THE INCIDENCE AND SEVERITY OF SMALL OVERLAP FRONTAL CRASHES IN NASS-CDS

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ABSTRACT

The Insurance Institute for Highway Safety has recently introduced a small overlap frontal crash test in its frontal rating scheme. Another small overlap frontal crash test is under development by the National Highway Traffic Safety Administration (NHTSA). Whereas the IIHS test is conducted against a fixed rigid barrier, the NHTSA test is conducted with a moving deformable barrier that overlaps 35% of the vehicle being tested and the angle between the longitudinal axis of the barrier and the longitudinal axis of the test vehicle is 15 degrees. The field relevance of the IIHS test and the NHTSA test has been the subject of papers by Prasad et al. (2014a,b). The current study is aimed at examining the combined relevance of the two tests as representing frontal corner impacts involving small overlap. The field relevance is indicated by the frequency of occurrence of real world crashes that are simulated by the test conditions, the proportion of serious-to-fatal real world injuries explained by the test conditions, and rates of serious injury to the head, chest and other body regions in the real world crashes resembling the test condition. The database examined for real world crashes is NASS-CDS. The frontal corner impacts as represented by the 25% Small overlap frontal and the NHTSA tests together address slightly less than 9% of all frontal crashes and 6% to 12% of all MAIS3+F injuries to the drivers in these crashes. The IIHS test has a somewhat higher contribution in both the incidence and severity. The two crash modes together address 4.6% to 8.2% of all MAIS3+F head injuries. Similarly, the proportion of all frontal MAIS3+F chest injuries addressed by the two crash modes or corner tests is estimated to be 6% to 10.6%.

The available data for the passenger involved in driver-side frontal corner crashes indicate that elderly female occupants predominantly experience serious head and chest injuries. All, except one, injured passengers were females. The average age of injured females who had chest injuries was slightly over 65 years. Injury rates of the head and the chest are substantially lowered in far-side than in near-side frontal impacts. Crash test ATD rotational responses of the head in the tests substantially over predict the real world risk of serious-to-fatal brain injuries.

INTRODUCTION

Light vehicles are currently designed to meet or exceed the requirements of the FMVSS 208 in frontal impacts. This regulation includes perpendicular and angular tests against a rigid barrier and a 40% offset test against a deformable barrier. The rigid barrier tests are conducted at 25 mph with unbelted dummies, and at 35 mph with belted dummies. Whereas the offset, deformable barrier test is conducted at 25 mph for the FMVSS 208, vehicles are also designed to perform well in the IIHS 40% offset, deformable barrier tests. Over the years, most vehicles had achieved the highest ratings in the IIHS frontal tests, and also good ratings in NHTSA's frontal NCAP. This prompted the IIHS and NHTSA to investigate additional test configurations for frontal impacts. The IIHS has adopted a 64 kph frontal crash test in which 25% of the front-end of a vehicle is engaged by a rigid barrier, generally referred to as a Small Overlap Impact (SOI) test, and is shown in Figure 1. The structural and dummy responses are used to rate the vehicle as Good, Acceptable, Marginal or Poor. To get the highest rating, Top Safety Pick+ (TSP+), the vehicle has to achieve at least an acceptable rating in the new test. Mueller et al. of the IIHS have reported on various structural design strategies adopted in vehicles redesigned to perform well in the SOI mode.

Simultaneously, NHTSA conducted a meeting of NHTSA experts to examine the reasons why vehicle occupants are killed despite being belted and protected by airbags in frontal Impacts (Bean et al. and Rudd et al. (2009)). A detailed study of 122 fatal frontal crashes in NASS was performed in which primary and secondary causes were subject to group consensus. 49 of the 122 crashes (40%) were considered to be exceedingly severe or had anomalies. 29 of the 122 (24%) were **corner and/or oblique impacts** in which it was judged that the primary factor affecting fatalities was limited structural engagement of the front longitudinal rails of vehicles that are designed for energy absorption. The frequency of occurrence of the corner and/or oblique crashes in the NASS database was not estimated. This study led to a research program of crash testing by NHTSA and some of the test results have been reported by Saunders et al. (2011, 2012, 2013 and 2014).

