number 2012-4-92, Chevrolet Malibu During Investigation Showing More Damage to the Passenger's Side (*left*) and the Instrument Panel Showing a Suppressed Passenger Airbag (*right*)

The EDR recorded one event and reported a two stage deployment of the driver's airbag at 22 milliseconds and 30 milliseconds. The passenger's airbag was expressly identified as being suppressed by the EDR. Further, the EDR confirmed that both the driver and passenger pretensioners fired. Finally, the SIR light was not illuminated which indicates that the supplemental restraint system was not faulting prior to or during the crash. Again, information provided by this EDR provides convincing evidence of proper operation of advanced airbags during field crashes.

5.5.4.2 2007 Chevrolet Impala

A 1999 Pontiac Sunfire was traveling north and a 2007 Chevy Impala was traveling east at an intersection when the left side of the Sunfire and front of the Impala contacted. After the initial contact the Sunfire rotated clockwise and the Impala counterclockwise resulting in a side slap impact of the left back of the Sunfire and the right middle of the Impala. Both vehicles traveled in a northeasterly path across the roadway after the side slap where the Impala came to rest after striking a building with its back where it came to rest just west of the Sunfire Ford (NASS Case No. 2010-45-166). Both vehicles were towed due to vehicle damage; the damage to the front of the Impala is presented in Figure 71-*left*.

The driver's frontal airbag deployed, but the passenger's top-mounted frontal airbag suppressed (Figure 71-*right*). The driver and the passenger were both transported and released. The driver was not belted and sustained bilateral knee contusions a cervical spine strain and facial hematoma, all were minor injuries. The ten year old female passenger, weighing 27 kilograms (classified as a 6 year old) was belted. She sustained injuries that were determined to be caused by the seat belt with a probable confidence level including a muscle contusion on her neck and an abdominal hematoma. These were also minor (AIS 1) injuries.

Figure 71. NASS Case Number 2010-45-166, Chevrolet Impala During Investigation Showing More Damage to the Passenger's Side (*left*) and the Instrument Panel Showing a Suppressed Passenger Airbag (*right*)

The EDR recorded one event and reported a two stage deployment of the driver's airbag at 22 milliseconds and 28 milliseconds. The passenger's airbag was expressly identified as being suppressed by the EDR and recorded the passenger seat as being occupied by a small occupant. Further, the EDR confirmed that both the driver and passenger pretensioners fired. Finally, the SIR light was not illuminated which indicates that the supplemental restraint system was not faulting prior to or during the crash. This case provides another example of an advanced airbag identifying a child and suppressing.

5.5.5 Select Advanced Airbags That Deployed

In another 17 cases within the EDR database, the advanced airbags deployed. The following subsection will detail three of these cases: one involving a 2006 Chevrolet Uplander (NASS Case No. 2010-12-178), another involving a GMC Yukon (NASS Case No. 2011-48-206) and finally one involving a GMC Terrain (NASS Case No. 2012-43-208).

5.5.5.1 2006 Chevrolet Uplander

A 2006 Chevrolet Uplander and a 1998 Oldsmobile Bravada were both headed west on a two lane road, the Bravada was in front of the Uplander. The Uplander intended to continue straight while the Bravada intended to turn right onto a private drive. The front of the Uplander contacted the back of the Bravada (NASS-CDS Case No. 2010-12-178). The Uplander was towed due to damage as shown in Figure 72-*left* which shows the frontal damage to the vehicle was concentrated more on the driver's side. The driver and passenger frontal airbags deployed (Figure 72-*right*).

The driver was unrestrained and was not treated at a medical facility but sustained minor injuries to their knees. The 9 year old male passenger weighing 45 kilograms (classified as a 12 year old) did not sustain any injuries and as a result was not treated at a medical facility.

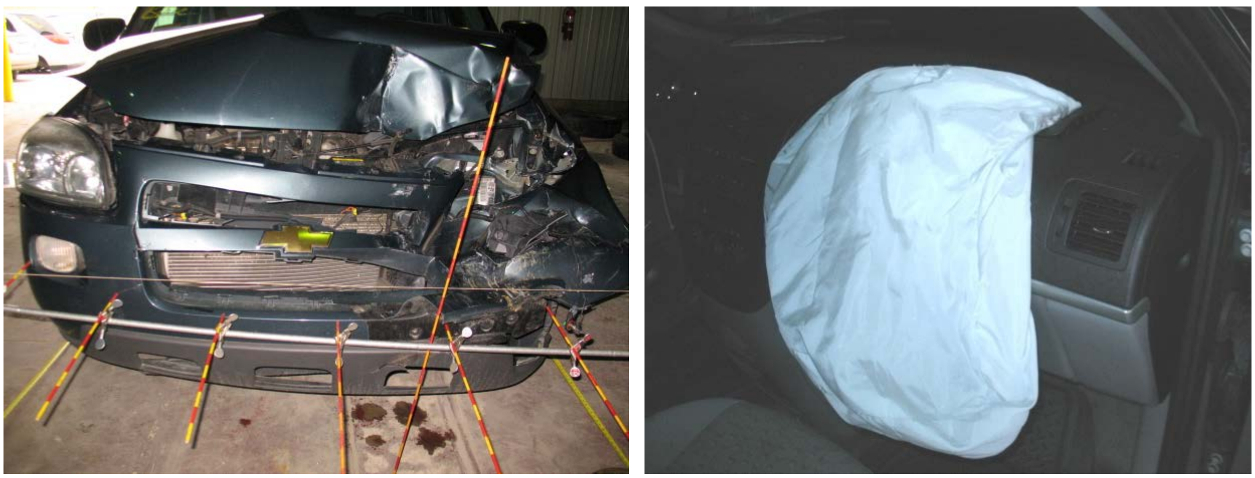

Figure 72. NASS Case Number 2010-12-78, Chevrolet Uplander During Investigation Showing More Damage to the Driver's Side (*left*) and the Instrument Panel Showing a Deployed Passenger Airbag (*right*)

The EDR recorded two events, the SIR warning light was not illuminated. The driver steering wheel hub mounted and passenger top instrument panel mounted airbags deployed at 32.5 milliseconds, both airbags only fired one stage (LRD). Further, the EDR recorded both the driver's and the passenger's seat as being forward. NASS-CDS reports both seat belt pretensioners as firing, but the EDR does not mention pretensioners.

