US SIDE NCAP RATING TRENDS SINCE 2011

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ABSTRACT

The purpose of this study was to identify side impact crashworthiness trends since the enhanced NCAP rating system was implemented for 2011 and later model year vehicles. Publically available test results from NHTSA's crashworthiness database for 2011 to 2016 model year vehicles were collected. This study used new vehicle tests only. No carry over performance data was used. Commercial statistics software was used to observe vehicle crashworthiness performance, injury metrics, restraint, and vehicle deformation trends. Mean side impact relative risk score improved from 2011 to 2015, with the largest improvement occurring from 2012 and 2013. Both the driver and rear occupant demonstrated reduced injury metrics over the years examined, with the largest reductions from 2012 to 2013. During this same time period, the use of torso-abdomen-pelvis side airbags increased by 13.5 percent. Additionally, B-pillar deformation was reduced by 55 mm over the study period with the largest reduction occurring from 2012 to 2013. Though causative mechanisms for injury metric reductions could not be determined, this study documented the changes observed in crashworthiness performance, restraint system, and vehicle deformation.

BACKGROUND AND OBJECTIVE

In January of 2007, the US National Highway Traffic Safety Administration (NHTSA) announced its intention to enhance the existing New Car Assessment Program (NCAP) to better "distinguish meaningful performance differences between vehicles" and to encourage automobile manufacturers to design vehicles that exceed safety regulation requirements [1]. Beginning with 2011 model years, NHTSA began a new method for evaluating side impact crashworthiness performance. This new method adopted two dynamic performance assessments: a crabbed 62 km/h lateral impact movable deformable barrier (MDB) and an oblique 75˚ 32 km/h pole impact aimed at the driver head's center of mass. In the MDB test, injury metrics are evaluated with a EuroSID-2re (driver) and SID-IIs (rear passenger) anthropomorphic test devices (ATD). This update was predicted to reduce injuries and fatalities in side impact motor vehicle crashes. Yet, there is limited information on broader vehicle performance trends and restraint content since the introduction of these test modes. Therefore, the objective of the present study was to identify trends in injury metrics and vehicle performance correlated with NCAP side impact ratings for 2011 – 2016 model years.

METHODS

Data was obtained from the public NHTSA Vehicle Crashworthiness Database [2]. This database includes NHTSA-selected and voluntary NCAP tests for each NCAP year. For this study, side impact NCAP [SINCAP] MDB and SINCAP Pole test data were obtained. For each crash test mode conducted, NHTSA collected vehicle dynamic and static measurements and recorded vehicle characteristics. The subset of these data selected for this study are shown in Table 1. These include B-pillar crush (at mid door [referred to as level 2], hip point [referred to as level 3], and window sill [referred to as level 4] heights), maximum vehicle crush (at sill top, mid door, hip point, and window sill heights), sill height (at front wheel well, front door leading edge, B-pillar, and rear wheel well), sill height to window bottom sill, front window opening height, occupant seating measurements (hip point to striker x distance, chest to steering wheel distance, head to side header, head to side window, arm to door, and hip point to door), vehicle mass, and front and rear SAB types. In addition, peak injury metric results were obtained from NHTSA's NCAP Combined Crashworthiness Rating Calculators for each dummy in the two side impact rating tests [3-8]. These injury metrics are shown in Table 2.

Table 1.
Vehicle Characteristics and Measurements Used in This Study

Vehicle Type	Front Window Opening
Front SAB Type	B-Pillar Crush at Mid Door Height (L2)
Rear SAB Type (if present)	B-Pillar Crush at Occupant Hip Point Height (L3)
Automatic Door Locks	B-Pillar Crush at Window Sill Height (L4)
ADL Disable Capability	Sill Top Height Max Crush
Front Axle Mass	Mid Door Height Max Crush
Rear Axle Mass	Occupant Hip Point Height Max Crush
Front PT Deployed	Window Sill Height Max Crush
Rear PT Deployed	Occupant Hip Point to Striker
Sill Height at Front Wheel Well	Chest to Steering Wheel
Sill Height at Front Door Leading Edge	Head to Side Header
Sill Height at B-Pillar	Head to Side Window
Sill Height at Rear Wheel Well	Arm to Door
Sill Height to Window Bottom Sill	Hip Point to Door

