Effect of Cargo Loading on Occupant Injury and Seat Deformation in Motor-Vehicle Crashes

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Purpose: NHTSA studied interior loose objects in the 2000-04 NASS-CDS as part of rulemaking on cargo retention testing in FMVSS 208. This study extends the investigation of cargo and loose interior object loading on occupant injury and seat deformation by cargo in motor-vehicle crashes using NASS-CDS data.

Methods: 1996-2011 NASS-CDS was used to investigate the effects of loose interior objects and seat responses on occupant injury in motor vehicle crashes. Crashes were grouped by front, side, rear and rollover. Light vehicles were included with model year 1994+. NASS-CDS added new variables for cargo loading as an injury source and cause for seat deformation in 2007. NASS-CDS electronic cases were analyzed for rear occupants with moderate to severe injury (AIS 2+) from loose objects and MAIS 4+F injury with cargo deforming seats in frontal crashes.

Results: There were no AIS 2+ injuries due to cargo loading in the 16 years of NASS-CDS, including specific coding from 2007–11 and by case evaluation in earlier years. In frontal crashes, loose or other interior objects accounted for 250 AIS 2+ injuries in drivers, 32 in front passengers and 206 in 2nd row occupants. The overall rate of AIS 2+ injury was 1.000% for 2nd row occupants due to loose or other interior objects. The individual cases of AIS 2+ injury from loose or other interior objects in 2nd row occupants involved 16 occupants with 44 injuries in frontal crashes. Two cases involved police vehicles and one, an ambulance. In two other cases, the loose interior object was a bike placed in the 3rd row of a station wagon and an unsecured fan in the 2nd row. Each year, there were 540 driver seats deformed by cargo, 438 front-passenger seats and 889 in 2nd row seats. Most cargo deformation of front seats occurred in frontal crashes. Annually, there were 462 driver seats deformed by cargo in frontal crashes, 143 front-passenger seats and 660 in 2nd row seats.

Conclusions: This analysis supports NHTSA’s earlier conclusion that cargo is not a major source of injury in frontal crashes. While anecdotal cases have been presented in the literature, there were no cases in NASS-CDS. NASS-CDS also showed that when untethered cargo deforms rear seats, it was not related to severe injury to 2nd row occupants.

Keywords: cargo, loose interior objects, frontal crashes, occupant injury, rear seats

Introduction

In 2004, NHTSA was petitioned to amend FMVSS 208 by adopting a cargo retention test defined by ECE R-17 for the approval of seats, anchorages and head restraints (Coben and Cantor 2004). ECE R-17 was revised in 1998 to assess the performance of rear seatbacks during dynamic cargo loading from the trunk in frontal crashes (R-17 2004). The requirement applied to new cars from August 2000 and all cars from August 2002. It involved a frontal sled test at 50 km/h (30 mph) with peak acceleration of 20–28 g and duration of 100-120 ms. Two 18 kg (40 lb) blocks are placed 200 mm (7.9”) rearward of the rear seatback. The cargo should not extend forward more than 150 mm (6”) of a vertical plane through the R-point (seating reference point or H-point) and should not intrude into the passenger compartment in the test. There is no US dynamic test for untethered cargo in the trunk. The petitioners also requested that belted dummies be used in the rear seats in frontal crash testing, but the request was declined. At this time, 2nd row dummies are not required in US frontal crash regulations.

NHTSA examined real-world crashes in the 2000-2004 NASS-CDS where an occupant sustained AIS 3+ injury from contact with an “interior loose object,” in a frontal crash where there was a “seat performance failure.” The query yielded no cases matching the criteria in five years of NASS. NHTSA expanded the search and found one case with driver injury associated with a loose object (2004-049-105). It was a rollover where the passenger-side door beam was torn from the door and deformed the driver’s seat injuring the driver. NHTSA concluded that there were no anecdotal cases that occurred...
in NASS real-world investigated crashes. They denied the petition (Kratzke 2006).

