How Have Changes in Front Airbag Designs Affected Frontal Crash Death Rates? An Update

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ABSTRACT

Objective: Provide updated death rates comparing latest generations of frontal airbags in fatal crashes.

Methods: Rates of driver and right-front passenger deaths in frontal crashes per 10 million registered vehicle years were compared using Poisson marginal structural models for passenger vehicles equipped with airbags certified as advanced and compliant (CAC), sled-certified airbags with advanced features, and sled-certified airbags without any advanced features. Analyses of driver death rates were disaggregated by age group, gender, and belt use.

Results: CAC airbags were associated with slightly elevated nonsignificant frontal crash death rates for both drivers and right-front passengers, compared with sled-certified airbags with advanced features. Sled-certified airbags with advanced features were associated with significant benefits for drivers and for right-front passengers compared with sled certified airbags without advanced features. CAC airbags were associated with a significant increase in belted driver death rate and a comparable but nonsignificant decrease in unbelted driver death rate compared with sled-certified airbags with advanced features. Sled-certified airbags with advanced features were associated with a nonsignificant 2 percent increase in belted driver death rate and a significant 26 percent decrease in unbelted driver death rate, relative to sled-certified airbags without advanced features.

Conclusions: Implementing advanced features to sled-certified airbags was beneficial, overall, to drivers and right-front passengers with sled-certified airbags. No overall benefit was observed for CAC airbags, compared with sled-certified airbags with advanced features. Further study is needed to understand the reduction in belted driver protection observed for CAC airbags.

Keywords: Frontal airbags, Advanced airbags, Frontal crashes

INTRODUCTION

Driver and passenger frontal airbags are one of the chief countermeasures for frontal impact crashes, which account for a large portion of passenger vehicle occupant deaths each year. As of January 1, 2009, these airbags have saved more than 28,000 lives but also have been responsible for the deaths of an estimated 296 people who otherwise would have been expected to have relatively minor injuries (National Highway Traffic Safety Administration [NHTSA], 2009a). Nearly 90 percent of these deaths occurred in pre-1998 model year vehicles. Of the 296 deaths, 191 were children seated in the right-front passenger position. Due largely to state laws and publicity campaigns, children now tend to ride in the back seat, virtually eliminating possible interaction with airbags (NHTSA, 2009b). Airbags are regulated by NHTSA. These regulations include mandating airbag fitment as well as specifying performance criteria as measured through crash tests or other types of tests.

When airbags were first mandated, performance requirements specified maximum injury measures taken from 50th percentile male dummies in crash tests conducted at up to 30 mph head-on into a rigid barrier (NHTSA, 2012). Vehicles were tested using both belted and unbelted dummies, and both driver and right-front passenger airbags were subject to these performance requirements. Because airbag-related deaths resulted from inflation forces, it became clear that depowering airbags, or significantly reducing deployment energy, could prevent many of the deaths and injuries caused by them (NHTSA, 1996; Lund et al., 1996). However, performance requirements in the unbelted rigid barrier crash test often could not be achieved with less powerful airbags, as it requires substantial energy to restrain an unbelted 50th percentile male dummy in the upper end of the speed range over which these requirements must be met. As a result, NHTSA amended FMVSS 208 in 1997 to temporarily allow manufacturers the option to certify performance for unbelted occupant protection with an alternative sled test in which the test vehicle is mounted to a crash simulation sled and subjected to a specified crash pulse corresponding to a 30 mph impact (Office of the Federal Register, 1997). Although it represented the same impact speed as the rigid barrier crash test, the sled test was designed to subject the unbelted dummy to less severe crash forces, allowing airbags with lower inflation pressure and rise speed to be certified (Hinch et al., 2001; Kahane, 2006). These airbags, which existed during model years 1998-2006 and hereafter are referred to as sled-certified airbags, resulted in equivalent or improved occupant

protection overall (Braver et al., 2005; Kahane, 2006; Braver et al., 2008a) as well as fewer cases of airbag-related driver deaths (NHTSA, 2009b).

In 2000, NHTSA published a final rule requiring manufacturers to equip all passenger vehicles with more sophisticated frontal airbags by model year 2007 (FMVSS 208, as amended by 65 FR 3079, May 12, 2000). These airbags, known as certified as advanced and compliant (with FMVSS 208), or CAC, were subject to a wider variety of performance tests (see Appendix A). In particular, a rigid barrier crash test was required to certify unbelted occupant protection, but with a maximum test speed of 25 mph and conducted with both 50th percentile male and 5th percentile female dummies. The rigid barrier test for the belted 50th percentile male was retained, and a 30 mph rigid barrier test was added for the belted 5th percentile female. The maximum test speed was increased from 30 to 35 mph by model year 2011 for the 50th percentile male. In 2006, NHTSA issued a final rule requiring the 35 mph test for the 5th percentile female dummy by model year 2013 (FMVSS 208, as amended by 71 FR 51768, August 31, 2006). CAC airbags are equipped with special features including multiple (usually dual) level inflators and sensors that measure occupant size, weight, seating position, and belt use. These advancements enabled the airbag triggering algorithms and the deployment energies to be more carefully tailored to impact severity, belt use, and occupant size. In some cases, such as a small-statured adult seated close to the airbag or a small child, deployment might be completely suppressed. Even ahead of the CAC phase-in schedule, manufacturers began fitting some of these advanced features to vehicles with sled-certified airbags, most commonly belt use sensors and multiple stage inflators.