5.5.5.2 2003 GMC Yukon

A 2007 Ford Mustang was traveling eastbound and approaching a "T" intersection intending to turn left. A 2003 GMC Yukon was traveling southbound and approaching the same intersection. In the intersection, the front of the Yukon struck the left side of the Mustang. The Yukon deflected left and departed the road to the left side, where its front struck a signpost (NASS Case No. 2011-48-206). Both vehicles were towed due to damage; the GMC Yukon is pictured in Figure 73-*left*. The driver's and passenger's (Figure 73-*right*) airbags both deployed.

The restrained driver was not treated but sustained two minor injuries which included lacerations and bruises on the upper extremity. The passenger, a 9 year old male weighing 54 kilograms (classified as a 12 year old) was also not treated but was reported to have sustained a contusion or hematoma to the thorax. This injury was believed to have been associated with the seat belt.

Figure 73. NASS Case Number 2011-48-206, GMC Yukon During Investigation Showing Damage to the Front (*left*) and the Instrument Panel Showing a Deployed Passenger Airbag (*right*)

The EDR recorded one event and reported that the SIR warning light was not illuminated prior to or during the crash. Both the steering wheel mounted drivers and the mid-instrument panel mounted passenger's airbag deployed a single stage at 25 milliseconds. The passenger seat was registered as being in the rearward seat track position. Further, the EDR recorded that the driver was seat belted at the time of the crash.

5.5.5.3 2012 GMC Terrain

A 2012 GMC Terrain was heading northbound towards an intersection in lane four of a four lane divided roadway. A Ford F-series pickup truck was heading southbound towards the same intersection in lane two of a four lane divided roadway. Both vehicles entered the intersection, with the Terrain initiating a left turn. The front of the Terrain impacted the left side of the Ford (NASS Case No. 2012-43-208). Both vehicles were towed due to vehicle damage; the damage to the front of the Terrain is presented in Figure 74-*left*. The driver's and passenger's (Figure 74-*right*) frontal airbags deployed.

The driver was restrained and not injured or treated. The passenger an 8 year old male weighing 34 kilograms (classified as a 12 year old) was also not injured and not treated.

Figure 74. NASS Case Number 2012-43-208, GMC Terrain During Investigation Showing More Damage to the Front Driver's Side (*left*) and the Instrument Panel Showing a Deployed Passenger Airbag (*right*)

The EDR recorded one event and the SIR warning light was not illuminated prior to or during the crash. The child was explicitly classified as a small adult and the EDR recorded that both the driver and passenger were restrained. The driver's steering wheel mounted airbag deployed both stages at 28 milliseconds and 128 milliseconds respectively; the later deployment is considered a disposal deployment as outlined in Chapter 2. There was one vehicle, a 2009 Cadillac Escalade, in the EDR dataset that in lieu of reporting a firing time for the second stage explicitly referred to the deployment as a disposal. However, the passenger's top instrument panel mounted airbag deployed both stages at 28 milliseconds and 63 milliseconds respectively. Also noted in Chapter 2 top-mounted airbags tend to be deployed more aggressively due to the fact that they typically deploy upwards towards the windshield first and then back towards the passenger. However, these airbag firing times are interesting as the passenger airbag deployment appears more aggressive than the driver's deployment. This airbag was explicitly listed as an Autoliv airbag.

5.6 Conclusions

Using publicly available data a list of advanced airbag deployment strategies for three different child occupant classes was generated by vehicle model year, make and model. Most frequently airbags were certified to suppress for ALL occupants 0 – 6 years old, followed by a mixed deployment technique for the three occupant classes, least common was low risk deployment for occupants 1– 6 years old. Combined with this information it was possible to analyze whether the advanced airbags are working as designed or intended. It was not possible to evaluate whether the airbag behaved as designed for occupants classified as twelve year olds; however, it is interesting to evaluate whether the airbags in these crashes behaved in accordance with the certified strategy for the six year old occupant class or not. Since advanced airbags decide whether to deploy or not based on an occupant's weight, this analysis classified children into different child occupant classes by weight and evaluated the behavior of advanced airbags in comparison with the vehicle's certified technique.

In 10 of the cases an advanced airbag suppressed in agreement with the certified strategy. That is, for children classified by weight as being in a particular occupant class, the airbag suppressed which aligned with the certified strategy for that vehicle make and model. There was one case where an advanced airbag was classified as deploying as certified for an occupant classified as a six year old.

There was no evidence of advanced airbags that performed improperly. However, most of the cases involved children who were classified as 12 year old occupants for which deployment strategies are not required as such there is no way to know whether the airbag worked as intended.

Despite this, the behavior of the airbags in the presence of occupants classified as 12 year olds was analyzed. In some cases the airbag still suppressed for the older children. Interestingly, there were three advanced airbags that suppressed for children classified as 12 year olds when their deployment strategy for the 6 year old occupant class was suppression. For the vehicles in the advanced airbag group without certified deployment strategies, their probable strategies were predicted by using the following or previous model year's certified strategy.

In addition, the only three cases involving a moderately injured child in the right front passenger seat during a crash were examined. One of the three children required hospitalization, was likely hospitalized due to the number of injuries sustained. Most of these injuries were identified as being caused by the seat belt. According to NASS, none of the three moderate injury cases presented injuries associated with the airbag. One of the airbags suppressed, the other two deployed. The child seated in front of the airbag that suppressed weighed 48.9 kilograms (classified as a 12 year old by standards defined herein) was seated in close proximity to the instrument panel this occupant sustained a cerebral concussion with loss of consciousness for less than 30 minutes and a facial hematoma. The suspected cause of this injury was the instrument panel which may have been prevented if the airbag deployed. On the other hand the child could have been more seriously injured if the airbag had deployed. Additionally, one child was unrestrained, the remaining two were restrained. All of the advanced airbag cases involving moderate injuries had airbags which were certified for suppression for ALL occupants 0 – 6 years old. However, the occupants involved in the crashes examined were all older (11 and 12 years old). Further, one of the cases involving a moderate injury was also in the EDR database.

The EDR database was used to present cases where the passenger was seated in a child safety seat, children were unrestrained, the EDR expressly detected a child and finally cases where the advanced airbags suppressed or deployed respectively. The EDR database provided information regarding the seat belt status of the occupants, the airbag and pretensioner deployments as well as the number of events, status of the SIR warning lamp and on occasion seat track positioning for the occupants. None of the injuries sustained by children were identified as being related to the deployment of the airbag and a number of children were not injured.