Cargo has been observed as a source of injury in crashes (Le Claire and Visvikis 2001; Sherwood et al. 2003; Mandell et al. 2010). Le Claire and Visvikis (2001) identified five cases of cargo displacing forward in frontal crashes and injuring rear occupants. The study was an impetus for discussions on sled test requirements in Europe with untethered cargo and intrusion into the rear seat. During the deliberation, UN/ECE (2004) summarized two other studies on cargo in motor-vehicle crashes. The first was from Germany. They presented a 1998 study of 5,523 accident vehicles from 1993–97. The conclusion was that 5 vehicles involved occupants injured by unsecured objects or luggage representing 0.091% of the involved vehicles. Except for one particularly severe accident involving AIS 3 injury, the other injuries were minor AIS 1 (bruising, abrasion, etc.) or AIS 2 (1 case). The second study was from OICA (International Organization of Motor Vehicle Manufacturers). They presented data collected in the European Accident Causation Study. They reviewed 1,784 passenger cars involved in accidents in France, Germany, Italy, and Finland. The data showed that in 74% of the vehicles, the luggage compartment was empty. Low luggage load (<11 kg) was found in 10% of the crashes. Medium (11 to 30 kg) and high (>30 kg) luggage load was found in 8% of the cases. They concluded that the luggage load used in R17.07 (2 × 18 kg = 36 kg) more than adequately represented the vast majority of field accidents.

Mandell et al. (2010) evaluated CIREN cases and found four where a 2nd row occupant was seriously injured from untethered cargo. They also investigated NASS-CDS data to assess the risk of injury to 2nd row occupants in frontal crashes as a function of seat performance; however, they did not discriminate between seat failure and seat damage from intrusion or occupant loading. The case reviews may be subject to other interpretations on injury causation.

Loose cargo and interior objects have been a source of injury particularly in vehicles where the cargo area is part of the vehicle interior, including station wagons, minivans and SUVs. In a crash, the cargo or loose interior object may interact with an occupant in high-speed frontal crashes and rollovers. The car industry has considered the need for adequate tied-downs to secure cargo in the trunk. They have also considered the need for the rear seat to serve as a barrier for untethered cargo (Bacon and Gazeley 1984; Schaper and Zech 1986; Zivkovic 1996; Vroman et al. 2003; Donde et al. 2009).

Sahraei et al. (2009) and Bilstrom et al. (2010) have shown that more safety advances have been made for front passengers than rear seat occupants. Other studies have addressed priorities for rear seat safety based on field data (Parenteau and Viano 2003a,b; Durbin et al. 2005; Viano and Parenteau 2008, 2009) and rear seat occupancy (Trowbridge and Kent 2009; Parenteau and Viano 2014). There is a continued need for further safety improvements, but changes need to be based on real-world priorities.

This study extended the original investigation by NHTSA using 1996–2011 NASS-CDS to determine occupant injury due to cargo, loose or other interior object impacts in motor-vehicle crashes. A cargo variable was added to the injury sources and cause for seat deformation in NASS-CDS starting in 2007. This allowed a specific coding for the effect of cargo loading on occupant injury and seat performance. In earlier years, cargo was part of interior or loose objects in the NASS-CDS database.

Methodology

**NASS-CDS Data**

NASS-CDS is a stratified sample of crashes that are prospectively selected for in-depth investigation. Most of the vehicles are towed from the scene because of damage. The data includes information from NASS crash investigation teams, vehicle registration, medical records, the police report and interviews. In this study, the data was extrapolated to national estimates using weighting factors provided by NHTSA. The 1996-2011 NASS-CDS was used to study occupant injury in light vehicles (passenger cars, light trucks, SUV and vans (0 < bodytype < 50)) with model year 1994+ were included. The data for calendar years 2009–2011 is representative of model year 2000+.