A 2010 study examined the effects of adding advanced features to sled-certified airbags and compared CAC airbags to sled-certified ones with advanced features (Braver et al., 2010a). The addition of advanced features to sled-certified airbags was associated with a reduction in frontal crash death rate per vehicle registrations for both drivers and right-front passengers. However, CAC airbags were associated with slightly higher frontal crash death rates for drivers and right-front passengers, compared with sled-certified airbags with advanced features. Nonsignificant driver death rate increases associated with CAC versus sled-certified airbags with advanced features were present for different age groups and for males and females. However, CAC airbags were associated with a statistically significant 21 percent increase in the frontal crash death rate for belted drivers and with a nonsignificant 9 percent decrease for

unbelted drivers, relative to sled-certified airbags with advanced features. Based on the data available at the time of the study, a substantial portion of the CAC study group consisted of 2006 models involved in crashes during 2007.

The purpose of the current study was to update the main results of Braver et al. (2010a) with additional years of frontal crash deaths and vehicle models, particularly those equipped with CAC airbags. The increased precision afforded by more data provided stronger comparisons across airbag generation.

METHODS

Rates of driver and right-front passenger deaths in frontal crashes per 10 million registered vehicle years were computed for passenger vehicles equipped with airbags certified as advanced and compliant, sled-certified airbags with advanced features, and sled-certified airbags without any advanced features. Airbags were considered to have advanced features if they were equipped with at least one of the following: dual/multi-stage inflator, seat track position sensor, seat belt use sensor, occupant size/weight sensor. Analyses of driver death rates were disaggregated by age group, gender, and belt use.

Data Sources

Data on model year 1998-2010 vehicles were extracted for calendar years 2004-11 from the following sources: deaths in frontal crashes from the Fatality Analysis Reporting System (FARS); annual vehicle registrations from R.L. Polk and Company; age/gender distributions of insured rated drivers by make, series, model year, and calendar year from the Highway Loss Data Institute (HLDI); data on ESC availability and vehicle design generation from HLDI; data on airbag generation and features from Braver et al. (2008b). CAC airbags were required for all vehicles in the 2007 and later model years. Sled-certified airbags were dichotomized as having any advanced features or none at all. Dual-stage inflators were, by far, the most common and earliest adopted advanced feature.

Study Groups

Two comparisons were examined. Death rates were compared in sled-certified airbag-equipped vehicles with/without advanced features, and vehicles with sled-certified airbags with advanced features

were compared with vehicles equipped with CAC airbags. In both comparisons, a vehicle make/series (e.g., Honda Accord four-door) was included only if the following two conditions were met: the vehicle was not redesigned in the same model year as the airbag change, and the vehicle's ESC status (standard vs. optional or not available) did not change at the same model year as the airbag change. These conditions also defined the range of model years included in the study, which ensured that changes in crashworthiness or in crash risk were not erroneously attributed to changes in airbag generation.

For example, the Honda Civic four-door with sled-certified airbags was fitted with advanced features beginning in model year 2001 and was upgraded to CAC airbags in model year 2006. However, these model years also marked substantial redesigns, so the Honda Civic four-door was excluded from both analyses. On the other hand, the Honda Accord four-door was redesigned in 1998, 2003, and 2008, and was fitted with sled-certified airbags in 1998, sled-certified airbags with advanced features in 2001, and CAC airbags in 2004. Therefore, it was included in both analyses, where 1998-2000 models were compared with 2001-2002 models to study the effect of advanced features on sled-certified airbags, and 2003 models were compared with 2004-2007 models to study CAC airbags versus sled-certified ones with advanced features. The Honda Accord four-door was fitted with standard ESC when it was redesigned in 2008, so this did not affect which model years were included.

Unlike in Braver et al. (2010a), no vehicle make/series were combined (e.g., two-door with four-door, two-wheel-drive with four-wheel-drive, convertible with hardtop), as there were no benefits of combining different make/series that clearly outweighed the uncertainty created by ignoring possible differences in crashworthiness and driver demographics. The full list of study vehicles is included in Appendices B and C.

Age and Gender

All analyses were restricted to persons at least 15 years of age. In the disaggregated analyses, driver age was dichotomized as 15-59 years and 60 years and older. Registration data did not contain information on age or gender, so total registration counts were partitioned by age group and gender at the make/series/model year/calendar year level according to age/gender distributions of rated drivers provided by HLDI. The rated driver of a vehicle is not necessarily the primary driver of the vehicle, but rather is the driver on which the insurance policy is based.

Statistical Techniques

Marginal structural Poisson models were used to estimate the standardized mortality rate ratio adjusted for calendar year trend both overall and in the disaggregated analyses (Robins et al., 2000; Sato and Matsuyama, 2003). Functionally, the marginal structural Poisson modeling procedure was conducted by fitting weighted Poisson models with weights given by:

$$\text{weight}_{\text{make/series, calendar year}}$$

$$= \text{odds(advanced features | make/series, calendar year)} \div \text{odds(advanced features)}$$

in models comparing sled-certified airbags with and without advanced features, and

$$\text{weight}_{\text{make/series, calendar year}}$$

$$= \text{odds(CAC | make/series, calendar year)} \div \text{odds(CAC)}$$

in models comparing CAC airbags to sled-certified airbags with advanced features (Robins et al., 2000). The log of the number of registrations was included as an offset term to account for exposure differences across vehicles. This effectively models death rate instead of deaths. The Poisson models were adjusted for overdispersion, and standard errors were computed taking into account the repeated measure structure of the data (i.e., counts for each calendar year of the same model years of a given vehicle).