Table 2.
Recorded Injury Metrics

Recorded Injury Metrics		
MDB Test		Pole Test
Driver	*Rear Passenger*	*Driver*
HIC36*	HIC 36*	HIC 36*
Rib Deflection*	Rib Deflection	Rib Deflection
Lower Spine Acceleration	Lower Spine Acceleration	Lower Spine Acceleration
Abdomen Load*	Combined Pelvis Force*	Combined Pelvis Force*
Pelvic Load*		

*Indicates an injury metric used to calculate the RRS for that occupant

Analysis of MDB and Side Pole test results and vehicle characteristics with respect to model year was conducted with Minitab (version 17, Minitab, Inc. State College, PA). Although vehicle ratings may carry over from year to year, in this study each model change which warranted testing occurred in the data only the first year it was in the market. Analysis was intended to find trends with respect to model year and to identify vehicle features correlated with dummy injury metrics. The relative risk score (RRS) is commonly used to quantify the injury risk associated with each occupant in NHTSA's test modes. A combination of each occupant RRS in the side impact tests was used to quantify each vehicle's side impact performance. The driver RRS consists of the MDB (80%) and the Pole (20%) results. The following injury metrics were used to determine the driver RRS in the MDB test: HIC36, maximum rib deflection, abdomen force, and pelvis load. Two injury metrics from the Pole test were also used to determine the front occupant RRS: HIC and combined pelvis force. The rear passenger RRS was determined by HIC and combined pelvis force recorded during the MDB test. Table 3 shows how RRS relates to NHTSA's 5-star rating scheme [3].

Table 3.
RRS Correlation to Star Rating

Star Rating	RRS Values
5 Stars	RRS < 0.67
4 Stars	0.67 ≤ RRS < 1.00
3 Stars	1.00 ≤ RRS < 1.33
2 Stars	1.33 ≤ RRS < 2.67
1 Star	RRS ≥ 2.67

RESULTS

This database investigation yielded complete data for 279 new or majorly updated vehicles. The sample size and the vehicle type distribution varied each year (Fig. 1). The largest sample size was in 2012; the smallest sample size was in 2016. Car and unibody SUVs made up the majority of each year's sample.

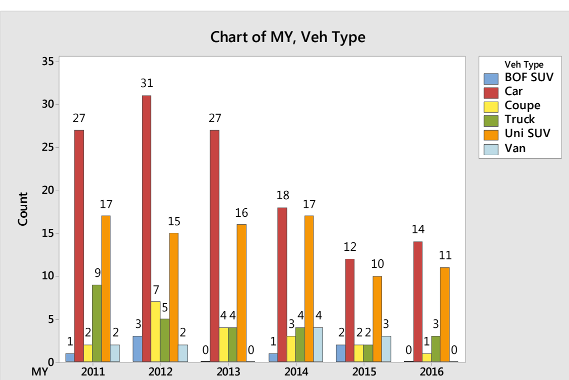

Figure 1. The sample sizes of each vehicle type (Body on Frame SUV, Car, Coupe, Truck, Unibody SUV, and Van) with available data from 2011 to 2016 (not including performance carry over).

Side Impact Relative Risk Score

From 2011 to 2015 the mean side impact RRS decreased from 0.64 to 0.33 (Fig. 2). The period from 2012 to 2013 accounted for 76% of this decrease.

