STUDY OF AIRBAG EFFECTIVENESS IN HIGH SEVERITY FRONTAL CRASHES

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ABSTRACT

The primary objective of this study was to determine the effectiveness of second-generation (depowered) airbags (1998 model years and later) in reducing driver fatalities in severe frontal crashes. The analysis focused on front-to-front crashes involving belted drivers in light vehicles.

US fatal accident data from the Fatality Analysis Reporting System (FARS, 1998-2007) for frontal (head-on) two-vehicle (car-to-car, car-to-truck and truck-to-truck) crashes were analyzed. To select vehicles equipped with second-generation airbags, at least one (the *subject)* vehicle in each crash was model year 1998 or later. A matched-pair analysis was used to create driver pairs from the *subject* and the *other* vehicles in each crash, where the belted driver of the other vehicle was killed as a result of the accident. The high severity of the accidents was ensured by selecting records with fatal drivers in the opposite vehicle. About 3,000 fatal crashes were examined to study the influence of airbag deployment on the likelihood of fatality to belted drivers. Logistic regression was used to control for other potential confounding factors including mass ratio of the two vehicles, driver age, and driver alcohol presence. In addition, the longitudinal delta-V distribution for the studied frontal collisions, risk of serious (MAIS 3-6/fatal) injury by delta-V, and airbag deployment rates by delta-V were studied using the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) data for the years 1997-2007.

Field data on high severity frontal crashes involving depowered airbags indicates that airbag deployment is not a statistically significant predictor influencing the likelihood of driver fatality. Other factors, including mass ratio of the two vehicles in a crash, driver age, and alcohol were found to be significant predictors of the odds of fatality. The fatal crashes studied where airbag deployment was not significant were crashes with an average delta-V of about 35 mph (56 kmh). About 67% of these crashes were with delta-V greater than 30 mph (48 kmh) and 24% were with delta-V of 20-30 mph (32-48 kmh).

Analysis of airbag deployment by delta-V shows that, even in high delta-V crashes (over 25 mph, or 40 kmh), about 5% of airbags did not deploy.

Keywords: ACTIVE SAFETY, AIRBAGS, FRONTAL IMPACTS, INJURY PROBABILITY

BACKGROUND

Frontal airbags saved the lives of an estimated 16,905 drivers and adult or teenage right-front passengers from 1987 through 2004 (Kahane, 2006). Nevertheless, airbags presented risks to occupants positioned close to the airbag at the time of deployment. Hence, in 1995, the National Highway Traffic Safety Administration (NHTSA) initiated a series of immediate, mid-term and long-term actions to reduce and eventually eliminate the adverse effect of airbags for infants and children while retaining the great life-saving benefits of airbags for most people. On March 1997, NHTSA amended FMVSS 208, effective immediately, relaxing some aspects of the frontal impact test for the unrestrained dummy in order to facilitate the introduction of “redesigned” airbags that deploy less forcefully. Redesigned airbags were introduced in the 1998 models. Accompanying the depowering effort were concerns that crash protection would be compromised in some cases, particularly severe crashes. A blue ribbon panel was set up in 2001 to study the field performance of depowered airbags. As part of this effort, studies compared injuries to occupants in depowered airbag vehicles with those in first-generation airbag vehicles (Segui-Gomez, 2000; Schneider, et al, 2003; Durbin, 2003).

A study conducted for first-generation airbags showed that airbags are highly effective at low velocities (Nusholtz, et al, 2003). But no study has been done to address the effectiveness of depowered airbags in high severity crashes.

DATA SOURCES

VEHICLE SELECTION DATA – The first step in the analysis was to identify vehicles equipped with second-generation airbags. This was accomplished by including only 1998 model year or later vehicles in the subject vehicle selection.

FIELD PERFORMANCE DATA – FARS data (1998-2007) was used to address the odds of driver fatality in frontal crashes, and NASS data (1997-2007) was used to analyze the airbag deployment as a function of delta-V in frontal crashes. The starting year 1998 for the FARS analysis was chosen to take advantage of a more detailed airbag coding (NHTSA, 2008).

FARS is a census of all US traffic crashes that occur on public roads and result in death within 30 days of the crash. FARS data is compiled from police accident reports, vehicle registration files, driver licensing files, death certificates, medical examiner reports, state highway department data, and hospital/EMS records, and extensive quality control procedures are used by the state and federal FARS technical professionals to ensure accuracy and completeness of each piece of information entered into the database. Because more than 100 data elements associated with accident, vehicle, and occupant-related factors are coded for each fatal traffic crash, FARS data files are widely used by crash and vehicle safety investigators.