RESULTS

The analyses of overall driver and right-front passenger frontal crash death rates by airbag generation are presented in Table 1. The driver death rate in frontal crashes for vehicles with CAC airbags was slightly higher than for those same models fitted with sled-certified airbags with advanced features, with the adjusted rate ratio indicating a nonsignificant 2 percent disbenefit of CAC airbags. Among vehicles with sled-certified airbags, those fitted with advanced features had a statistically significant 10 percent lower driver death rate than those without advanced features. The right-front passenger death rate was lower for CAC vehicles, but the adjusted rate ratio indicated a nonsignificant 3 percent disbenefit, compared with the same models fitted with sled-certified airbags with advanced features. A statistically significant benefit of advanced features for vehicles with sled-certified airbags was found for right-front passengers.

The results of the comparisons of CAC driver airbags and sled-certified airbags with advanced features for different driver sub-groups are presented in Table 2a. Most differences were not statistically significant. CAC airbags were associated with a 2 percent lower death rate among drivers ages 15-59 compared with sled-certified airbags with advanced features. For drivers 60 and older, there was a 8 percent disbenefit of CAC airbags. The largest disbenefit of CAC airbags was among women 60 and older, which was statistically significant, although this group had one of the lowest sample sizes of any group in the study. A statistically significant 12 percent disbenefit of CAC airbags was observed for belted drivers and a nonsignificant 12 percent benefit of CAC airbags was observed for unbelted drivers.

Table 2b presents the comparison of sled-certified airbags with/without advanced features by driver age group, gender, and belt use. Advanced features were associated with lower driver death rates in all categories except belted drivers, in which advanced features were associated with a nonsignificant 2 percent disbenefit. The benefit of advanced features among sled-certified airbags was strongest for unbelted men, with a statistically significant 31 percent lower driver death rate.

DISCUSSION

The results observed in the present study followed a similar pattern as those of Braver et al. (2010a), but generally were smaller in magnitude. This study reaffirmed the finding that drivers and right-front passengers in frontal crashes benefitted from the fitment of advanced features to vehicles with sled-certified airbags and that there was little overall difference when vehicles with sled-certified airbags with advanced features were fitted with CAC airbags. On one hand, this would suggest that overall occupant protection was not reduced (albeit not improved either) by CAC airbags. However, the minimal overall effect for drivers is composed of a 12 percent benefit for unbelted drivers coupled with a 12 percent disbenefit for belted drivers, suggesting some kind of unintentional tradeoff in occupant protection between belted and unbelted drivers. Alternatively, it is possible that any problems with belted driver protection were unrelated to unbelted driver protection.

This study was not able to identify the underlying mechanisms of such a situation for drivers with CAC airbags. One possibility is that airbags might be suppressed in situations in which they would have been helpful, for example, by misclassifying a driver as small statured and/or out of position. Misclassifications resulting in failure to deploy may be more harmful than misclassifications resulting in

unnecessary deployment. A study of frontal airbag nondeployments in fatal frontal crashes found that CAC airbags had higher rates of nondeployment than earlier airbag generations (Braver et al., 2010b). The study examined detailed crash investigation cases from the National Automotive Sampling System Crashworthiness Data System, but was unable to find sufficient CAC nondeployment cases to study how many would have been helpful had they deployed. Another possibility is that changes in regulatory compliance crash tests might have reduced the level of occupant protection for belted occupants by encouraging modifications to airbags that are having a disbenefit in some crashes. This might involve, for example, increased aggressivity of the airbags associated with reverting to requiring rigid barrier crash tests for compliance with unbelted occupant protection requirements. Currently, there is no evidence that either inappropriate nondeployments are occurring or that CAC airbags are overly aggressive.

One change in FMVSS 208 was not accounted for in the classification of airbag generations in this study. NHTSA increased the maximum test speed of the rigid barrier tests using belted 50th percentile male and belted 5th percentile female dummies from 30 to 35 mph. The phase-in schedule began in the 2008 model year for 50th percentile males and in the 2010 model year for the 5th percentile females, so none of these airbags were included in Braver et al. (2010a or b). However, the current study included some CAC airbags subject to the higher speed test. The similarity of the present results to those reported by Braver et al. (2010a or b) suggests that this change probably did not have a large effect on the design of newer airbags. In fact, the smaller estimated disbenefit of CAC airbags in the present study suggests a possible improvement from increasing the belted occupant test speeds. NHTSA also made changes to the evaluation of its New Car Assessment Program that could have influenced airbag designs in later models. However, the fact that the new NCAP evaluation did not begin until the 2011 model year suggests that it is not likely to have been a significant influence of airbag designs in this study.

Use of registration counts as denominators in this study provided important information on relative exposure of the study vehicles, but these data were not without limitations. For instance, data on vehicle miles travelled were not available at the make/series or even the vehicle type level. The results could be biased if vehicle miles traveled varied within study vehicles, for example, if newer vehicles with CAC airbags tended to be driven more than the comparison vehicles with sled-certified airbags with advanced features. Unlike in Braver et al. (2010a), the current study did not apply vehicle age corrections

as current estimates of vehicle age effects on fatal crash rates are unavailable. Another possible limitation was formed by the partitioning of registration counts by age group and gender based on data on insured drivers as the characteristics of the rated driver population in the HLDI databases differ from the characteristics of the general driving population. However, any associated misclassification would affect the study results only if it varied by airbag generation, and misclassification of driver age was reduced by using two broad age categories. Belt use was unknown for study vehicles not involved in fatal crashes. If belt use was lower among older vehicles, particularly if related to airbag generation, then analyses of driver deaths per registrations would overestimate the benefit for unbelted drivers and underestimate the benefit (or overestimate the disbenefit) for belted drivers.