**Crash Types**

Crash types were defined as:

- **Front:** Vehicles involved in frontal impacts where the greatest damage was to the front (GAD1 = F). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤0).
- **Side:** Vehicles involved in side impacts where the greatest damage was to the left or right side (GAD1 = L or R). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤0).
- **Rear:** Vehicles involved in rear impacts where the greatest damage was to the rear (GAD1 = B). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤0).
- **Rollover:** Vehicles involved in rollover were those with a rollover >0.
- **Other:** Vehicles involved in other impacts where the greatest damage was to the top or undercarriage (GAD1 = U or T). Collisions in which a rollover occurred were excluded from the sample (Rollover ≤0).
- **Unknown:** Vehicles involved in impacts with unknown damage information.

**Occupant Types**

Occupants were defined as:

- **Drivers:** Occupants with role = 1.
- **Front-passengers:** Occupants in seat position 11 or 13 and with role = 2.
- **2nd row occupants:** Occupants in seat position 21–27.
- **3rd row occupants:** Occupants in seat position 31–37.
Effect of Cargo Loading

Injury Severity

Injury severity of the occupant was assessed using the Maximum Abbreviated Injury Scale (MAIS) and the “TREATMNT” variable. MAIS represents the assessment of life-threatening injuries at the time of first medical evaluation and not long-term consequences. It ranges from MAIS 0 to 9, where MAIS 9 is an injury with unknown severity. MAIS 4-6 represents a severe-to-unsurvivable injury. Fatality was also used to determine if the occupant died of injuries in the accident. To define a fatality (F), the following variables were used:

- Treatment: TREATMNT = 1 since it means that the occupant was fatally injured and not transported to the hospital.
- ISS 75: Injury Severity Score = 75 represents a fatality
- Police injury severity: INJSEV = 4 represents the fatality from police rating.

Because fatalities can occur at any MAIS level, severely injured occupants were defined as those with MAIS 4-6 or fatality. The shorthand notation for this is MAIS 4+F. Injury severity was classified as AIS 2+ (moderate to severe injury).

Loose Object/Cargo Injury Sources

The contact sources of AIS 2+ injuries were determined using the “injsou” variable. Since “injsou” coding may vary from year to year, the variations were taken into account for consistency of the injury source.

- Other interior object was identified as injsou = 163 from calendar years 1996–2011
- Interior loose object was identified as injsou = 161 for calendars years 1996–2011 and as 571 for years 2002–2007.
- Cargo was identified as injsou = 576 for the 2007–2011 calendar years.

Seat Performance

The performance of the driver, front and rear seats was assessed using the “SEATPERF” variable. This variable is used by crash investigators to identify whether the seat failed or was deformed. The variable is coded as:

- (1) No failure.
- (2) Adjuster failure, includes failure of the height adjustment, longitudinal seat track adjustment, rocker adjustment, swivel/rotational adjustment, or seat back recliner adjustment.
- (3) Seatback failure is when the mechanism designed to lock the seat back in its upright position fails or separates allowing the seatback to move during the collision as a result of occupant loading.
- (4) Tracks-anchors failure is used if the seat separates, to any degree, from a seat track during the crash.
- (5) Deformed by occupant is when the seat form is changed from its original design due to occupant loading during the crash.
- (6) Deformed by intrusion is when the seat is deformed or failed by intrusion of an interior vehicle component(s) or exterior vehicle component(s) into the passenger compartment.
- (7) Combination is when two or more of (2)-(6) occurs.
- (8) (8/98) Other is used when the only seat failure or deformation is not
- (9) Deformed by cargo (variable available in 2007+ data).
- (10) Deformed by other occupant loading (variable available in 2007+ data).

Weighted Data

National estimates for the number of occupants and injuries in each category were made using the Ratio Weight (ratwgt) variable in the NASS-CDS. All calculations were based on weighted values.

Standard Errors

In our early papers, standard errors (SE) were estimated for the weighted injury counts in NASS-CDS using an equation from NHTSA (1997). The equation used only the RATWGT-weighted count and two constants: SE = exp [a + b(ln(x))]**2, where x was the weighted count with a = 3.837986 and b = 0.04538 (Viano et al. 2007, 2008; Edwards et al. 2009).