NASS/CDS DATA – The NASS/CDS database, which is maintained by NHTSA, is a nation-wide representative sample of tow-away crashes investigated in detail by NASS teams consisting of engineers, biomechanical experts, medical personnel, and statisticians. The NASS data files contain information on over 500 variables addressing crash/vehicle/occupant and injury factors associated with real world crashes and hence, are widely used by NHTSA and other highway safety researchers in the US to examine injury experience in rollovers. The NASS Crashworthiness Data System (NASS/CDS), used for this study, investigates about 5,000 crashes a year involving passenger cars and light trucks. Nation-wide estimates are extrapolated using a stratified sampling system to ensure the results are representative.

METHOD

FARS ANALYSIS – The study included frontal (head-on) two-vehicle (passenger car-to-passenger car, passenger car-to-light truck, and light truck-to-light truck) crashes of light vehicles model years 1990-2007. Light vehicles, which included passenger cars and light trucks, were identified according to the NHTSA codes (NHTSA, 2008). To select vehicles equipped with second-generation airbags, at least one (the *subject)* vehicle in each crash was a 1998 model year or later. The study included fatal non rollover crashes with exactly two vehicles in each crash. An analysis data set was created by selecting driver pairs from the *subject* and the *other* vehicles in each crash, where the belted driver of the other vehicle was killed as a result of the accident. If both vehicles satisfied the above criteria, each one of them was considered as “subject”, one at a time, thus creating two driver pairs to be analyzed. For each vehicle, the initial and the principal points of impact were restricted to the frontal part of the vehicle, defined as the 12 o’clock position in the FARS database (NHTSA, 2008).

To examine the importance of airbag deployment in reducing odds of fatality for the subject vehicle driver, a case/control method was used. The control group was the subject vehicle drivers with no airbag deployment. The response group included the subject vehicle drivers with airbags deployed in the crash. To ensure the stability of the conclusions against different definitions of the control group, two logistic regression models were developed: 1) For the subject vehicle’s airbag deployment status, the values “airbag deployed=yes” and “airbag deployed=no” were used; 2) For the subject vehicle’s airbag deployment status the values “airbag deployed=yes” and “airbag deployed=airbag not connected” were used. Other predictors were included in the model as explained below. The binary response variable was defined as subject vehicle driver fatal=1, non-fatal=0.

LOGISTIC REGRESSION – Logistic regression is a generalization of a multiple regression method for data with a dichotomous outcome variable, which permits analysis at a case-by-case level using the maximum likelihood fit. For this study, logistic regression was used to model the odds of driver fatality. To properly measure the association between the likelihood of fatality and a vehicular factor such as airbag deployment, the effects of other factors that might also influence the accident outcome must be explored concurrently. Logistic regression facilitates that exploration. The logistic procedure, PROC LOGISTIC, integrated within the SAS (Statistical Analysis System) software was used to perform the logistic model fit to the data (Allison, 1999). The commonly accepted standard significance threshold of 0.05 for parameter estimates was used.