A sensitivity analysis was conducted to investigate any effects of the minor methodological differences between the current paper and Braver et al. (2010a) on the findings. This analyses restricted the data to 1998-2006 model vehicles in fatal crashes occurring during 2004-2007, as in Braver et al. (2010a). The results were similar to those reported by Braver et al. (2010a).

Finally, the study looked only at crash fatalities. There are likely effects of frontal airbag generation on nonfatal injuries as well. Investigating the role of airbag generation on injury risk patterns would aid in the understanding of differences in belted and unbelted driver protection afforded by the different airbag generations, and how these differences may arise.

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Table 1
Frontal crash death rates by airbag generation, 2004-2011

	Deaths	Registered vehicle years	Deaths per 10 million registered vehicle years	Adjusted RR	95% CI
Drivers					
Certified as advanced and compliant	2,079	80,870,080	257.08	1.02	(0.95, 1.10)
Sled-certified with advanced features	2,850	113,763,484	250.52	1	
Sled-certified with advanced features	2,065	73,561,978	280.72	0.90	(0.85, 0.95)
Sled-certified without advanced features	2,508	79,078,641	317.15	1	
Right-front passengers					
Certified as advanced and compliant	499	80,870,080	61.70	1.03	(0.89, 1.19)
Sled-certified with advanced features	713	113,763,484	62.67	1	
Sled-certified with advanced features	455	73,561,978	61.85	0.84	(0.75, 0.95)
Sled-certified without advanced features	547	79,078,641	69.17	1	

Table 2a
Frontal crash death rates by age group, gender, and belt use comparing CAC airbags with sled-certified airbags with advanced features, 2004-2011

	Deaths	Registered vehicle years	Deaths per 10 million registered vehicle years	Adjusted RR	95% CI
15-59					
Certified as advanced and compliant	1,354	58,693,622	230.69	0.98	(0.89, 1.08)
Sled-certified with advanced features	1,931	79,867,594	241.78	1	
60+					
Certified as advanced and compliant	723	19,738,393	366.29	1.08	(0.97, 1.21)
Sled-certified with advanced features	918	25,270,655	363.27	1	
Men					
Certified as advanced and compliant	1,274	32,436,047	392.77	1.00	(0.91, 1.10)
Sled-certified with advanced features	1,815	44,597,197	406.98	1	
Men, 60+					
Certified as advanced and compliant	438	8,015,141	546.47	0.96	(0.84, 1.10)
Sled-certified with advanced features	595	10,053,929	591.81	1	
Women					
Certified as advanced and compliant	805	45,995,968	175.02	1.04	(0.94, 1.15)
Sled-certified with advanced features	1,035	60,541,052	170.96	1	
Women, 60+					
Certified as advanced and compliant	285	10,313,530	276.34	1.23	(1.02, 1.50)
Sled-certified with advanced features	323	13,591,671	237.65	1	
Belted					
Certified as advanced and compliant	1,222	80,870,080	151.11	1.12	(1.04, 1.20)
Sled-certified with advanced features	1,543	113,763,484	135.63	1	
Unbelted					
Certified as advanced and compliant	702	80,870,080	86.81	0.88	(0.74, 1.06)
Sled-certified with advanced features	1,093	113,763,484	96.08	1	
Men, unbelted					
Certified as advanced and compliant	489	32,436,047	150.76	0.89	(0.72, 1.10)
Sled-certified with advanced features	762	44,597,197	170.86	1	
Women, unbelted					
Certified as advanced and compliant	213	45,995,968	46.31	0.85	(0.67, 1.07)
Sled-certified with advanced features	331	60,541,052	54.67	1	

Table 2b
Frontal crash death rates by age group, gender, and belt use comparing sled-certified airbags with advanced features with sled-certified airbags without advanced features, 2004-2011

	Deaths	Registered vehicle years	Deaths per 10 million registered vehicle years	Adjusted RR	95% CI
15-59					
Sled-certified with advanced features	1,415	47,851,136	295.71	0.87	(0.79, 0.96)
Sled-certified without advanced features	1,819	36,390,546	499.86	1	
60+					
Sled-certified with advanced features	649	16,239,411	399.65	0.96	(0.82, 1.12)
Sled-certified without advanced features	685	10,824,013	632.85	1	
Men					
Sled-certified with advanced features	1,319	27,338,698	482.47	0.88	(0.81, 0.97)
Sled-certified without advanced features	1,651	20,809,755	793.38	1	
Men, 60+					
Sled-certified with advanced features	386	6,103,608	632.41	0.89	(0.72, 1.10)
Sled-certified without advanced features	438	4,130,651	1,060.37	1	
Women					
Sled-certified with advanced features	746	36,751,849	202.98	0.94	(0.84, 1.06)
Sled-certified without advanced features	857	26,404,804	324.56	1	
Women, 60+					
Sled-certified with advanced features	263	9,028,866	291.29	0.98	(0.72, 1.32)
Sled-certified without advanced features	247	5,872,360	420.61	1	
Belted					
Sled-certified with advanced features	1,089	73,561,978	148.04	1.02	(0.89, 1.18)
Sled-certified without advanced features	1,221	79,078,641	154.40	1	
Unbelted					
Sled-certified with advanced features	803	73,561,978	109.16	0.74	(0.63, 0.87)
Sled-certified without advanced features	1,112	79,078,641	140.62	1	
Men, unbelted					
Sled-certified with advanced features	555	27,338,698	203.01	0.69	(0.57, 0.84)
Sled-certified without advanced features	811	20,809,755	389.72	1	
Women, unbelted					
Sled-certified with advanced features	248	36,751,849	67.48	0.99	(0.79, 1.24)
Sled-certified without advanced features	301	26,404,804	113.99	1	