In about 2008, SAS was available with a procedure to estimate SE in NASS-CDS data. The following command string was used in SAS: PROC SURVEYFREQ DATA = ; WEIGHT RATWGT. There were several reasons we used this approach, including the following from a NASS-CDS user manual: “Estimates of National totals for crash characteristics can be obtained using the Ratio Inflation Factor (RIF). However, because the RIFs have been adjusted to actual crash counts, some of the sampling variation has been removed. Therefore they will produce more precise estimates than the National Inflation Factor. It is for this reason that the RIF or Ratio Weight is the only weight on the analysis” (NHTSA 2009, p. 13). RATWGT represents RIF or Ratio Weight. This approach was used in several studies (Viano and Parenteau 2010a–d, 2012; Parenteau and Viano 2011).

In recent private communications, NHTSA has recommended using RATWGT and PSUSTRAT to estimate SE. This approach does not appear in any NASS-CDS user manual to our knowledge. It uses the following command string in SAS: PROC SURVEYFREQ DATA = ; STRATA PSUSTRAT; CLUSTER PSU; WEIGHT RATWGT. NHTSA further recommends that only “IF-THEN” statements be used and that “WHERE” statements not be used. It is our understanding that NHTSA will provide a public document with this latest procedure and recommended practices to estimate SE. In this study, standard errors (se) were determined using the SAS procedure “SURVEYFREQ”, accounting for PSU and weight factors, according to NHTSA's latest recommendation.
Table 1. Annual AIS 2+ injury by injury source, crash type and seating position

| AIS 2+ Injuries by Source | Year code avail. | Crash Type | Front | Side | Rear | Rollover | Other | Total w/ unk |
|--------------------------|------------------|------------|-------|------|------|----------|-------|--------------|
| Cargo                    | 07–11            | Driver     | 0     | 0    | 0    | 0        | 0     | 0            |
| Loose int. obj.          | 96–11            | 49         | 51    | 0    | 164  | 3        | 3     | 267          |
| Other int. obj.          | 96–11            | 201        | 462   | 36   | 94   | 12       | 12    | 805          |
| Other                    | 96–11            | 115,858    | 57,379| 4,407| 54,767| 3,859    | 3     | 261,316      |
| Total                    | 116,108          | 57,891     | 4,443 | 55,025| 3,875 | 3        | 3     | 262,388      |
| Cargo                    | 07–11            | Front-Passenger | 0 | 0 | 0 | 0 | 0 | 0 |
| Loose int. obj.          | 96–11            | 8          | 1     | 0    | 0    | 0        | 0     | 9            |
| Other int. obj.          | 96–11            | 25         | 71    | 34   | 41   | 0        | 0     | 170          |
| Other                    | 96–11            | 26,443     | 14,633| 1,255| 12,210| 748      | 748   | 62,231       |
| Total                    | 26,476           | 14,705     | 1,289 | 12,250| 748   | 748      | 748   | 62,409       |
| Cargo                    | 07–11            | 2nd Row Occupant | 0 | 0 | 0 | 0 | 0 | 0 |
| Loose int. obj.          | 96–11            | 44         | 9     | 0    | 11   | 0        | 0     | 64           |
| Other int. obj.          | 96–11            | 162        | 25    | 9    | 3    | 0        | 0     | 220          |
| Other                    | 96–11            | 7,182      | 7,210 | 1,430| 8,441 | 445      | 445   | 28,127       |
| Total                    | 7,388            | 7,244      | 1,439 | 8,455 | 445   | 445      | 445   | 28,411       |
| Cargo                    | 07–11            | 3rd Row Occupant | 0 | 0 | 0 | 0 | 0 | 0 |
| Loose int. obj.          | 96–11            | 0          | 0     | 0    | 0    | 0        | 0     | 0            |
| Other int. obj.          | 96–11            | 0          | 0     | 0    | 0    | 0        | 0     | 0            |
| Other                    | 96–11            | 361        | 348   | 245  | 1,080 | 109      | 109   | 2,318        |
| Total                    | 361              | 348        | 245   | 1,080 | 109   | 109      | 109   | 2,319        |

**Rate Analysis**

The rate of injury was determined by dividing the number of injuries by the number of occupants with known injury status, MAIS 0-6 or F (MAIS 0/F). Occupants with unknown injury were removed from the exposure group used to determine rate. Standard errors for injuries and rates were determined.