After conducting a large number of developmental frontal crash tests, NHTSA has selected a movable deformable barrier crash test, shown in Figure 1, in which a Research Moving Deformable Barrier (RMDB) impacts the test vehicle on its left or on its right front corner a vehicle. The test vehicle is stationary and positioned at a target angle of 15˚ and at a target overlap of 35% to the forward line of motion of the RMDB. The RMDB is towed down the test track in a full forward direction, without any crabbing, and at the targeted impact velocity of 90.12 kph (56.0 mph) into the test vehicle. Regardless of the test vehicle's mass, RMDB's mass is 2490.7 kg (5491 lbs.). At the time of writing of this paper, results of eighteen (18) crash tests conducted by NHTSA have been placed in the public domain. Test reports of 6 RMDB tests of vehicles rated "Good" in the IIHS SOI test have also been added to the website. NHTSA's rationale for selecting the Oblique RMDB test has been outlined in several papers by Saunders et al referenced earlier.

It is worth noting that both tests shown in figure 1 could be classified as corner impacts. In the IIHS SOI test the stationary barrier overlaps the front end of the tested vehicle by 25% leading to missing the front rail entirely in virtually all vehicles in the US fleet. This test comes close to the definition of a corner crash not involving the front rails as in Bean et al. In the RMDB test, the barrier overlaps the front-end of the impacted vehicle by 35%. This initial impact geometry ensures that the barrier impacts the front-rail in the vast majority of light vehicles, but at an angle. Both test conditions are also referred to as "small overlap" frontal tests.