There were a total of 30 advanced airbag cases in the database. A total of 10 suppressed, 17 deployed and for the remaining three there was no deployment; most cases involved older children though there was one newborn. Two cases involved children seated in belt positioning booster seats, both of those airbags suppressed. There were another two cases that involved unrestrained children, one was an newborn who appeared to have been riding in an infant seat that may not have been restrained to the Chevrolet C/K-Series pickup and the other was a 12 year old who was riding in a Hummer H3. The Chevrolet suppressed the bag and the newborn was not injured; however, several of the Hummer's airbags deployed, but there were no injuries reported for that occupant. Another two EDRs expressly detected a child in the RFP seat, both were Ford vehicles. One was an Escape which was occupied by a 5 year old in a booster seat, the airbag suppressed and the child sustained minor injuries. However, the driver of the Escape sustained several severe injuries and was hospitalized for 17 days. The other was an F-150 wherein a 9 year old was restrained in the RFP seat, neither airbags deployed during in the crash. The occupant was not injured.

In the two cases examined involving an advanced airbag that suppressed, the children suffered minor injuries resulting from the seat belt. Two of the three cases examined involving advanced airbags that deployed involved children who were not injured, one suffered minor injuries resulting from the seat belt. Interestingly, one airbag appeared to have deployed more aggressively than the driver's airbag as evidenced by the second stage deployment times reported by the EDR this child was not injured.

An evaluation of EDR data revealed that the advanced airbags could detect children and suppress the airbag in their presence or deploy in such a way as to prevent serious injury. Further, the EDR data provided information regarding pre-tensioner and second stage airbag deployment times. A majority of the cases with EDR data revealed that the driver and passenger airbags fired at similar times, though this could have been due to the fact that older children were seated in front of advanced airbags.

6 Conclusions

The first half of this thesis described the motivation for the development of advanced airbags and discussed how the advanced airbags are tested and certified. Namely, an advanced airbag can be designed to deploy or suppress the airbag for child occupants classified as 1-, 3- or 6-years old. The airbag deployment strategy or technique was defined as the combination of whether or not the airbag was designed to suppress or deploy in a low risk manner for each occupant class. In other words, a suppression strategy would indicate that the airbag was designed or certified to suppress for the 1-, 3- and 6-years old occupants.

6.1 Fatality Risk

A child fatality analysis was performed using the Fatality Analysis Reporting System (FARS) 1995 -2013 to explore the factors and risks pertaining to children seated in the right front passenger seat. Frontal and rollover crashes present the highest fatality risk to children (< 13 years old) amongst all crash modes. The FARS fatality analysis was coupled with an exposure analysis using NASS-GES. Encouragingly, with time and newer vehicles children were less likely to be seated in the RFP where a frontal airbag would deploy. When children were seated in the RFP seat they were older. In addition, children were also more likely to be restrained in recent calendar years and newer vehicles.

6.2 Advanced Airbags Present Lower Risk of Injury for Children

NASS-CDS was used to extract real-world crashes involving children seated in the RFP location. Young children are less likely to be seated in front of an airbag due to widespread advertising and information campaigns and as a result the sample size of children seated in front of advanced airbags in NASS-CDS was relatively small. A logistic regression analysis was performed on the resulting data to compare previous airbag generations to advanced airbags. Though the sample size was small, the probability of moderate injury for a child seated in front of an advanced airbag was significantly lower than that for non-advanced (1st and 2nd generation) airbags and vehicles not equipped with airbags. First generation airbags were estimated to present roughly 26 times greater odds of moderate injury than advanced airbags and similarly second generation airbags present 19 times higher odds of moderate injury for children seated in front of these bags during a crash. Even with the risk of moderate injury being lower for children seated in front of an advanced airbag versus any other airbag type, the safest place for a child is in the back seat of a vehicle.

It is interesting that there is a difference between no airbag and advanced airbags considering that for many occupant sizes the advanced airbags are designed to suppress essentially rendering that occupant without an airbag. This suggests that other vehicle safety features may also be providing some of the protective benefit to children in the front seat. Encouragingly, the most injurious cases within the advanced airbag group were moderate (AIS 2) and further there were only three cases at that severity, the remainder of the injuries were minor (AIS 1). The factors affecting the probability of moderate injury were longitudinal delta-V, airbag generation and airbag deployment. However, airbag deployment was not an indicator of the probability of moderate injury amongst the advanced airbag group.

6.2.1 Injuries by Body Region

Injuries sustained by children in all four airbag groups were further analyzed by body region for children sustaining any injury including minor (AIS 1) injuries. In general, the proportions of injuries while seated in front of an advanced airbag regardless of whether it deployed were lower than earlier airbag generations, with a few exceptions.

Children injured in a crash while in front of an advanced airbag appear to sustain head injuries as frequently as those seated in front of second generation airbags. Further, there were proportionally more injured children seated in front of an advanced airbag that did not deploy who sustained head injuries than those in front of first or second generation airbags. However, the head injuries in the advanced airbag group ranged from minor to moderate.

Also, though minor (AIS 1) in severity, proportionally more children sustained neck injuries seated in front of an advanced airbag that did not deploy than those who were seated in front of advanced airbags that did deploy. Proportionally more children sustained minor chest injuries when seated in front of an advanced airbag which did not deploy than those in front of advanced airbags that did deploy. Finally, a large proportion of children injured as a result of a crash, while seated in front of an advanced airbag which did not deploy, sustained minor lower extremity injuries.

6.3 Advanced Airbag Performance Analysis

Using publicly available data, a list of advanced airbag deployment strategies for three different child occupant classes was generated by vehicle model year, make and model. Most frequently airbags were certified to suppress for ALL occupants 0 – 6 years old, followed by a mixed deployment technique for the three occupant classes. Least common was low risk deployment for occupants 1– 6 years old. Combined with this information it was possible to analyze whether the advanced airbags were working as designed or intended. Because there is not special regulatory deployment requirement for 12-year olds, it was not possible to evaluate whether the airbag behaved as designed for occupants classified as twelve year olds; however, it is interesting to evaluate whether the airbags in these crashes behaved in accordance with the certified strategy for the six year old occupant class or not. Since advanced airbags decide whether to deploy or not based on an occupant's weight, this analysis classified children into different child occupant classes by weight and evaluated the behavior of advanced airbags in comparison with the vehicle's certified technique.