Appendix A

Frontal airbag regulatory compliance tests

Dummy	First generation	Sled-certified (with or without advanced features)	Certified as advanced and compliant
50th percentile male, belted	≤30 mph rigid barrier crash test (driver and rfp)	≤30 mph rigid barrier crash test (driver and rfp)	≤30[1] mph rigid barrier crash test (driver and rfp)
50th percentile male, unbelted	≤30 mph rigid barrier crash test (driver and rfp)	≤30 mph rigid barrier crash test (driver and rfp) OR 30 mph sled test (driver and rfp airbags)	20-25 mph rigid barrier crash test (driver and rfp)[2]
5th percentile female, belted	—	—	≤30[3] mph rigid barrier crash test (driver and rfp) AND ≤25 mph offset[4] deformable barrier crash test (driver and rfp) AND suppression (out of position) (driver) AND low risk deployment (driver)
5th percentile female, unbelted	—	—	20-25 mph rigid barrier crash test (driver and rfp)
1 year-old, rear facing CRS	—	—	Suppression (presence) (rfp) OR low risk deployment (rfp)
3 year-old	—	—	Suppression (presence) (rfp) OR suppression (out of position) (rfp) OR low risk deployment (rfp)
6 year-old	—	—	Suppression (presence) (rfp) OR suppression (out of position) (rfp) OR low risk deployment (rfp)

rfp = right-front passenger

[1] 35 mph by model year 2011

[2] Perpendicular and oblique up to 30 degrees. All other tests referenced in this table are conducted only perpendicular to the barrier.

[3] 35 mph by model year 2013

[4] 40 percent of the left side of the test vehicle overlaps with the deformable barrier

Appendix B

Study vehicles used to compare CAC airbags and sled-certified airbags with advanced features

	Sled-certified with advanced features		CAC	
	Min	Max	Min	Max
Acura				
3.2 TL 4d	2004	2004	2005	2008
TSX 4d	2004	2005	2006	2008
Audi				
A4 4d 2wd	2002	2004	2005	2005
A4 Avant Quattro Sw 4wd	2002	2004	2005	2005
A4 Cabriolet	2003	2004	2005	2006
A4 Cabriolet Quattro	2004	2004	2005	2006
A4 Quattro 4d 4wd	2002	2004	2005	2005
A8 Quattro 4d 4wd	2005	2005	2006	2010
A8l Quattro 4d 4wd	2004	2005	2006	2010
S4 Avant Quattro Sw 4wd	2004	2004	2005	2005
S4 Cabriolet Quattro	2004	2004	2005	2006
BMW				
325 iT Sw	2001	2004	2005	2005
325 Xi 4d 4wd	2002	2004	2005	2005
325 XiT Sw 4wd	2002	2004	2005	2005
330 Ci 2d	2001	2004	2005	2006
330 Ci Conv	2001	2004	2005	2006
330 i 4d	2001	2004	2005	2005
330 Xi 4d 4wd	2002	2004	2005	2005
745 i 4d	2002	2003	2004	2005
745 Li 4d	2002	2003	2004	2005
760 Li 4d	2003	2003	2004	2008
M3/M3 Ci 2d	2001	2004	2005	2006
M3/M3 Ci Conv	2001	2004	2005	2006
X5 4d 4wd	2001	2003	2004	2006
Z4 Roadster Conv	2003	2003	2004	2008
Buick				
Rainier 4d 4x2	2004	2004	2005	2005
Rainier 4d 4x4	2004	2004	2005	2005
Rendezvous 4d 2wd	2002	2004	2005	2007
Rendezvous 4d 4wd	2002	2004	2005	2006
Cadillac				
CTS 4d 2wd/4wd	2003	2004	2005	2007
Escalade 4d 4x2	2003	2003	2004	2006
Escalade 4d 4x4	2003	2003	2004	2006
Escalade Ext 4d 4x4	2002	2003	2004	2006
SRX 4d 2wd/4wd	2004	2006	2007	2008
SRX 4d 4wd	2005	2006	2007	2007
XLR Roadster Conv	2004	2005	2006	2009
Chevrolet				
Cobalt 2d	2005	2005	2006	2010
Cobalt 4d	2005	2005	2006	2010
Cobalt SS Superchrgd 2d	2005	2005	2006	2007
Corvette 2d	2005	2005	2006	2010
Corvette Conv	2005	2005	2006	2010
Malibu 4d	2004	2006	2007	2008
Monte Carlo 2d	2002	2005	2006	2007
Chevrolet Truck				
Colorado Cr Pu 4x2	2004	2005	2006	2008
Colorado Cr Pu 4x4	2004	2005	2006	2008
Colorado Pu 4x2	2004	2005	2006	2008
Colorado Pu 4x4	2004	2005	2006	2008
Colorado Pu E C 4x2	2004	2005	2006	2008
Colorado Pu E C 4x4	2004	2005	2006	2008
S10 Blazer 2d 4x2	2003	2004	2005	2005
TrailBlazer 4d 4x2	2003	2004	2005	2005
TrailBlazer 4d 4x4	2003	2004	2005	2005
TrailBlazer Ext 4d 4x2	2003	2004	2005	2005
TrailBlazer Ext 4d 4x4	2003	2004	2005	2005
Chry/Plym Truck				
Town & Country Lwb 2wd	2001	2004	2005	2007
Chrysler Truck				
Pacifica 4d 2wd	2004	2004	2005	2006
Pacifica 4d 4wd	2004	2004	2005	2006
Dodge				
Viper Conv	2003	2006	2008	2010