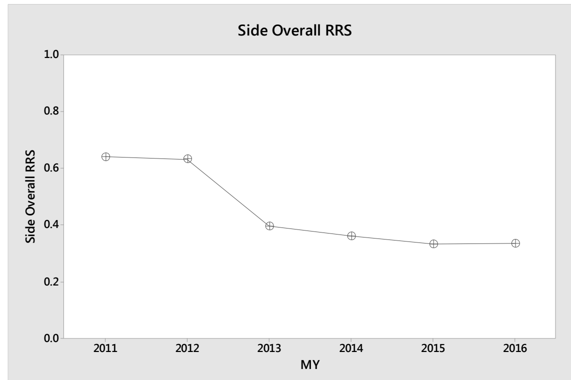

Figure 2. Side overall RRS results with respect to NCAP model year.

ATD Results

To understand the correlations with side impact RRS trends, individual occupant RRSs were investigated.

Driver MDB driver mean RRS decreased each year from 0.64 in 2011 to 0.34 in 2015 (Fig. 3). Pole driver mean RRS decreased from 2012 to 2015 (Fig. 4). Both Pole and MDB driver RRS experienced the largest decrease from 2012 to 2013 (49% and 51% of the corresponding ranges were accounted for by this one year).

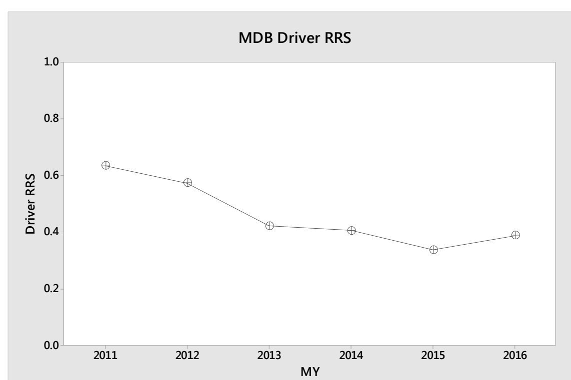

Figure 3. MDB driver mean RRS with respect to NCAP model year.

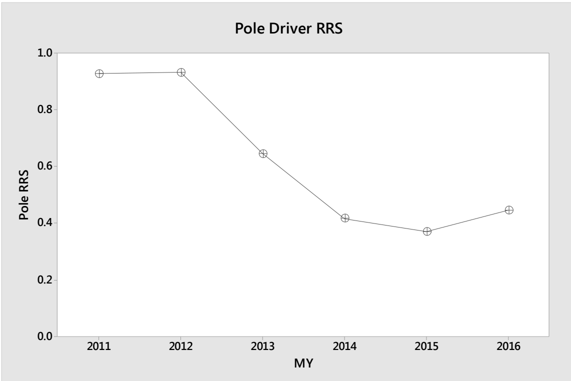

Figure 4. Pole driver mean RRS results with respect to NCAP model year.

<u>Rear Passenger</u> The rear passenger mean RRS (from the MDB test) ranged from 0.59 in 2012 to 0.27 in 2016 (Fig. 5). Of this range, 83% was accounted for by the change from 2012 to 2013.

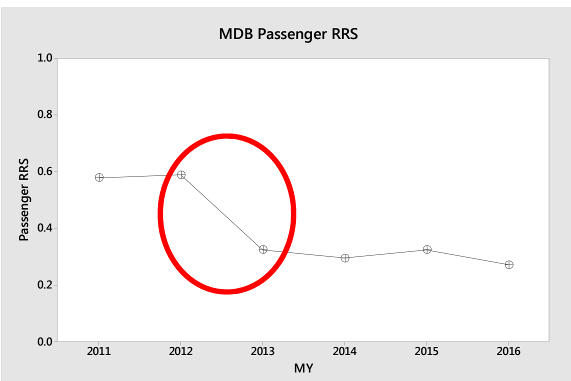

Figure 5. The MDB rear passenger mean RRS results with respect to NCAP model year.

Injury Metric Results

Both driver and rear passenger RRS values experienced the most improvement from 2012 to 2013. Injury metric results were examined to provide a more detailed breakdown of these improvements. Injury metric results were obtained from NHTSA's NCAP Combined Crashworthiness Rating Calculator [3-8]. Injury risk lines are shown in this section's figures to provide a reference of injury metric severity.