**NASS-CDS Electronic Cases**

All electronic cases involving 2nd row occupants with AIS 2+ injury from cargo/object loading in frontal impacts were downloaded from NHTSA (www.nhtsa.gov). The cases were analyzed for crash circumstances and occupant injury. Photographs of the vehicle and interior were reviewed.

**Results**

Table 1 shows the annual count of AIS 2+ by crash type and injury source (the unweighted count is given in Appendix Table A1). There were no AIS 2+ injuries due to cargo loading in the 16 years of NASS-CDS data. The rate of AIS 2+ injury was 0.227% in 2nd row occupants due to loose interior objects. For other interior objects, the rate was 0.773% in 2nd row occupants, 0.307% in drivers and 0.272% in front-passengers. In frontal crashes, loose interior objects accounted for 49 AIS 2+ injuries in drivers, 8 in front passengers and 44 in 2nd row occupants.

There were 262,388 AIS 2+ injuries in drivers, 62,409 in front-passengers, 28,411 in 2nd row occupants and 2,319 in 3rd row occupants in all crashes annually (Appendix Table A2 gives the annual count and Table A3, the unweighted data). The number of AIS 2+ injuries exceeds the number of MAIS 2+F injured occupants, since an occupant can have up to 15 injuries listed. More than 48% of driver and front-passenger AIS 2+ injuries occurred in frontal impacts, excluding unknown and other crash types. Most 2nd row and 3rd row AIS 2+ injuries occurred in rollovers. The frequency was 34.5% and 53.1% respectively. Rear crashes accounted for the least number of AIS 2+ injuries.

Table 2 gives the distribution of AIS 2+ injuries by body region due to cargo, loose or other interior objects. For 2nd row occupants, most injuries were to the lower extremity followed by the head. Spine injuries were most common in drivers followed by head injuries. Abdominal injuries were most common in front passengers followed by facial injuries.

Each year, there were 1,992,758 drivers, 487,042 front-passengers, 326,836 2nd row and 22,033 3rd occupants exposed to tow-away crashes based on 16 years of NASS-CDS data from 1996–2011 (see Appendix Table A4 for the annual count and Table A5 for the unweighted data).
were 879,223 drivers, 200,656 front passengers and 129,358 2nd row occupants involved in frontal crashes per year. In frontal crashes annually, there were 423 ± 89 2nd row occupants with AIS 4+F. The rate for MAIS 4+F was 0.337% ± 0.071%.

Table 3 summarizes the vehicle, occupant and injury information for the individual cases of AIS 2+ injury in 2nd row occupants from loose or other interior objects (the full injury listing is in Table A6 for each occupant). The cases were downloaded from the 1997–2011 electronic files at NHTSA for frontal crashes. The cases were analyzed to understand injury mechanisms. They involved 16 occupants with 44 AIS 2+ injuries. There were 2 cases that involved a police vehicle and one with an ambulance. Loose interior objects were observed in 2 cases. One case (2005-12-202B) was with a bike in the 3rd row of a station wagon. The loose object was not identified in the 16 years of NASS-CDS frontal crashes. The ratwgt for each case is given. Figure 1 shows photos of the crashes. The ratwgt was determined to be 52, 61 and 71 km/h (32, 37 and 44 mph). The seat deformation was not related to the severe occupant injury in any of the cases.

Each year, there were 1,415,966 driver’s seats with known performance (excluding unknowns, missing and non-use). 96% of the seats were not deformed. Seat deformed by occupant loading or intrusion occurred in 3.32% of the crashes, while failures occurred to adjusters, locks or tracks in 0.55% of crashes (see Appendix Table A7). For 2nd row seats, there were 251,572 with known performance. 97% had no deformation or failure. In 1.92% of crashes, there was rear seat deformation by occupant loading or intrusion occupants. Intrusion was the most common mechanism of rear seat deformation. There was failure of a seat lock, adjustor or anchor in 0.13% of the crashes. The unweighted data is shown in Appendix Table A8.