In 10 of the cases an advanced airbag suppressed in agreement with the certified strategy. That is, for children classified by weight as being in a particular occupant class, the airbag suppressed which aligned with the certified strategy for that vehicle make and model. There was one case where an advanced airbag was classified as deploying as certified for an occupant classified as a six year old. Though there have been no fatalities or serious injuries to children seated in front of advanced airbags, this research also presents anecdotal evidence using our EDR database to evaluate how the advanced airbags are working during real-world crashes. The EDR database provided information regarding the seat belt status of the occupants, the airbag and pre-tensioner deployments as well as the number of events, status of the SIR warning lamp and on occasion seat track positioning for the occupants. None of the injuries sustained by children were identified as being related to the deployment of the airbag and a number of children were not injured.

There was no evidence of cases in which advanced airbags that performed improperly. However, most of the cases involved children who were classified as 12-year-old occupants for which deployment strategies are not required as such there is no way to know whether the airbag worked as intended. Despite this, the behavior of the airbags in the presence of occupants classified as 12 year olds was analyzed. In some cases, the airbag still suppressed for the older children. Interestingly, there were three advanced airbags that suppressed for children classified as 12 year olds when their deployment strategy for the 6-year-old occupant class was suppression. For the vehicles in the advanced airbag group without certified deployment strategies, their probable strategies were predicted by using the following or previous model year's certified strategy.

6.3.1 Advanced Airbag Cases Involving Moderate Injuries

In addition, the only three cases involving a moderately injured child in the right front passenger seat during a crash were examined. One of the three children required hospitalization, was likely hospitalized due to the number of injuries sustained. Most of these injuries were identified as being caused by the seat belt. None of the three cases presented injuries associated with the airbag. One of the airbags suppressed while the other two airbags deployed. All of the advanced airbag cases involving moderate injuries had airbags which were certified for suppression for ALL occupants 0 – 6 years old. However, the occupants involved in the crashes examined were all older (11 and 12 years old). Further, one of the cases involving a moderate injury was also in the EDR database.

6.3.2 EDRs Indicate Advanced Airbags Are Working In Real World Crashes

The EDR 2006-2013 database was used to identify cases where the passenger was seated in a child safety seat, children were unrestrained, the EDR expressly detected a child and finally cases where the advanced airbags suppressed or deployed respectively. The EDR database provided information regarding the seat belt status of the occupants, the airbag and pretensioner deployments as well as the number of events, status of the airbag warning lamp and on occasion seat track positioning for the occupants. None of the injuries sustained by children were identified as being related to the deployment of the airbag and a number of children were not injured.

There were a total of 30 advanced airbag cases in the EDR database. A total of 10 suppressed, 17 deployed and for the remaining three there was no deployment. Most cases involved older children though there was one newborn. Two cases involved children seated in belt positioning booster seats, both of those airbags suppressed. Another two EDRs (both Fords) expressly detected a child in the RFP seat. One was a Ford Escape which was occupied by a 5 year old in a booster seat. In this case, the airbag suppressed and the child sustained minor injuries. However, the driver of the Escape sustained several severe injuries and was hospitalized for 17 days. The other case was a Ford F-150 wherein a 9 year old was restrained in the RFP seat. In this case, neither airbag deployed during the crash, and the occupant was not injured.

In the two cases examined involving an advanced airbag that suppressed, the children suffered minor injuries resulting from the seat belt. Two of the three cases examined involving advanced airbags that deployed involved children who were not injured, one suffered minor injuries resulting from the seat belt. Interestingly, one airbag appeared to have deployed more aggressively than the driver's airbag as evidenced by the second stage deployment times reported by the EDR this child was not injured.

6.4 LIMITATIONS

Though this work found a statistically significant difference between the injury risk to children in front of advanced airbags as compared with a vehicle with any other generation airbag including those not equipped with airbags, this difference was based on three unweighted cases. The small sample size, while in some ways indicative of the safety benefits provided by advanced airbags, may have exaggerated the differences between advanced airbags and prior generation airbags. The comparison of the certified strategy and the actual response of advanced airbags in a real-world crash reinforced the results of the safety study. Further, the anecdotal case studies revealed cases where occupants, mainly drivers, within the same vehicle were more severely injured than the child. Nonetheless, the small sample size is an inherent limitation within this study that must be considered while interpreting the results presented herein.

This study also does not address or differentiate between the effect of advanced airbags and other safety technologies that set vehicles with advanced airbags apart from vehicles from prior vehicle generations. In the period between model year 1980 and 2013, NHTSA's regulation and verification of vehicle safety devices has inspired numerous safety advancements within the auto industry, including forward collision and lane departure warning systems [64]. Since the dataset was already limited and separation of these safety advancements is outside the scope of the work, it is important to consider the conclusions in light of this limitation.

Safety features are not the only thing that has changed during the 19-year period studied. There have been numerous public safety programs aimed at changing the behaviors of drivers in the US between 1995 and 2013. One of the behavior safety initiatives, noted throughout this work, has focused on informing parents and caregivers that the safest place for children riding in vehicles is the backseat. Because the program has been very effective, it has been difficult to analyze the effects of advanced airbags on children. Some other behavior initiatives that span the period studied and may affect the results include: (1) seat belt use, (2) proper child safety seat selection and installation, (3) speed limit changes and enforcement, (4) alcohol- and drug-involved driving, and (5) fatigue and distracted driving awareness. The effects of behavioral initiatives may have affected the results reported within this work as well; these effects were not specifically factored into the analysis of the results, but as exposures to each of the behaviors has increased or decreased, so has the risk associated with those behaviors.

Finally, economic factors have at times increased or decreased the vehicle miles traveled (VMT) and as a result the exposure of children riding within vehicles would directly correlate to those economic changes. Any change in exposure could affect the results obtained since the data analyzed by and large was derived from a nationally representative sample.

6.5 SUMMARY

The probability of moderate injury for a child seated in front of an advanced airbag is significantly lower than that for non-advanced (1st and 2nd generation) airbags and vehicles not equipped with airbags. Some of the injury risk reduction appears to be related to the incorporation of other safety features within newer vehicles, not just the advanced airbag itself as one option for an advanced airbag is suppression which would render the occupant without an airbag. Despite that, children involved in crashes within vehicles equipped with an advanced airbag were still at a lower risk of injury than a child in a vehicle not equipped with an airbag at the same delta-V.