<u>Driver</u> The yearly mean of each injury metric are shown in Figures 6-9. There was no clear trend in HIC36. Average rib deflection ranged from 26.5 mm in 2011 to 20.4 mm in 2015. The largest decrease occurred from 2012 to 2013 (25.7 mm to 21.6 mm). Abdomen load decreased from 960 N in 2012 to 742 N in 2015 with the largest decrease of 118 N from 2012 to 2013. The pelvic load decreased each year. The pelvic load ranged from 1943 N in 2011 to 1405 N in 2016.

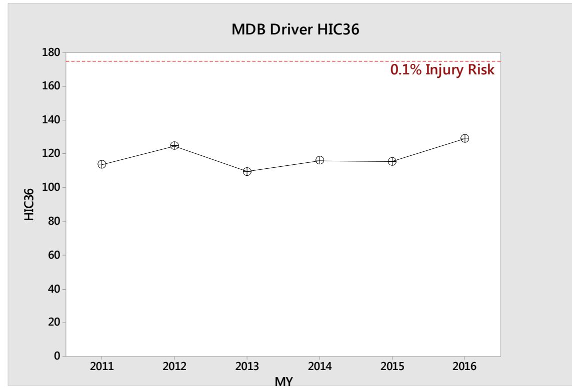

Figure 6. MDB driver mean HIC with respect to NCAP model year.

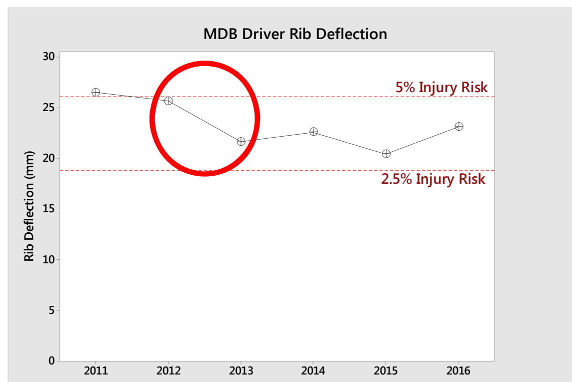

Figure 7. MDB driver mean rib deflection with respect to NCAP model year.

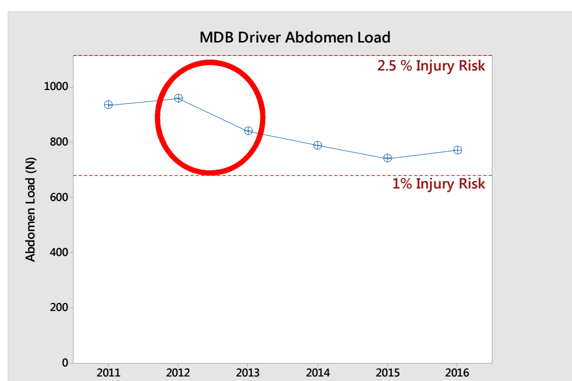

Figure 8. MDB driver mean abdomen load with respect to NCAP model year.

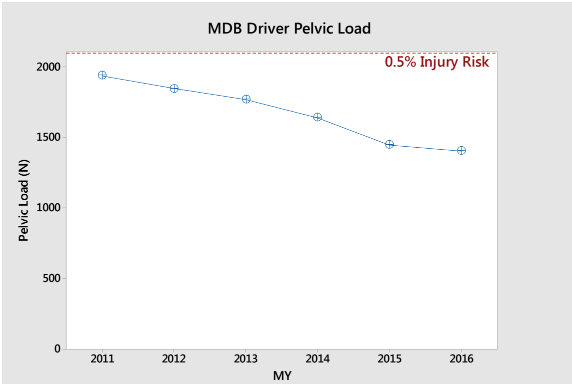

Figure 9. MDB driver mean pelvic load with respect to NCAP model year.