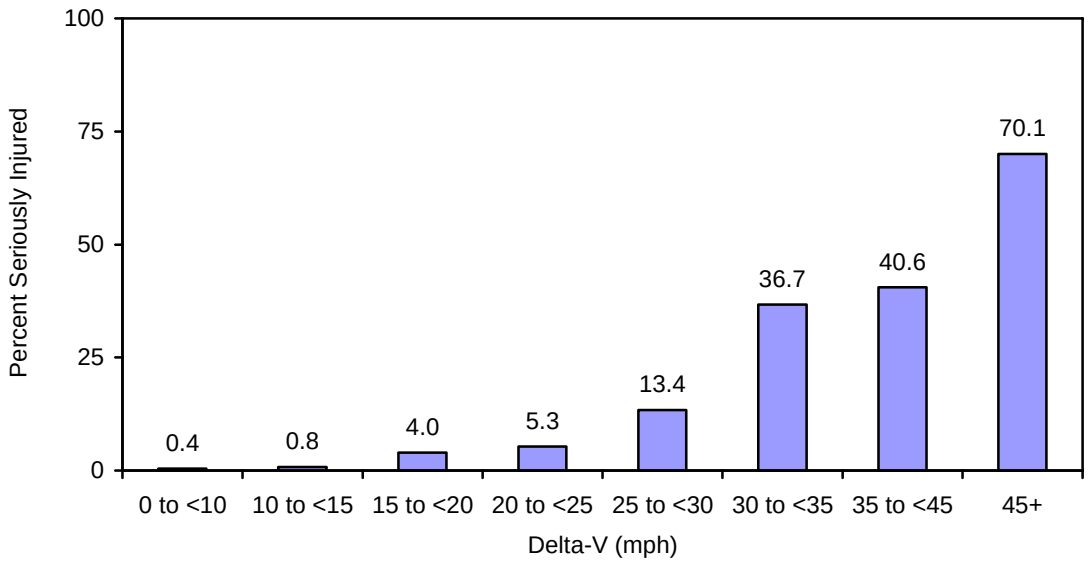
The key *vehicle* variables examined were: mass ratio of the subject and the other vehicle in the front-to-front collision and vehicle make/model/year (derived from VIN coding) to identify the second-generation airbag presence. The primary occupant variables considered were: injury severity (fatal or non-fatal), restraint use, age, gender, and alcohol involvement. The collision variables considered were: number of vehicles involved in the crash (limited to exactly two vehicles in each crash) and type of crash (front-to-front, non-rollover).

NASS/CDS ANALYSIS – The NASS/CDS data was used to examine serious injury risk (MAIS 3-6/fatal) by delta-V, deployment rates by delta-V and quantify the average delta-V for the fatal crashes selected for the FARS study. The airbag deployment rate by delta-V and injury risk by delta-V were developed using NASS/CDS data (1997-2007) for 1998-2007 model year light vehicles. The data was restricted to vehicles which had airbags available, excluding cases where airbags were disconnected or not active. To estimate the range of the delta-V's involved in the selected set of front-to-front fatal crashes in the FARS database, similar crash configurations were selected from the NASS/CDS data and the corresponding delta-V distribution was obtained. In addition, 23 NASS/CDS cases with 25 mph (40 kmh) or higher longitudinal delta-V and no airbag deployment were reviewed.

RESULTS

Figure 1 presents the risk of serious injury/fatality by delta-V for belted drivers in frontal crashes with airbag deployment. The data shows that, the risk of injury increases as delta-V increases.

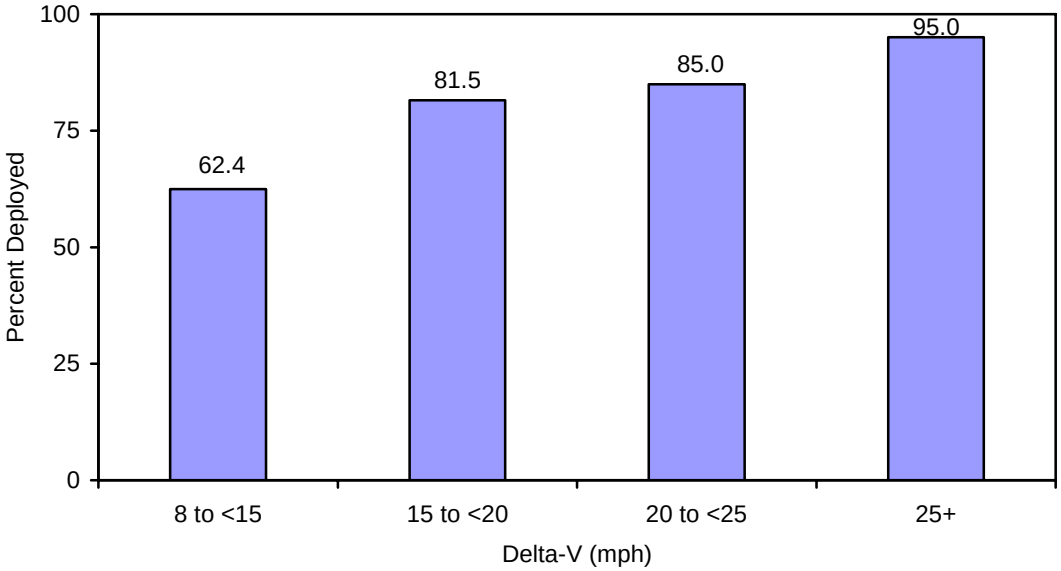
Figure 1. Risk of Serious Injury (MAIS 3-6/fatal) with Airbag Deployment, Frontal Impacts, Belted Drivers in Light Vehicles



Source: NASS/CDS, 1997-2007. Includes 1998-2007 model year light vehicles.
(Delta-V unit of 1 mph is equivalent to 1.61 kmh.)