Advanced airbag performance during real-world crashes where a child was seated in the RFP seat was compared with the manufacturer's certified strategy. There was no evidence of advanced airbags that performed improperly. An evaluation of EDR data revealed that the advanced airbags could detect children and suppress the airbag in their presence or deploy in such a way as to prevent serious injury. Further, the EDR data provided information regarding pre-tensioner and second stage airbag deployment times. A majority of the cases with EDR data revealed that the driver and passenger airbags fired at similar times, though this could have been due to the fact that older children were seated in front of advanced airbags.

Compared to first generation airbags, the outcomes for children involved in crashes while seated in the front seat are vastly improved. However, the back seat remains the safest place for children; this work in no way advocates that children should be seated in the RFP seat.

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8 APPENDIX

Table 19. Tabulation of advanced airbag deployment strategies by model year, make and model; strategies are listed for 12-month old, 3 year old, and 6 year old respectively
S = suppression, L = low risk deployment, * = conflicting strategies

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
ACUR	CL/TL	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
ACUR	Legend/RL	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
ACUR	MDX	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
ACUR	Other Auto						SSL	SSL	SSL
ACUR	RDX				SSL	SSL	SSL	SSL	SSL
ACUR	TSX		SSL	SSL	SSL	SSL	SSL	SSL	SSL
ACUR	ZDX							SSL	SSL
AM	Hummer H3	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
AUDI	A3		SLL	SLL	SLL	SLL	SLL	SLL	SLL
AUDI	A4	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
AUDI	A5				SLL	SLL	SLL	SLL	SLL
AUDI	A6	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
AUDI	A8		SLL	SLL	SLL	SLL	SLL	SLL	SLL
AUDI	Cabriolet			SLL	SLL	SLL	SLL	SLL	SLL
AUDI	Q5					SLL	SLL	SLL	SLL
AUDI	Q7			SLL	SLL	SLL	SLL	SLL	SLL
AUDI	R8				SLL	SLL	SLL	SLL	SLL
AUDI	S4	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
AUDI	S6			SLL	SLL	SLL	SLL	SLL	SLL
AUDI	S7								SLL
AUDI	S8			SLL	SLL	SLL	SLL	SLL	SLL
AUDI	TT				SLL	SLL	SLL	SLL	SLL
BENT	Arnage & Continental							SLL	SLL
BMW	1-series				SLL	SLL	SLL	SLL	SLL
BMW	3-series	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
BMW	5-series	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
BMW	6-series		SLL	SLL	SLL	SLL	SLL	SLL	SLL
BMW	7-series	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
BMW	x3	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
BMW	x5		SSS	SSS	SLL	SLL	SLL	SLL	SLL
BMW	x-6					SLL	SLL	SLL	SLL
BMW	z4	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
BUIC	Enclave				SSS	SSS	SLL	SLL	SLL
BUIC	Lacrosse	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SLL
BUIC	Lucerne		SSS	SSS	SSS	SSS	SSS	SSS	SSS
BUIC	Rainier	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
BUIC	Regal							SSS	SSS
BUIC	Rendezvous		SSS	SSS	SSS	SSS	SSS	SSS	SSS
BUIC	Terraza		SSS	SSS	SSS	SSS	SSS	SSS	SSS
BUIC	Verano								SLL
CADI	CTS	SSS	SSS	SSS	SSS	LLL	LLL	SLL	SLL
CADI	DTS		SSS	SSS	SSS	SSS	SSS	SSS	SSS
CADI	Escalade			SSS	SSS	LLL	SLL	SLL	SLL
CADI	Escalade ESV		SSS	SSS	SSS	LLL	SLL	SLL	SLL
CADI	Escalade EXT		SSS	SSS	SSS	LLL	LLL	SLL	SLL
CADI	SRX				SSS	SSS	SSS	SSS	SSS
CADI	STS	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
CADI	XLR		SSS	SSS	SSS	SSS	SSS	SSS	SSS
CHEV	Avalanche		SSS	SSS	SSS	LLL	SLL	SLL	SLL
CHEV	Aveo		SSS	SSS	SSS	SSS	SSS	SSS	SSS
CHEV	Camaro						SSS	SSS	SSS
CHEV	Caprice PPV							SLL	SSS
CHEV	Captiva							SSS	SSS
CHEV	Cobalt		SSS	SSS	SSS	SLL	SLL	SLL	SLL
CHEV	Colorado		SSS	SSS	SSS	SSS	SSS	SSS	SSS
CHEV	Corvette		SSS	SSS	SSS	SSS	SSS	SSS	SSS
CHEV	Cruze							SSS	SLL
CHEV	Equinox				SSS	SSS	SSS	SLL	SLL
CHEV	G-series Van				SSS	SSS	SSS	SSS	SSS
CHEV	HHR		SSS	SSS	SSS	SLL	SLL	SLL	SLL
CHEV	Impala		SSS	SSS	SSS	LLL	SLL	SLL	SLL
CHEV	Malibu				SSS	SSS	SSS	SSS	SSS
CHEV	Monte Carlo		SSS	SSS	SSS	SSS	SSS	SSS	SSS
CHEV	Other lt truck		SSS	SSS	SSS	LLL	SLL	SLL	SLL
CHEV	Sonic								SSS
CHEV	Suburban			SSS	SSS	LLL	SLL	SLL	SLL
CHEV	Trail Blazer	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
CHEV	Traverse					LLL	SLL	SLL	SLL
CHEV	Uplander	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
CHEV	Volt							SLL	SLL
CHRY	200							LLL	LLL
CHRY	300 M		SLL	SLL	LLL	LLL	LLL	LLL	LLL
CHRY	Aspen				LLL	LLL	LLL	LLL	LLL
CHRY	Conquest	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
CHRY	Crossfire				SSS	SSS	SSS	SSS	SSS
CHRY	Oth LT Truck								LLL
CHRY	Pacifica	SSS	SSS	SSS	LLL	LLL	LLL	LLL	LLL
CHRY	PT Cruiser		SSS	SSS	SLL	SSS	SSS	SSS	SSS
CHRY	Sebring				LLL	LLL	LLL	LLL	LLL