The Pole results show that HIC36 trended toward a stable value of approximately 300, while combined pelvis force steadily decreased from 4080.8 N in 2011 to 3161.5 N in 2015 (Figs. 10-11). It is important to note that four tests from 2012 and one test from 2013 had some HIC36 values not compliant with FMVSS 214, which was phasing in during this period. This may have biased the means during that year. Therefore, Figure 10 shows median values with solid blue dots.

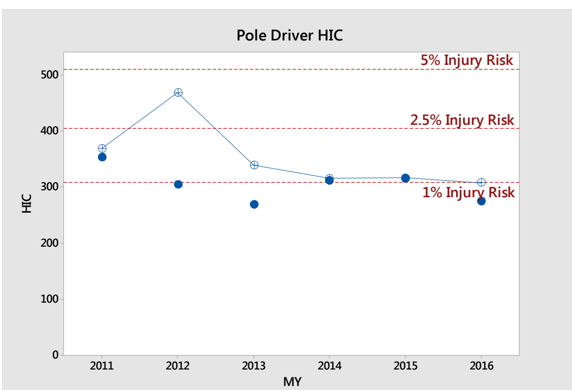

Figure 10. Pole driver mean and median HIC with respect to NCAP model year.

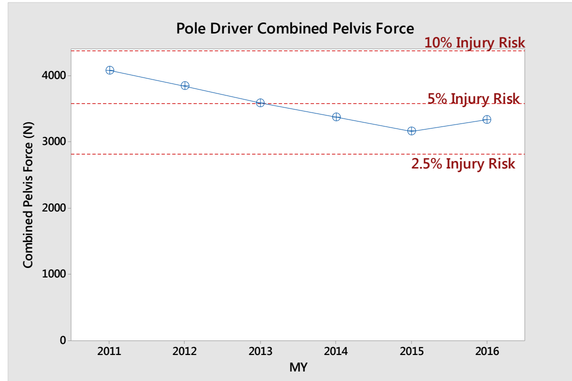

Figure 11. Pole driver mean combined pelvis force with respect to NCAP model year.

<u>Rear Passenger</u> HIC36 showed no trend during the years observed (Fig. 12). However, pelvis load decreased each year from 3388.1 N in 2011 to 2625.8 N in 2016, with the largest load reduction of 334.1 N occurring from 2012 to 2013 (Fig. 13).

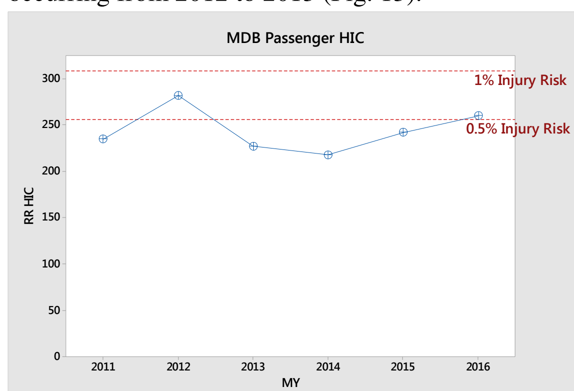

Figure 12. MDB rear passenger mean HIC with respect to NCAP model year.

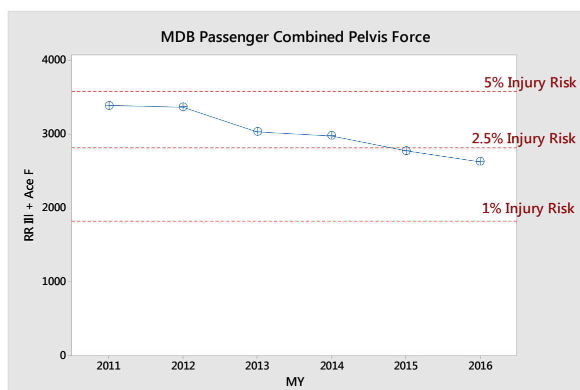

Figure 13. MDB rear passenger mean combined pelvis force with respect to NCAP model year.