Seats deformation by cargo was specifically coded in 2007 and later NASS-CDS data. Each year, there were 540 driver seats deformed by cargo, 438 front-passenger seats and 889 in 2nd row seats (Appendix Table A7). There were none in 3rd row seats. Most cargo deformation of front seats occurred in frontal crashes. Annually, there were 462 driver seats deformed by cargo in frontal crashes, 143 front-passenger seats and 660 in 2nd row seats. For 2nd row seats, cargo loading was most frequent in side impacts.

Table 4 shows the maximum injury severity (MAIS) in frontal crashes by seating position and seat performance. Each year, there were 147 occupants severely injured or killed (MAIS 4+F) and the seat performance variable listed as deformed by cargo. This involved 92 drivers and 54 2nd row occupants. The unweighted cases by MAIS are given in Appendix Table A9. There were 13 cases involving a severely injured occupant. This involved 9 drivers and four 2nd row occupants. The 4 cases with a severely injured 2nd row occupant were downloaded for review.

Table 5 lists the individual cases of rear seat deformation by cargo and MAIS 4+F injury to a 2nd row occupant. There were four cases that weighted to 272 in the 16 years of NASS-CDS. The ratwgt for each case is given. Figure 1 shows photos of the vehicle crash and seat deformation, highlighting the severity of the crash. In three cases, the delta V was determined to be 52, 61 and 71 km/h (32, 37 and 44 mph). The seat deformation was not related to the severe occupant injury in any of the cases.

### Discussion

The analysis 1996-2011 NASS-CDS found no real-world cases with cargo deforming the seatback and injuring a 2nd row occupant in 16 years of NASS-CDS frontal crashes. Moderate to severe injuries due to loose or other interior objects were infrequent. They occurred at a rate of 0.409% in drivers, 0.286% in front-passengers and 1.000% in 2nd row occupants. The analysis also showed that seat deformation due to cargo loading was infrequent. For 2nd row occupants involved in a frontal crash, the rear seat remained intact in 99% of the cases. Seat intrusion was observed in 0.46% of occupied seats,
and cargo loading in 0.52%. These results differ from those reported by Mandell et al. (2010). The authors analyzed the 1993-2006 NASS-CDS and reported a seatback intrusion or failure in 8.3% of cases involving a belted 2nd row occupant in frontal crashes. The definition for seat failure was not provided and the results were based on unweighted data. The unweighted data for 2nd row occupants in frontal crashes in Appendix 8 gives 96.04% of cases with no seat deformation or failure. In 0.39%, there was a seat failure of an adjuster, fold lock or anchor/track. In 1.47%, there was deformation due to intrusion and in 0.73% deformation due to occupant loading.

This analysis supports the earlier decision by NHTSA not to adopt a cargo retention test in FMVSS 208. While anecdotal cases have been presented in the literature, the lack of cases in NASS-CDS indicates there are higher priority topics for rulemaking and crash testing. IIHS continues to develop crash tests that address safety priorities in real-world crashes. The recent shallow offset and earlier side impact testing with a