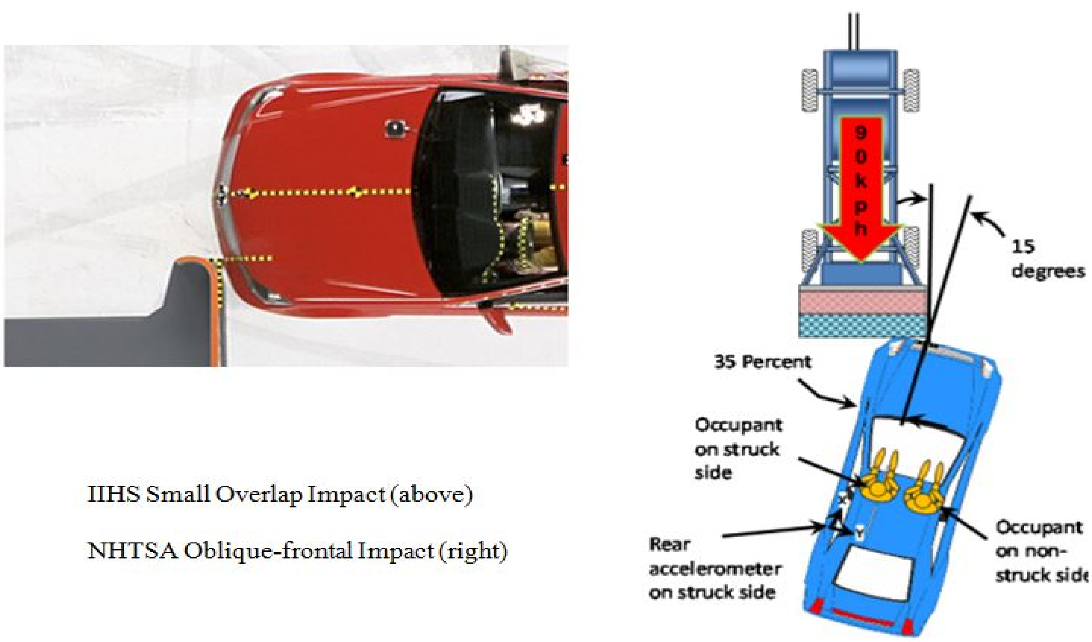

Figure 1. Small Overlap Crash Tests

Saunders and Parent (2014) summarized the status of NHTSA's research in January 2014 and have placed their analysis on NHTSA's website. Their analysis of existing data indicates that the Oblique RMDB test is representative of vehicle-to-vehicle crashes and the test procedure is repeatable. Testing of newer, high sales volume vehicles show injury risk trends similar to previous older vehicles. Far-side dummy occupant responses in these tests show head rotational velocities associated with high risk of brain injury.

Saunders and Parent (2014) also tested six vehicles that had achieved the IIHS Top Safety Pick+ (TSP+) rating utilizing the Oblique RMDB test procedure and compared their results with those of non-TSP+ vehicles. In general, the five TSP+ vehicles in the NHTSA Oblique RMDB tests yielded lower passenger compartment intrusions than the fourteen non-TSP+ vehicles, however injury risks as determined from the THOR dummy responses were similar in the two groups of vehicles. A particularly important finding was that the provisional Injury Assessment Reference Value (IARV) for rotational velocity of the head, BrIC, was exceeded in both the TSP+ and the non-TSP+ group of vehicles. Additionally, the average BrIC was higher for the far-side occupants than near side occupants, i.e. front seat passenger involved in a left corner impact as in figure 1.

FIELD RELEVANCE OF THE CORNER TESTS

The relative importance of the two tests in Figure 1 has been covered by several studies aimed at identifying the real world distribution of frontal crashes, in terms of frontal engagement and the proportion of all serious-to-fatal occupant injuries addressed in frontal crashes. A brief review of these studies follows.

The earliest study somewhat addressing small overlap frontal crashes in Sweden was reported by Planath et al. In 1993, Planath et al. reported the results of a study of frontal crashes in Sweden. A class of frontal crashes labeled as Severe Partial Overlap Crash (SPOC) occurred 3% of the time, but accounted for 14% of AIS2+ injuries to occupants of vehicles involved in frontal crashes. In a subsequent paper, Planath and Nilsson compared several frontal crash tests in regulations and mentioned that Volvo had developed an additional test procedure for SPOC that consisted of a 35% overlap, frontal test against a rigid barrier at 64 km/h. It was also stated "Exclusive use of SPOC in the development process would however be detrimental." This test did not gain too much attention, perhaps due to the introduction of the European 40% overlap against a fixed deformable barrier in the European regulation and by the IIHS in the USA and by NCAPs around the world. The results of further crash studies in Sweden performed by Lindquist et al. in 2003 and 2004 once again focused the attention of researchers to Small Overlap Impacts (SOI). Lindquist claimed that nearly half of all frontal crash fatalities in Sweden were in these SOI's. In these crashes the front longitudinal members were not engaged resulting in substantially greater passenger compartment intrusions than in frontal crashes in which the rails were were engaged. The 2003 and 2004 studies kicked off similar studies in US and Europe. The IIHS conducted a study of frontal crashes of vehicles that were rated "Good" in their frontal crash program and at least one front-outboard occupant had an AIS>=3 injury unless the only such injury was to the extremities. Brumbelow and Zuby reported results of the study in 2009. They defined small overlap as being when the major load path was outboard of all major longitudinal members. The small overlap accounted for nearly 25% of all the cases included in the study. The IIHS followed up by conducting several frontal crash tests to help them develop the test shown in Figure 1.

Kuehn et al. (2013) from the German Insurers Accident Research Group conducted a retrospective analysis of 3242 accidents involving passenger cars- 1930 of these were frontal collisions and 485 of which involved collisions in which the frontal engagement was considered to be small overlap. Unlike the results from Sweden, their conclusion was that "In terms of fatalities, the relevance of small-overlap car accidents is low. In terms of serious injuries (AIS2+) to the lower extremities, the relevance of small-overlap car accidents is high."