	Sled-certified with advanced features		CAC	
	Min	Max	Min	Max
Dodge Truck				
Caravan Van 2wd	2001	2004	2005	2007
Durango 4d 4x4	2004	2004	2005	2006
Grand Caravan 2wd	2001	2004	2005	2007
Ram 1500 Crew C Pu 4x2	2006	2006	2007	2008
Ram 1500 Crew C Pu 4x4	2006	2006	2007	2008
Ram 1500 Pu 4x2	2006	2006	2007	2008
Ram 2500 Crew C Pu 4x2	2004	2006	2007	2009
Ram 2500 Crew C Pu 4x4	2004	2006	2007	2009
Ram 2500 Pu 4x2	2004	2006	2007	2009
Ram 2500 Pu 4x4	2004	2005	2007	2009
Ram 3500 Crew C Pu 4x2	2004	2006	2007	2009
Ram 3500 Crew C Pu 4x4	2004	2006	2007	2009
Ram 3500 Pu 4x2	2004	2006	2007	2009
Ram 3500 Pu 4x4	2004	2005	2007	2009
Ford				
Focus 3d	2003	2004	2005	2007
Focus 4d	2003	2004	2005	2007
Focus Sw	2003	2004	2005	2007
Ltd/Crown Victoria 4d	2003	2004	2005	2009
Taurus 4d	2000	2003	2004	2007
Taurus Sw	2000	2003	2004	2005
Ford Truck				
Explorer Spt Trac 4x4	2003	2004	2005	2005
Freestar Van	2004	2004	2005	2007
GMC Truck				
Canyon Cr Pu 4x2	2004	2005	2006	2008
Canyon Cr Pu 4x4	2004	2005	2006	2008
Canyon Pu 4x2	2004	2005	2006	2008
Canyon Pu 4x4	2004	2005	2006	2008
Canyon Pu E C 4x2	2004	2005	2006	2008
Canyon Pu E C 4x4	2004	2005	2006	2008
Envoy 4d 4x2	2002	2004	2005	2005
Envoy 4d 4x4	2002	2004	2005	2005
Envoy XL 4d 4x2	2002	2004	2005	2005
Envoy XL 4d 4x4	2002	2004	2005	2005

	Sled-certified with advanced features		CAC	
	Min	Max	Min	Max
Envoy XUV 4d 4x2	2004	2004	2005	2005
Envoy XUV 4d 4x4	2004	2004	2005	2005
Honda				
Accord 2d	2003	2003	2004	2007
Accord 4d	2003	2003	2004	2007
Odyssey Van (New)	2002	2002	2003	2004
Pilot 4d 4wd	2003	2004	2005	2005
Hyundai				
Elantra 4d	2001	2003	2004	2006
Infiniti				
FX35 4d 2wd	2003	2005	2006	2008
FX35 4d 4wd	2003	2005	2006	2008
FX45 4d 4wd	2003	2005	2006	2008
G35 2d 2wd	2003	2004	2005	2007
G35 4d 2wd	2003	2005	2006	2006
Q45 4d	2002	2005	2006	2006
Isuzu				
Ascender 4d 4x2	2004	2004	2005	2005
Ascender 4d 4x4	2004	2004	2005	2005
Ascender Ext 4d 4x2	2004	2004	2005	2005
Ascender Ext 4d 4x4	2004	2004	2005	2005
Jaguar				
S-Type 4d	2003	2003	2004	2008
Super V8 Lwb 4d	2005	2005	2006	2009
X-Type 4d 4wd	2002	2004	2005	2006
XJ8 Swb 4d	2004	2004	2005	2009
XJR Swb 4d	2004	2004	2005	2009
XK8 2d	2001	2005	2006	2006
XK8 Conv	2001	2004	2005	2006
XKR 2d	2001	2005	2006	2006
XKR Conv	2001	2005	2006	2006
Jeep				
Liberty 4d 4x2	2002	2003	2004	2005
Liberty 4d 4x4	2002	2003	2004	2005
Land Rover				
Range Rover 4d 4x4	2004	2005	2006	2010