| Driver | 0 | 1-2 | 3 | 4+ | Total w/ unk |
|--------|---|-----|---|----|--------------|
| None   | 408,859 | 317,079 | 9,922 | 2,737 | 738,607 |
| Failure | 47 | 509 | 18 | 9 | 740 |
| Adjusters | 407 | 387 | 37 | 10 | 875 |
| Fold Lock | 31 | 479 | 135 | 104 | 752 |
| Track/Anchor | 58 | 1,119 | 377 | 555 | 2,358 |
| Deform. | 1,171 | 3,235 | 385 | 478 | 5,601 |
| Intrusion | 745 | 1,059 | 241 | 35 | 2,133 |
| Occ loading | 2 | 159 | 208 | 92 | 462 |
| Other occ | 1 | 64 | 80 | 153 | 300 |
| Cargo | 39 | 242 | 56 | 91 | 462 |
| Combination | 18,807 | 7,640 | 633 | 686 | 99,842 |
| Total | 429,652 | 331,134 | 11,784 | 4,862 | 879,242 |
| Front-Passenger | 109,000 | 71,216 | 2,344 | 7 | 190,574 |
| Failure | 0 | 3 | 6 | 0 | 10 |
| Adjusters | 32 | 434 | 6 | 16 | 515 |
| Fold Lock | 0 | 39 | 2 | 7 | 48 |
| Track/Anchor | 0 | 184 | 34 | 75 | 315 |
| Deform. | 556 | 980 | 210 | 93 | 1,950 |
| Intrusion | 270 | 1,658 | 706 | 30 | 2,698 |
| Occ loading | 0 | 104 | 38 | 0 | 143 |
| Other occ | 0 | 44 | 13 | 32 | 94 |
| Cargo | 30 | 233 | 45 | 9 | 318 |
| Combination | 3,369 | 1,847 | 493 | 76 | 5,945 |
| Total | 113,072 | 75,529 | 3,382 | 1,025 | 200,656 |
| 2nd Row Occupant | 88,396 | 31,086 | 641 | 277 | 124,297 |
| Failure | 22 | 0 | 0 | 0 | 22 |
| Adjusters | 12 | 8 | 7 | 8 | 35 |
| Fold Lock | 0 | 17 | 0 | 1 | 18 |
| Track/Anchor | 110 | 257 | 104 | 73 | 575 |
| Deform. | 38 | 69 | 8 | 13 | 146 |
| Intrusion | 0 | 39 | 9 | 0 | 47 |
| Occ loading | 0 | 183 | 279 | 85 | 660 |
| Other occ | 2 | 2 | 6 | 4 | 18 |
| Cargo | 41 | 67 | 9 | 8 | 143 |
| Combination | 2,346 | 1,336 | 65 | 22 | 3,884 |
| Total | 91,024 | 32,943 | 869 | 423 | 129,358 |
| 3rd Row Occupant | 5,734 | 1,130 | 137 | 8 | 7,276 |
| Failure | 0 | 0 | 0 | 0 | 0 |
| Adjusters | 0 | 0 | 0 | 0 | 0 |
| Fold Lock | 0 | 0 | 0 | 0 | 0 |
| Track/Anchor | 24 | 24 | 3 | 0 | 51 |
| Deform. | 0 | 3 | 0 | 3 | 7 |
| Intrusion | 73 | 4 | 0 | 0 | 77 |
| Occ loading | 0 | 0 | 0 | 0 | 0 |
| Other occ | 0 | 0 | 0 | 0 | 0 |
| Cargo | 0 | 0 | 0 | 0 | 0 |
| Combination | 0 | 0 | 0 | 0 | 0 |
| Other | 0 | 0 | 0 | 0 | 0 |
| Not seated/miss/unk | 498 | 57 | 13 | 0 | 567 |
| Total | 6,328 | 1,229 | 153 | 12 | 7,989 |
Effect of Cargo Loading

high-hood barrier were reasonable tests requiring the industry to make design changes in vehicle structures and occupant restraints. The lack of issues with cargo retention indicates that the attachment of rear seats provides a reasonable barrier to untethered cargo in the trunk. The use of tie-down straps would further minimize cargo loading on the rear seat and in open trunk areas of station wagons, SUVs and vans.

Parenteau and Viano (2003a,b), Durbin et al. (2005), Viano and Parenteau (2008, 2009) analyzed 2nd row adult, children, toddler and infant injuries and provided priorities for improving occupant protection. There have been changes that improved the safety of rear seats. Anton’s law has required lap-shoulder belts in all rear seating positions and the availability of the LATCH system has simplified the installation of child safety seats. The revision to FMVSS 301 to conduct a 50 mph offset deformable barrier has improved the crashworthiness of rear structures and reduced intrusion of 2nd row seats. Other rear seat improvements have included the implementation of inflatable side curtains and inflatable belts for rear occupants. Further safety advances are needed, because recent studies have shown that more safety advances have been made for the front-passenger than rear occupants (Sahraei et al. 2009; Bilston and Brown 2010). Any further changes should be based on real-world injury priorities.