Restraints and Intrusion Characteristics
Airbag type and intrusion characteristics were gathered from NHTSA's published test reports. Torso-Abdomen-Pelvis (TAP) side airbags were increasingly implemented in the vehicles observed each year after 2012. A 13.5% rise in TAP airbag use was observed from 2012 to 2013 and a 35% rise occurred from 2012 to 2016 (Fig. 14). Note again that these results do not include carry over vehicles. The percentage of SABs in each year's sample does not represent SAB percentage in that year's fleet.

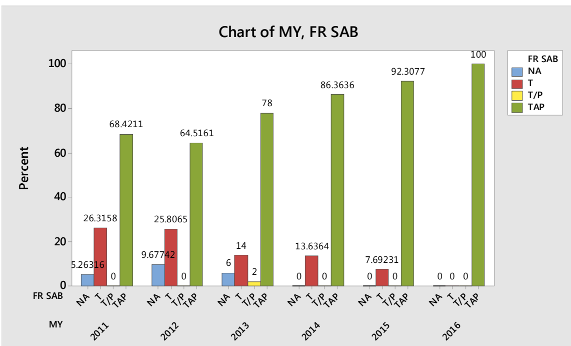

Figure 14. Side airbag in the new vehicles each year as a percentage of the sample size (Fig. 1). TAP airbags are shown in green.

Mean B-pillar crush at mid door height (L2), hip point height (L3), and window sill height (L4) decreased the most from 2012 to 2013 (Fig. 15). L2 ranged from 214.6 to 159.5 mm, L3 ranged from 210.5 to 159.1 mm, and L4 ranged from 119.1 to 82.8 mm.

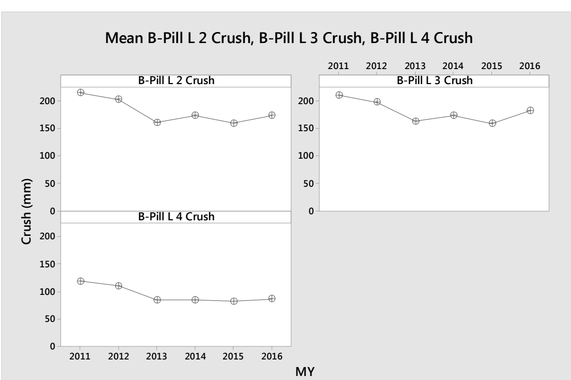

Figure 15. The mean B-pillar crush at three heights with respect to NCAP model year.

DISCUSSION

The purpose of this study was to identify side impact crashworthiness rating trends since the enhanced NCAP rating system was implemented for 2011 and later model year vehicles. Several trends were observed in the gathered data. The highest level trend observed was the reduction in side overall RRS from 2011 to 2013 (Fig. 2). Additionally, side overall RRS experienced the largest decrease from 2012 to 2015. Since side overall RRS depends on SINCAP Pole driver and MDB driver and passenger RRS, the authors then looked for similar trends in those individual RRS values. Both driver RRSs followed the same trend as the side overall RRS. The MDB rear passenger however, experienced a large decrease from 2012 to 2013 and appeared to level off after that change (Fig. 5).

Driver Injury Metric Trends Rib deflection, abdomen load, and pelvis load from the MDB tests showed clear trends. All three mean injury metrics improved from 2012 to 2013 and from 2014 to 2015. Table 4 below shows the injury metric change direction from year to year (downward arrows represent improvement). Green cells were used to indicate injury metric changes with the same change direction as the occupant RRS. Bold arrows represent the largest change observed for that injury metric.

Table 4.
Injury Metric and RRS Yearly Change Direction for MDB Driver

		Change from...				
		2011 to 2012	2012 to 2013	2013 to 2014	2014 to 2015	2015 to 2016
MDB Driver RRS		↓	**↓**	↓	↓	↑
MDB Driver Trends	Rib Deflection	↓	**↓**	↑	↓	↑
	Abdomen Load	↑	**↓**	↓	↓	↑
	Pelvis Load	↓	↓	↓	**↓**	↓

The large rib deflection and abdomen load reductions from 2012 to 2013 contributed to the largest improvement in MDB driver RRS.