	Sled-certified with advanced features		CAC	
	Min	Max	Min	Max
Lexus				
GS 430 4d 2wd	2006	2006	2007	2007
GX 470 4d 4x4	2003	2004	2005	2009
LX 470 4d 4x4	2000	2006	2007	2007
SC 430 Conv	2002	2006	2007	2010
Lincoln				
LS Sedan 4d	2003	2004	2005	2006
Town Car Lwb 4d	2003	2004	2005	2010
Town Car/Cont 4d	2003	2004	2005	2010
Mazda				
6 4d 2wd	2004	2004	2005	2008
6 5d 2wd	2004	2004	2005	2008
6 Sw 2wd	2004	2004	2005	2007
Rx-8 2d	2004	2005	2006	2010
Mercury				
Marquis/G. Marq. 4d	2003	2004	2005	2010
Monterey Van	2004	2004	2005	2007
Sable 4d	2000	2003	2004	2005
Sable Sw	2000	2003	2004	2005
MINI				
Cooper 2d	2002	2004	2005	2006
Nissan				
350Z 2d	2003	2006	2007	2008
350Z Roadster Conv	2005	2006	2007	2009
Altima 4d	2002	2004	2005	2006
Murano 4d 2wd	2003	2005	2006	2007
Murano 4d 4wd	2003	2005	2006	2007
Pontiac				
G6 4d	2005	2005	2006	2009
Grand Prix 4d	2004	2005	2006	2008
Montana Van Lwb 2wd	2002	2004	2005	2005
Vibe Sw 2wd	2003	2004	2005	2008
Vibe Sw 4wd	2003	2004	2005	2006
Saab				
9-2x Aero Sw 4wd	2005	2005	2006	2006
9-2x Linear Sw 4wd	2005	2005	2006	2006
9-3 4d 2wd	2003	2005	2006	2010
9-3 Conv	2004	2005	2006	2010
9-5 4d 2wd	2003	2005	2006	2010
9-5 Sw 2wd	2003	2005	2006	2010
Saturn				
Ion 4d	2003	2004	2005	2007
Ion Quad Coupe 2d	2003	2004	2005	2007
Vue 4d 2wd	2004	2005	2006	2007
Vue 4d 4wd	2004	2005	2006	2007
Scion				
tC 2d	2005	2005	2006	2010
xA 5d	2004	2005	2006	2006
xB Sw	2004	2005	2006	2006
Toyota				
4Runner 4d 4x2	2003	2005	2006	2009
4Runner 4d 4x4	2003	2005	2006	2009
Avalon 4d	2005	2005	2006	2008
Camry 4d 2wd	2002	2003	2004	2006
Corolla Sedan 2wd	2003	2004	2005	2008
Land Cruiser 4d 4x4	2000	2005	2006	2007
Matrix Sw 2wd	2003	2004	2005	2008
Matrix Sw 4wd	2003	2004	2005	2006
Prius Hybrid 4d	2004	2005	2006	2009
Sequoia 4d 4x2	2001	2004	2005	2007
Sequoia 4d 4x4	2001	2004	2005	2007
Sienna Van 2wd	2004	2004	2005	2007
Sienna Van 4wd	2004	2004	2005	2005
Tundra Pu Ac Cab 4x2	2000	2004	2005	2006
Tundra Pu Ac Cab 4x4	2000	2004	2005	2006
Tundra Pu Dbl Cab Sh 4x2	2004	2004	2005	2006
Tundra Pu Dbl Cab Sh 4x4	2004	2004	2005	2006
Tundra Pu Sh 4x2	2000	2004	2005	2006
Tundra Pu Sh 4x4	2000	2004	2005	2006
Volkswagen				
Golf 4d	2001	2005	2006	2006
Jetta Sedan	2001	2004	2005	2005

	Sled-certified with advanced features		CAC	
	Min	Max	Min	Max
Jetta Sw	2001	2004	2005	2005
New Beetle 2d	2001	2004	2005	2006
New Beetle Conv	2003	2003	2004	2005
Volvo				
S40 4d 2wd (New)	2004	2004	2005	2006
S60 4d 2wd	2001	2005	2006	2006
S60 4d 4wd	2002	2005	2006	2006
S60 R 4d 4wd	2004	2004	2006	2007
S80 4d 2wd	2000	2005	2006	2006
S80 4d 4wd	2004	2005	2006	2006
V70 Sw 2wd	2001	2004	2005	2006
V70 Sw 4wd	2001	2004	2005	2006
XC90 4d 2wd	2003	2004	2005	2010
XC90 4d 4wd	2003	2004	2005	2010

Abbreviations: 2d = two door, 4d = four-door, 2wd = two-wheel drive, 4wd = four-wheel drive, Conv = convertible, Sw = station wagon, Cr = crew, Crew C = crew cab, Pu = pickup, E C = extended cab, Ext = extended, Lwb = long wheelbase, Swb = short wheelbase

Appendix C

Study vehicles used to compare sled-certified airbags with advanced features and sled-certified airbags without advanced features