Limitations

In this study, cargo loading was assessed using the injury source variable “injsou” coded by the NASS-CDS crash investigator. The source represents the object that directly contacts and causes the injury. It does not necessarily describe the injury mechanism. In some instances, it is possible that cargo may indirectly contribute to loading applied on the occupant and affect the injury outcome. It is not possible to assess the indirect contribution of cargo loading using NASS-CDS data. Furthermore, cargo or loose objects may have been removed prior to the NASS-CDS cash investigation. As a result, the rate of cargo or loose object loading may be under-estimated in this study.

NASS-CDS data documents the object that caused the injury through the “injsou” variable. It also reports whether the object intruded into the occupant’s seating position and whether or not the injury was caused by direct contact with the object. The coding of these variables may not always be

Table 5. Cases with rear seat deformation by cargo and MAIS 4+F injury

| Year | PSU | Caseid | Ratwgt | Delta V (mph) | 2nd Row Occupant | Belt | Age/ Gender | Weight (kg) | Height (m) | MAIS 4+F injury | Source |
|------|-----|--------|--------|---------------|------------------|------|--------------|-------------|------------|----------------|--------|
| 2011 | 41  | 73J    | 21     | 37            | right            | None | 25 yo m      | 93.2        | 1.8        | Brain injury   | front seatback |
| 2008 | 13  | 134B   | 83     | 32            | center           | L-S  | 80 yo f      | 71.8        | 1.7        | Heart laceration| seatbelt webbing |
| 2008 | 72  | 72D    | 20     | Unk           | right            | None | 20 yo f      | 55.0        | 1.7        | C1-C2 dislocation| instrument panel |
| 2007 | 48  | 135B   | 149    | 44            | right            | L-S  | 13 yo m      | 55.0        | 1.7        | C1-C2 dislocation| front seatback |
complete since it is based on post-crash information. The information is generally collected at the time of the crash investigation from medical reports or from interviews. The reliability of the data can be assessed using the confidence level provided by the investigator. In this study, the reliability of the injury source data was not assessed.

Vehicles sold in Europe since about 2002 are equipped with cargo retention systems that satisfy ECE crash test requirements. Those technologies are not always used in the US version of a vehicle. In this study, all occupants in light vehicles light vehicles (passenger cars, light trucks, SUV and vans (0 < bodysize < 50)) with model year 1994+ were included. The data for calendar years 2009–2011 is representative of model year 2000+. The effect of cargo retention systems was not assessed and merits continued research.

The rate of cargo loading may also vary with the design of 2nd row configuration such as ones with fold down seatbacks for trunk access or a split bench. As the sample size increases, an additional analysis based on 2nd row seat type may be worthwhile.

Injuries by loose objects and seat deformation by cargo are infrequent in motor vehicle crashes. This leads to a small sample of cases in NASS-CDS. However, the sample is not small. For example, there were 14,587 (unweighted) 2nd row occupants evaluated by NASS-CDS investigators over 16 years. There were on 37 cases where cargo deformed the rear seat. The weighted number of cases was 2,077,515 2nd row occupants with 10,564 cases of cargo deformation of the seat. This gives a weighted rate of 0.509% and indicates an infrequent event based on a large sample of investigated crashes.

One of the strengths of NASS-CDS is the ability to conduct clinical analysis of motor vehicle crash injuries. The approach we have used has been to study trends from the weighted field data and then do in-depth engineering and medical analysis of electronic cases to study underlying mechanisms. This dual approach helps avoid the pitfalls of small numbers of cases and allows findings only when supported by both the field data trends and electronic cases.

Supplemental Material

Supplemental data for this article can be accessed on the publisher’s website.

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