The Pole driver had a clear trend in combined pelvis load over the observed time period. Table 5 shows how the combined pelvis changed each year with respect to the Pole driver RRS.

Table 5.
Injury Metric and RRS Yearly Change Direction for Pole Driver

		Change from…				
		2011 to 2012	2012 to 2013	2013 to 2014	2014 to 2015	2015 to 2016
Pole Driver RRS		↓	↓	↓	↓	↑
	Combined Pelvis Load	↓	↓	↓	↓	↑

The direction of combined pelvis load change each year was the same as that of the Pole driver RRS change.

The injury metric changes in Tables 4 and 5 suggest that occupant protection technology changed each year, and improved from 2011 to 2015. Previous research has found that vehicle intrusion has a relationship with side impact occupant injury metrics [10, 11]. The chest deflection trend observed from the MDB test matched the B-pillar intrusion trends at levels two and three (Fig. 7 and 15). Therefore, the findings of this study agree with the literature. Additionally, side airbag use has been previously correlated with injury reductions [12]. Figure 14 shows a large increase of TAP side airbag implementation in new vehicles released between 2012 to 2013. TAP airbag use continued to increase the following years in smaller increments. This correlates well with the large injury metric improvements observed from 2012 to 2013 and the smaller improvements the following years in both the MDB and Pole tests.

While restraint changes and intrusion characteristics affect recorded occupant injury metrics, it is difficult to quantify their effect with a sample of different vehicle models each year. Therefore, these results should be interpreted as correlative rather than causative.

Passenger Injury Metric Trends The rear passenger from the MDB test had a clear reduction in combined pelvis load each year. Table 6 shows the yearly changes in this injury metric relative to the MDB rear passenger RRS.

Table 6.
Injury Metric and RRS Yearly Change Direction for MDB Passenger

		Change from…				
		2011 to 2012	2012 to 2013	2013 to 2014	2014 to 2015	2015 to 2016
MDB Passenger RRS		↑	↓	↓	↑	↓
	Combined Pelvis Load	↓	↓	↓	↓	↓

Intrusion characteristics or restraint trends for the rear seat were not investigated for this study. An additional study may be conducted in the future to observe injury, restraint, and intrusion correlations.

LIMITATIONS

Several limitations should be considered when interpreting the results of this study. First, the authors relied on NHTSA's publically available data and did not confirm report contents. Therefore, any data entry errors were not corrected. However, the authors attempted to control this by omitting any incomplete data from the study. Second, this study did not consider changes to vehicles not contained in NHTSA's test reports. For example, structural design changes or detailed SAB characteristics could not be explored. Yet, this sample comprised of only the available and complete test data found relevant trends in vehicle safety features. Third, carry over ratings and test data were not used to show whole fleet trends. However, this study does represent trends in new and majorly changed vehicles. Lastly, the vehicles in the sample were not the same each year, making direct comparisons difficult. However, by containing only new models in the sample, trends were observed for the newly engineered vehicles.

CONCLUSIONS

NHTSA's evaluation enhancements starting with model year 2011 were predicted to improve vehicle crashworthiness and reduce occupant injuries. The RRS associated with laboratory tested side impacts did decrease each year, with the largest drop occurring from 2012 to 2013. RRS improvement was traced back to a reduction in injury metrics in both MDB and Pole tests, and in both occupants during this time period. Mean B-pillar intrusion decreased the most from 2012 to 2013 at the three heights observed and TAP airbag use increased by 13.5%

that year. MDB Driver rib deflection had a similar trend to the B-pillar deformations observed at level two and three heights. Though direct cause of injury metric improvement cannot be determined due to many variables changing in the samples each year, correlations were observed between injury metrics, restraints, and intrusion characteristics.

DISCLAIMER

Any views or opinions expressed herein are those of the authors and do not necessarily reflect those of Toyota Motor North America.

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