Figure 2 presents the deployment rate by delta-V in frontal crashes. The deployment threshold for depowered airbags is between 8 to 14 mph (13 to 23 kmh) for all the vehicles registered in the U.S, but might be higher in post 2000 model year vehicles, due to an advanced airbag design. But the field data shows that, about 15% of vehicles in frontal crashes with delta-V 20-25 mph (32-40 kmh) and 5% of vehicles in crashes with delta-V 25 mph (40 kmh) or greater did not have airbags deployed. The NASS/CDS cases were reviewed to identify factors (if any) associated with non deployment in high delta-V crashes.

Figure 2. Airbag Deployment Rate in Frontal Impacts, Light Vehicles



Source: NASS/CDS, 1997-2007. Includes 1998-2007 model year light vehicles.
(Delta-V unit of 1 mph is equivalent to 1.61 kmh.)

Twenty-three (23) NASS/CDS cases did not have airbag deployment in crashes with delta-v greater than or equal to 25 mph (40 kmh). Of these, airbags did not deploy in 14 cases and airbags were disconnected in 9 cases. Nine (9) out of the 14 cases were light trucks. Three (3) of the 5 passenger car cases reviewed were post 2000 model year vehicles.

FARS ANALYSIS OF AIRBAG EFFECTIVENESS – The analysis included 2,777 belted drivers in front-to-front collisions. Logistic regression analysis was conducted to determine the influence of different factors on the likelihood of driver fatality in the subject vehicles. The factors considered were mass ratio of the vehicles in the crash, subject vehicle's driver age, presence of alcohol and the airbag deployment, and the other vehicle's driver age. The quality of the logistic fit was evaluated by examining the overall model significance, covariance matrix of the parameter estimates, and the concordance. The fit converged and the association of the predicted and observed outcomes (percent concordant) was found to be high – about 82% (Allison, 1999).

Two logistic models were developed:

1. Using the following values for the independent variable, "airbag deployment status": yes=1; no=not deployed=0; and
2. Using the following values for the independent variable, "airbag deployment status": yes=1; no=airbag not connected=0.

Tables 2A and 2B present the results for both the models.

Table 2A. Odds Ratios Estimated by the Logistic Model Fit (Airbag Deployment Status: No = Not deployed)

	Significance	Point Estimate	95% Lower Bound	95% Upper Bound
Log Mass Ratio (per 10% mass ratio increase)	S*(p<.0001)	1.54	1.47	1.62
Subject Vehicle Driver's Age (per 10 years increase)	S (p<.0001)	1.52	1.42	1.64
Subject Vehicle Driver's Alcohol (yes vs. no)	S (p<.0001)	2.03	1.43	2.89
Opposite Vehicle Driver's Age (per 10 years increase)	S (p<.0001)	0.86	0.81	0.92
Subject Vehicle's Airbag Deployed	NS (p=0.21)			

Table 2B. Odds Ratios Estimated by the Logistic Model Fit (Airbag Deployment Status: No=Not Connected)

	Significance	Point Estimate	95% Lower Bound	95% Upper Bound
Log Mass Ratio (per 10% mass ratio increase)	S (p<.0001)	1.53	1.46	1.61
Subject Vehicle Driver's Age (per 10 years increase)	S (p<.0001)	1.52	1.41	1.63
Subject Vehicle Driver's Alcohol	S (p<.0001)	2.1	1.47	3.01
Opposite Vehicle Driver's Age (per 10 years increase)	S (p<.0001)	0.87	0.82	0.93
Subject Vehicle's Airbag Deployed	NS (p=0.88)			