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
CHRY	Town & Country	SSS	SSS	SSS	SSS	LLL	LLL	LLL	LLL
DODG	Avenger				LLL	LLL	LLL	LLL	LLL
DODG	Caliber		SLL	SLL	LLL	LLL	LLL	LLL	LLL
DODG	Caravan	SSS	SSS	SSS	LLL	LLL	LLL	LLL	LLL
DODG	Challenger						LLL	LLL	LLL
DODG	Challenger					LLL	LLL	LLL	LLL
DODG	Charger				LLL	LLL	LLL	LLL	LLL
DODG	Charger		SLL	SLL	LLL	LLL	LLL	LLL	LLL
DODG	Dakota	SLL	SLL	SLL	LLL	LLL	LLL	LLL	LLL
DODG	Durango	SLL	SLL	SLL	LLL	LLL	LLL	LLL	LLL
DODG	Journey					LLL	LLL	LLL	LLL
DODG	Magnum	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
DODG	Nitro				SSS	SSS	SSS	SSS	SSS
DODG	Other lt Truck							LLL	LLL
DODG	Ram 1500 P/U				LLL	LLL	LLL	LLL	LLL
DODG	Ram C/V								LLL
DODG	Viper				SSS	SSS	SSS	SSS	SSS
FIAT	500 / 500c								LLL
FORD	Aspire	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Crown Victoria		SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Edge				SSS	SSS	SSS	SSS	SSS
FORD	Escape	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Explorer		SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Fiesta							SSS	SSS
FORD	Five Hundred	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Flex					SSS	SSS	SSS	SSS
FORD	Focus	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Freestar	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Freestyle	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	F-series P/U	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Fusion		SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Mustang	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Other lt truck								LLL
FORD	Ranger				SSS	SSS	SSS	SSS	SSS
FORD	Sport Trac			SSS	SSS	SSS	SSS	SSS	SSS
FORD	Taurus/Taurus X	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
FORD	Transit Connect						SSS	SSS	SSS
GMC	Acadia				SSS	LLL	SLL	SLL	SLL
GMC	Canyon		SSS	SSS	SSS	SSS	SSS	SSS	SSS
GMC	G-series Van				SSS	SSS	SSS	SSS	SSS
GMC	Jimmy Fullsize	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
GMC	Suburban		SSS	SSS	SSS	SSS	SLL	SLL	SLL
GMC	Terrain						SLL	SLL	SLL

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
HOND	Accord	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
HOND	Civic/CRX	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
HOND	C-RV	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
HOND	Element				SSL	SSL	SSL	SSL	SSL
HOND	FCX					SSL	SSL	SSL	SSL
HOND	Fit			SSL	SSL	SSL	SSL	SSL	SSL
HOND	Insight						SSL	SSL	SSL
HOND	Odyssey	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
HOND	Pilot	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
HOND	Ridgeline				SSL	SSL	SSL	SSL	SSL
HOND	S2000		SSL	SSL	SSL	SSL	SSL	SSL	SSL
HYUN	Accent		SSS	SSS	SSS	SSS	SSS	SLL	SLL
HYUN	Azera		SSS	SSS	SSS	SSS	SSS	SSS	SLL
HYUN	Elantra	SSS	SSS	SSS	SSS	SSS	SSS	*	*
HYUN	Entourage		SSS	SSS	SSS	SSS	SSS	SSS	SSS
HYUN	Equus							SLL	SLL
HYUN	Genesis					SSS	*	*	*
HYUN	Santa Fe	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
HYUN	Sonata		SSS	SSS	SSS	SSS	SSS	SLL	SLL
HYUN	Tiburon				SSS	SSS	SSS	SSS	SSS
HYUN	Tuscon	SSS	SSS	SSS	SSS	SSS	SLL	SLL	SLL
HYUN	Veloster								SLL
HYUN	Veracruz				SSS	SSS	SSS	SSS	SSS
INFI	EX35				SSS	SSS	SSS	SSS	SSS
INFI	FX35/45		SSS	SSS	SSS	SSS	SSS	SSS	SSS
INFI	G25/G35/G37	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
INFI	M35/M37/M45/ M56		SSS	SSS	SSS	SSS	SSS	SSS	SSS
INFI	Q45		SSS	SSS	SSS	SSS	SSS	SSS	SSS
INFI	QX56	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
ISUZ	Ascender	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
ISUZ	Other lt truck				SSS	SSS	SSS	SSS	SSS
JAG	XF/XF-R				SSS	SSS	SSS	SSS	SSS
JAG	XJ6/12 Sedan/Coupe		SSS	SSS	SSS	SSS	SSS	SSS	SSS
JAG	XJ-S Coupe	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
JAG	XK-E					SSS	SSS	SSS	SSS
JAG	XKR/XK	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
JAG	X-Type	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
JEEP	Commander		SLL	SLL	LLL	LLL	LLL	LLL	LLL
JEEP	Compass				LLL	LLL	LLL	LLL	LLL
JEEP	Grand Cherokee	SSS	SLL	SLL	LLL	LLL	LLL	LLL	LLL
JEEP	Liberty	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
JEEP	Patriot				LLL	LLL	LLL	LLL	LLL

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
JEEP	YJ-Wrangler				LLL	LLL	LLL	LLL	LLL
KIA	Amanti	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
KIA	Borrego					SLL	SLL	SLL	SLL
KIA	Forte						SLL	SLL	SLL
KIA	Optima		SSS	SSS	SSS	SLL	SLL	SLL	SLL
KIA	Rio		SSS	SSS	SSS	SSS	SSS	SLL	SLL
KIA	Rondo			SSS	SSS	SSS	SSS	SSS	SSS
KIA	Sedona		SSS	SSS	SSS	SSS	SSS	SSS	SSS
KIA	Sorrento	SSS	SSS	SSS	SSS	SSS	SSS	SLL	SLL
KIA	Soul						SLL	SLL	SLL
KIA	Spectra	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
KIA	Sportage	SSS	SSS	SSS	SSS	SSS	SSS	SLL	SLL
LEXS	CT200h							SSS	SSS
LEXS	ES-250 /300	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
LEXS	GS-300		SSS	SSS	SSS	SSS	SSS	SSS	SSS
LEXS	GX470	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
LEXS	HS250h						SSS	SSS	SSS
LEXS	IS-300			SSS	SSS	SSS	SSS	SSS	SSS
LEXS	LFA								SSS
LEXS	LS-400			SSS	SSS	SSS	SSS	SSS	SSS
LEXS	LX 450 /470			SSS	SSS	SSS	SSS	SSS	SSS
LEXS	Other Auto				SSS	SSS	SSS	SSS	SSS
LEXS	Other lt truck				SSS	SSS	SSS	SSS	SSS
LEXS	RX330 /350 / 400 h	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
LEXS	SC430			SSS	SSS	SSS	SSS	SSS	SSS
LINC	Mark LT				SSS	SSS	SSS	SSS	SSS
LINC	MKS					SSS	SSS	SSS	SSS
LINC	MKT						SSS	SSS	SSS
LINC	MKX				SSS	SSS	SSS	SSS	SSS
LINC	Navigator				LLL	LLL	LLL	LLL	LLL
LINC	Other Auto				SSS	SSS	SSS	SSS	SSS
LINC	TownCar	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
LINC	Zephyr		SSS	SSS	SSS	SSS	SSS	SSS	SSS
LROV	LR2			SSS	SSS	SSS	SSS	SSS	SSS
LROV	LR3	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
LROV	Other lt truck		SSS	SSS	SSS	SSS	SSS	SSS	SSS
MAZD	CX-7			SSS	SSS	SSS	SSS	SSS	SSS
MAZD	CX-9			SSS	SSS	SSS	SSS	SSS	SSS
MAZD	Mazda 2							SSS	SSS
MAZD	Mazda 3	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
MAZD	Mazda 5		SSS	SSS	SSS	SSS	SSS	SSS	SSS
MAZD	Mazda 6	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
MAZD	Miata		SSS	SSS	SSS	SSS	SSS	SSS	SSS