	Sled-certified without advanced features		Sled-certified with advanced features	
	Min	Max	Min	Max
Acura				
3.2 TL 4d	1999	2000	2001	2003
Audi				
A4 4d 2wd	1998	1999	2000	2001
A4 Avant Quattro Sw 4wd	1998	1999	2000	2001
A4 Quattro 4d 4wd	1998	1999	2000	2001
A6 4d 2wd	1998	1999	2000	2001
A6 Avant Quattro Sw 4wd	1999	1999	2000	2001
A6 Quattro 4d 4wd	1998	1999	2000	2001
A8 Quattro 4d 4wd	1999	1999	2000	2000
BMW				
M5 4d	2000	2000	2001	2003
X5 4d 4wd	2000	2000	2001	2003
Cadillac				
Escalade 4d 4x4	2002	2002	2003	2003
Chevrolet				
Corvette 2d	2001	2002	2003	2004
Corvette Conv	2001	2002	2003	2004
Impala 4d	2000	2000	2001	2005
Malibu 4d	1998	2002	2003	2003
Monte Carlo 2d	2000	2001	2002	2005
Chevrolet Truck				
S10 Blazer 2d 4x2	1998	2002	2003	2004
TrailBlazer 4d 4x2	2002	2002	2003	2004
TrailBlazer 4d 4x4	2002	2002	2003	2004
TrailBlazer Ext 4d 4x2	2002	2002	2003	2004
TrailBlazer Ext 4d 4x4	2002	2002	2003	2004
Dodge Truck				
Ram 1500 Crew C Pu 4x2	2002	2003	2004	2005
Ram 1500 Crew C Pu 4x4	2002	2003	2004	2005
Ram 1500 Pu 4x2	2002	2003	2004	2005
Ram 1500 Pu 4x4	2002	2003	2004	2005
Ram 2500 Crew C Pu 4x2	2003	2003	2004	2006
Ram 2500 Crew C Pu 4x4	2003	2003	2004	2006
Ram 2500 Pu 4x2	2003	2003	2004	2006
Ram 2500 Pu 4x4	2003	2006	2004	2005
Ram 3500 Crew C Pu 4x2	2003	2003	2004	2006
Ram 3500 Crew C Pu 4x4	2003	2003	2004	2006
Ram 3500 Pu 4x2	2003	2003	2004	2006
Ram 3500 Pu 4x4	2003	2006	2004	2005
Ford				
Focus 3d	2000	2002	2003	2004
Focus 4d	2000	2002	2003	2004
Focus Sw	2000	2002	2003	2004
Ltd/Crown Victoria 4d	1998	2000	2001	2002
Taurus 4d	1998	1999	2000	2003
Taurus Sw	1998	1999	2000	2003
Ford Truck				
Explorer 4d 4x2	2002	2002	2003	2004
Explorer 4d 4x4	2002	2002	2003	2004
Explorer Spt Trac 4x4	2001	2002	2003	2004
Honda				
Accord 2d	1998	2000	2001	2002
Accord 4d	1998	2000	2001	2002
Odyssey Van (New)	1999	2001	2002	2002
Hyundai				
Accent 2d	2000	2003	2004	2005
Accent 4d	2000	2003	2004	2005
Sonata 4d	1999	2000	2001	2005
Isuzu				
Ascender Ext 4d 4x2	2003	2003	2004	2004
Ascender Ext 4d 4x4	2003	2003	2004	2004
Jaguar				
S-Type 4d	2000	2001	2002	2002
XJ8 Swb 4d	1999	2000	2001	2003
XJR Swb 4d	1999	2000	2001	2003
XK8 2d	1999	2000	2001	2005

	Sled-certified without advanced features		Sled-certified with advanced features	
	Min	Max	Min	Max
XK8 Conv	1999	2000	2001	2004
XKR 2d	2000	2000	2001	2005
XKR Conv	2000	2000	2001	2005
Jeep				
Grand Cherokee 4d 4x2	1999	2003	2004	2004
Grand Cherokee 4d 4x4	1999	2003	2004	2004
Land Rover				
Range Rover 4d 4x4	2003	2003	2004	2005
Lincoln				
LS Sedan 4d	2000	2002	2003	2004
Town Car/Cont 4d	1998	2001	2002	2002
Mazda				
6 4d 2wd	2003	2003	2004	2004
Mercury				
Marquis/G. Marq. 4d	1998	2000	2001	2002
Sable 4d	1998	1999	2000	2003
Sable Sw	1998	1999	2000	2003
Nissan				
350Z 2d	2004	2004	2003	2006
350Z Roadster Conv	2004	2004	2005	2006
810/Maxima Sedan	2000	2001	2002	2003
Frontier Pu King C 4x2	1998	2002	2003	2004
Frontier Pu King C 4x4	1998	2002	2003	2004
Xterra 4d 4x2	2000	2001	2002	2004
Xterra 4d 4x4	2000	2001	2002	2004
Pontiac				
Grand Prix 4d	1998	2002	2003	2003
Montana Van Lwb 2wd	1999	2001	2002	2004
Saab				
9-3 Conv	1999	2002	2003	2003
9-5 4d 2wd	1999	2001	2002	2002
9-5 Sw 2wd	1999	2001	2002	2002
Saturn				
Vue 4d 2wd	2002	2003	2004	2005
Vue 4d 4wd	2002	2003	2004	2005

	Sled-certified without advanced features		Sled-certified with advanced features	
	Min	Max	Min	Max
Volkswagen				
Golf 2d	2000	2000	2001	2005
Golf 4d	2000	2000	2001	2005
Jetta Sedan	2000	2000	2001	2004
New Beetle 2d	1998	2000	2001	2004
Passat 4d 2wd	1998	2000	2001	2005
Passat 4d 4wd	2000	2000	2001	2005
Passat Sw 2wd	1998	2000	2001	2005
Passat Sw 4wd	1998	2000	2001	2005
Volvo				
C70 Conv	1999	1999	2000	2002
S60 R 4d 4wd	2005	2005	2004	2004
V70 Sw 2wd	1999	1999	2000	2000
V70 Sw 4wd	1999	1999	2000	2000

Abbreviations: 2d = two door, 4d = four-door, 2wd = two-wheel drive, 4wd = four-wheel drive, Conv = convertible, Sw = station wagon, Crew C = crew cab, Pu = pickup, Ext = extended, Lwb = long wheelbase, Swb = short wheelbase