*S = Significant, NS = Not Significant

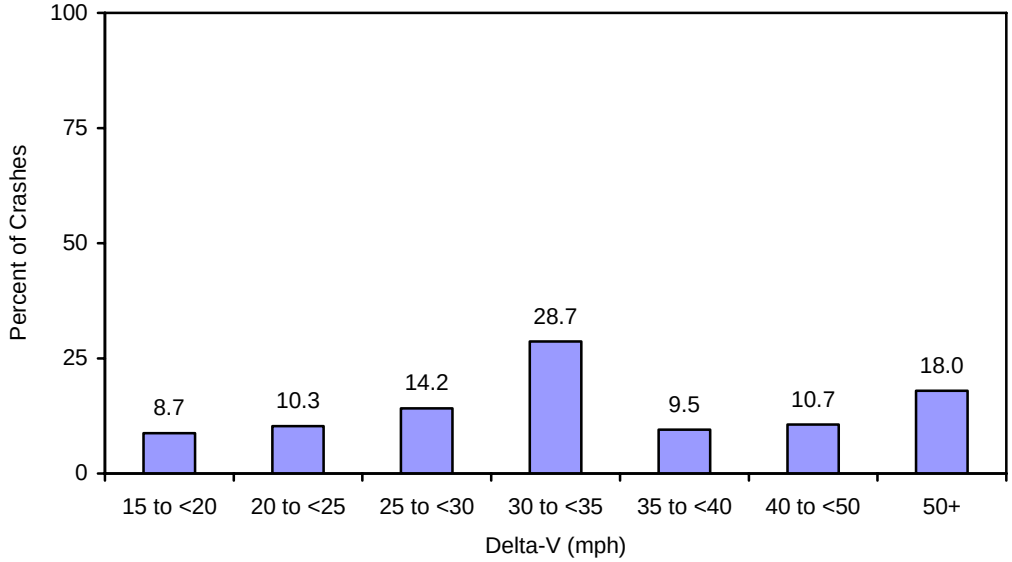
For example, Table 2A shows that:

- Increasing mass ratio by 10% increases the odds of fatality to belted driver in subject vehicle by 54%.
- Increasing subject vehicle's driver's age by 10 years increases his/her odds of fatality by 52%.
- Presence of alcohol for subject vehicle driver increases the odds of fatality by a factor of 2.
- Increasing other vehicle driver's age by 10 years decreases subject vehicle driver's odds of fatality by 14%.
- The airbag deployment was not found to be statistically significant in reducing odds of fatality to subject vehicle driver.

Table 2B presents similar findings. Hence, the airbag deployment was not a statistically significant predictor influencing the odds of driver fatality in severe frontal crashes.

NASS/CDS data was reviewed to quantify the range of delta-V crashes which closely reflect the FARS data set included in the study. A total of 19 cases were selected that fit the selection criteria used in the FARS study. The distribution of subject vehicle delta-V in these crashes is shown in Figure 3. The average delta-V is about 35 mph (56 kmh), and about 67% of these crashes were with delta-V greater than 30 mph and 24% were with delta-V 20-30 mph (32-48 kmh).

Figure 3. Distribution of Frontal Crashes by Delta-V for the Studied FARS Data Set Belted Drivers in Light Vehicles



Source: NASS/CDS, 1997-2007. Includes 1998-2007 model year light vehicles.
(Delta-V unit of 1 mph is equivalent to 1.61 kmh).

DISCUSSION

The FARS data used for the study included 2,777 belted drivers in frontal fatal crashes. Out of these, data was sparse for crashes where airbags did not deploy (121 cases) or airbags were not connected (88 cases). This resulted in wider confidence bounds for odds ratio estimates.

The matched pair approach that was used in this study permits better comparisons between airbag deployment and non-deployment, since the same model year ranges were used. Previous studies that had evaluated airbag effectiveness had compared older model year vehicles to more recent vehicles.

Data from NASS/CDS shows that high delta-V crashes where airbags did not deploy primarily involved light trucks. A more thorough examination of airbag design/sensors and other factors that are different between cars and light trucks is warranted.

CONCLUSIONS

Based on the FARS and NASS data analyses, the following conclusions were derived:

- The NASS/CDS data shows that in 5% of frontal crashes with delta-V greater than 25 mph (40 kmh) airbags did not deploy. Majority of the reviewed non-deployment NASS cases were light trucks.
- The risk of serious injury to belted drivers in crashes with airbag deployment increases as delta-V increases.
- In high severity fatal crashes, airbag deployment was not statistically significant in reducing the odds of belted drivers fatalities, while mass ratio of the vehicles, driver age and alcohol presence were found to be significant predictors of the likelihood of fatality. These severe crashes had an average delta-V of about 35 mph (56 kmh). About 67% of these crashes had delta-V of 30 mph (48 kmh) or higher. Consequently, based on the analyzed sample of fatal crashes, airbags are not very effective in reducing odds of fatality to a belted driver in a frontal crashes with delta-V of 30 mph (48 kmh) or greater.

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