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
MAZD	MPV	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
MAZD	Other auto					SSS	SSS	SSS	SSS
MAZD	RX-8	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
MAZD	Tribute				SSS	SSS	SSS	SSS	SSS
MERC	Mariner				SSS	SSS	SSS	SSS	SSS
MERC	Marquis				SSS	SSS	SSS	SSS	SSS
MERC	Milan		SSS	SSS	SSS	SSS	SSS	SSS	SSS
MERC	Mountaineer				SSS	SSS	SSS	SSS	SSS
MERC	Sable				SSS	SSS	SSS	SSS	SSS
MERC	Tracer								SSS
MERZ	200 -300 Sedan/Coupe	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	220 /280 C	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	230 /280 SL	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	280 /300 SEL			SLL	SLL	SLL	SLL	SLL	SLL
MERZ	300		SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	300 -450 SE	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	300 -560 SL	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	400/500 E		SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	B Class				SSS	SSS	SSS	SLL	SLL
MERZ	CL	BBB	BBB	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	CLK	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	CLS Class	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	E Class	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	G Class	BBB	BBB						
MERZ	GL Class			SLL	SLL	SLL	SLL	SLL	SLL
MERZ	GLK Class						SLL	SLL	SLL
MERZ	M Class	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	Maybach	BBB	BBB	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	R Class		SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	S Class	BBB	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	SL Class	BBB	BBB	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	SLK	BBB	BBB	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	SLR McLaren	BBB	BBB	SLL	SLL	SLL	SLL	SLL	SLL
MERZ	SLS Class							SLL	SLL
MINI	Clubman				SLL	SLL	SLL	SLL	SLL
MINI	Cooper	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
MITS	Eclipse		SSL	SSL	SSL	SSL	SSL	SSL	SSL
MITS	Endeavor	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
MITS	Galant	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
MITS	Lancer				SSL	SSL	SSL	SSL	SSL
MITS	Outlander	SSL	SSL	SSL	SSL	SSL	SSL	SSL	SSL
MITS	Raider				LLL	LLL	LLL	LLL	LLL
NISS	370Z			SSS	SSS	SSS	SSS	SSS	SSS

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
NISS	Altima	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	Armada	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	Cube					SSS	SSS	SSS	SSS
NISS	Frontier	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	GT-R					SSS	SSS	SSS	SSS
NISS	Juke							SSS	SSS
NISS	Leaf							SSS	SSS
NISS	Maxima	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	Murano		SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	Pathfinder	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	Quest	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	Rogue				SSS	SSS	SSS	SSS	SSS
NISS	Sentra			SSS	SSS	SSS	SSS	SSS	SSS
NISS	Titan	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
NISS	Versa			SSS	SSS	SSS	SSS	SSS	SSS
NISS	X-terra	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
PONT	G3					SSS	SSS	SSS	SSS
PONT	G5				SSS	SLL	SLL	SLL	SLL
PONT	G6		SSS	SSS	SSS	SSS	SSS	SSS	SSS
PONT	G8				SSS	SSS	SSS	SSS	SSS
PONT	Grand Prix				SSS	SSS	SSS	SSS	SSS
PONT	Oth lt Truck		SSS	SSS	SSS	SSS	SSS	SSS	SSS
PONT	Solstice		SSS	SSS	SSS	SSS	SSS	SSS	SSS
PONT	Torrent		SSS	SSS	SSS	SSS	SSS	SSS	SSS
PONT	Vibe	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
PORS	911		SLL	SSS	SLL	SLL	SLL	SLL	SLL
PORS	Boxster		SLL	SSS	SLL	SLL	SLL	SLL	SLL
PORS	Cayenne		SLL	SLL	SLL	SLL	SLL	SLL	SLL
PORS	Cayman		SLL	SSS	SLL	SLL	SLL	SLL	SLL
PORS	Panamera						SLL	SLL	SLL
SAAB	9-2X		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SAAB	9-3		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SAAB	9-5		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SAAB	9-7X		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SAAB	Other Auto							SSS	SSS
SATN	Astra				SSS	SSS	SSS	SSS	SSS
SATN	Aura				SSS	SSS	SSS	SSS	SSS
SATN	Ion		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SATN	Outlook				SSS	LLL	SLL	SLL	SLL
SATN	Relay		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SATN	Sky				SSS	SSS	SSS	SSS	SSS
SATN	Vue		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SCIN	iQ							SSS	SSS

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
SCIN	tC			SSS	SSS	SSS	SSS	SSS	SSS
SCIN	xB		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SCIN	xD				SSS	SSS	SSS	SSS	SSS
SMRT	ForTwo				SLL	SLL	SLL	SLL	SLL
SMRT	Other Auto						SLL	SLL	SLL
SUBA	B9 Tribeca		SLL	SSS	SSS	SSS	SSS	SSS	SSS
SUBA	Baja		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUBA	BRZ								SLL
SUBA	Forester		SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUBA	Impreza		SLL	SSS	SSS	SSS	SSS	SSS	SSS
SUBA	Legacy	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUBA	Outback	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUZU	Aerio	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUZU	Equator					SSS	SSS	SSS	SSS
SUZU	Forenza	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUZU	Grand Vitara	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUZU	Kizashi						SSS	SSS	SSS
SUZU	Reno	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUZU	SX4				SSS	SSS	SSS	SSS	SSS
SUZU	Verona	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
SUZU	XL7				SSS	SSS	SSS	SSS	SSS
TOYT	4-Runner	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Avalon	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Camry	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SLL
TOYT	Corolla	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	FJ Cruiser		SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Highlander	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Landcruiser			SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Matrix	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Prius		SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	RAV-4		SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Sequoia	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Sienna	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Solara	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Tacoma	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Tundra	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
TOYT	Venza					SSS	SSS	SSS	SSS
TOYT	Yaris		SSS	SSS	SSS	SSS	SSS	SSS	SSS
VOLV	40 Series	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
VOLV	60 Series		SSS	SSS	SSS	SSS	SSS	SSS	SSS
VOLV	70 Series	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
VOLV	80 Series		SSS	SSS	SSS	SSS	SSS	SSS	SSS
VOLV	C3				SSS	SSS	SSS	SSS	SSS

Make	Model	2005	2006	2007	2008	2009	2010	2011	2012
VOLV	Other Auto				SSS	SSS	SSS	SSS	SSS
VOLV	V5	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
VOLV	XC6					SSS	SSS	SSS	SSS
VOLV	XC7	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
VOLV	XC9	SSS	SSS	SSS	SSS	SSS	SSS	SSS	SSS
VW	CC						SLL	SLL	SLL
VW	Eos				SLL	SLL	SLL	SLL	SLL
VW	Golf		SLL	SLL	SLL	SLL	SLL	SLL	SLL
VW	Jetta	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
VW	New Beetle	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
VW	Other Auto				SLL	SLL	SLL	SLL	SLL
VW	Passat		SLL	SLL	SLL	SLL	SLL	SLL	SLL
VW	Phaeton	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL
VW	Rabbit			SLL	SLL	SLL	SLL	SLL	SLL
VW	Routan					LLL	LLL	LLL	LLL
VW	Tiguan					SLL	SLL	SLL	SLL
VW	Touareg	SLL	SLL	SLL	SLL	SLL	SLL	SLL	SLL

Table 20. List of vehicles equipped with an advanced airbag during the phase-in period (MY 2003 - 2006); * Indicates Vehicles Identified by NHTSA [52]

Make	Model	Model Year First Equipped
Acura	MDX	2003
Acura	RL	2005
Acura	TL	2005
Acura	TSX	2006*
Audi	A4	2005
Audi	A6	2005
Audi	A8	2006*
BMW	3-Series	2005
BMW	5-Series	2004
BMW	6-Series	2004
BMW	7-Series	2004
BMW	X3	2004
BMW	X5	2006*
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	Escalade EXT	2005
Cadillac	STS	2005
Cadillac	XLR	2006*
Chevrolet	Avalanche	2003
Chevrolet	Aveo	2006*
Chevrolet	Blazer/Tahoe	2003
Chevrolet	C/K-Series Pickup	2003
Chevrolet	Cobalt	2006*
Chevrolet	Colorado	2006*
Chevrolet	Corvette	2006*
Chevrolet	Malibu	2006*
Chevrolet	Monte Carlo	2006*
Chevrolet	Suburban	2003
Chevrolet	Trail Blazer	2005
Chevrolet	Uplander	2005
Chrysler	300	2005
Chrysler	Pacifica	2005
Chrysler	Town & Country	2005
Dodge	Dakota	2005

Make	Model	Model Year First Equipped
Dodge	Durango	2004
Dodge	Caravan & Grand Caravan	2006*
Dodge	Magnum	2005
Ford	Crown Victoria	2005
Ford	Escape	2005
Ford	Five Hundred	2005
Ford	Focus	2005
Ford	Freestar	2005
Ford	Freestyle	2005
Ford	Freestyle	2005
Ford	F-Series	2004
Ford	Mustang	2005
Ford	Taurus	2004
GMC	C,K,R,V-Series	2003
GMC	Canyon	2006*
GMC	Jimmy	2003
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	FX35	2006*
Infiniti	M45	2006
Infiniti	Q45	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	Sorrento	2005
Kia	Spectra	2004

Make	Model	Model Year First Equipped
Kia	Sportage	2005
Land	LR3	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	RX-8	2006*
Mazda	Tribute	2005
Mercedes	C Class	2005
Mercedes	CLK Class	2005
Mercedes	E Class	2005
Mercury	Mariner	2005
Mercury	Marquis	2005
Mercury	Montego	2005
Mini	Cooper S	2005
Mitsubishi	Endeavor	2005
Mitsubishi	Galant	2004
Mitsubishi	Lancer	2006*
Mitsubishi	Outlander	2005
Nissan	Altima	2005
Nissan	Armada	2005
Nissan	Frontier	2005
Nissan	Maxima	2005
Nissan	Murano	2006*
Nissan	Pathfinder	2004
Nissan	Quest	2004
Nissan	Titan	2004
Nissan	Xterra	2005
Pontiac	G6	2006*
Pontiac	GTO	2006*
Pontiac	Grand Prix	2006*
Pontiac	Solstice	2006
Pontiac	Trans	2005
Pontiac	Vibe	2005
Saab	9-2X	2006*
Saab	9-3	2006*
Saab	9-5	2006*
Saab	9-7X	2005
Saturn	Relay	2005

Make	Model	Model Year First Equipped
Saturn	Vue	2006*
Subaru	Forester	2006*
Subaru	Imprezza	2006*
Subaru	Legacy	2005
Subaru	Outback	2005
Suzuki	Aerio Gx	2005
Suzuki	Forenza	2005
Suzuki	Grand Vitara	2004
Suzuki	Reno	2005
Suzuki	Verona	2005
Toyota	4-Runner	2006*
Toyota	Camry	2004
Toyota	Corolla	2005
Toyota	Highlander	2004
Toyota	Matrix	2005
Toyota	Sequoia	2005
Toyota	Sienna	2005
Toyota	Solara	2005
Toyota	Tacoma	2005
Toyota	Tundra	2005
Volvo	S40	2005
Volvo	S60	2006*
Volvo	S80	2006*
Volvo	V50	2005
Volvo	V70	2005
Volvo	XC90	2005
VW	Beetle	2004
VW	Jetta	2005
VW	Phaeton	2005
VW	Touareg	2005