A Frontal Impact Taxonomy study was conducted by Sullivan et al. (2008), in which all NASS frontal crashes were distributed in eight different bins. The proportional contribution of each bin was determined in terms of frequency of occurrence and injury severity. Sullivan et al. reported that nearly two-thirds of all frontal crashes were full-engagement and offset with a nearly even split. A bin classified as SS/Corner accounted for slightly less than 14% of all frontal crashes, slightly less than 12% of all vehicles in which at least one occupant had an MAIS3+ injury and slightly over 10.5% of all vehicles in which at least one occupant was fatally injured. This bin would contain the IIHS 25% offset and NHTSA's Oblique RMDB test conditions and vehicle deformations, and would give an upper limit of the incidence of the two crash types combined and injuries associated with them.

Scullion et al. (2010) modified the Frontal Impact Taxonomy study of Sullivan et al. into seven bins and concentrated on identifying the frequency of occurrence of and injury rate in small overlap frontal crashes in NASS. They defined small offset as a case in which the frame rail was not engaged and the center of damage was located entirely outside the frame rails. This case would fit the conditions produced in the IIHS SOI tests. In this study, slightly over 69% of all frontal crashes could be described by offset plus full engagement and 7.5% could be classified as small offset. The MAIS3+ injury risk was slightly lower than that in full-engagement crashes. Although the relative contribution of the small offset crashes as a proportion of all MAIS3+ frontal crashes was not reported, it had to be much less than that of offset plus full engagement crashes. In subsequent papers by Scullion et al. and Morgan et al. the small offset crashes continued to show up as relatively much smaller proportion of frontal crash modes than the full engagement and offset crashes.

Samaha et al. have reported the results of a more detailed FIT study of the NASS CDS cases for MY 1985-2011 vehicles involving belted drivers in vehicles equipped with airbags. In this study, the light vehicle fleet was partitioned into four weight classes and the FIT of individual weight classes was determined. In their crash classification the corner impact bin was separated into two classes- "small offset front" and "small offset side." The combined corner bin accounted for 7% of all crashes and 10% of all MAIS3+ driver injuries. The vehicle fleet was also divided in two groups of MY's- 1985 to 1999 and 2000+. Two driver age groups were also studied- 16 – 50 years and 50+ years. For both age groups, the involvement and injury rates were estimated as a function of FIT classification. The distribution of various body regions with moderate- and serious-to-fatal injuries by FIT classification was also determined for the two MY groups and age groups. For example, in the 16-to-50 yr. age group, full engagement and offset crashes accounted for approximately 79% of all serious-to-fatal head injuries and the corner crashes accounted for approximately 10% of all serious-to-fatal head injuries. Similar results were observed for lower extremity injuries- the corner crashes accounted for approximately 8% of all serious-to-fatal lower extremity injuries.

During the course of the Samaha et al. study, random check of photographs of case vehicles binned in the "small offset side" category, showed that some of them would not fit the damage patterns produced in either the IIHS SOI tests or in the Oblique RMDB tests conducted by NHTSA. Subsequently, a NASS case review process was used by Prasad et al. (2014a,b) that relied on hard copy reviews of frontal crashes in NASS-CDS. This involved binning potential corner crashes in either the IIHS like crashes or in NHTSA's Oblique RMDB like crashes.

Objective

The objective of this paper is to consolidate the main results of the two studies as they relate to frontal corner impacts and add further observations not covered in the earlier studies.

To establish the field relevance, the frequency of occurrence of the crash types and the resulting rates of serious-to-fatal injuries in real world frontal crashes were estimated from the publicly available database, NASS.

Collision Deformation Classification (CDC): Since these studies utilize the Collision Deformation Classification (CDC) as the first filter of the frontal crash data in NASS for comparison with test data, a brief introduction of the CDC is deemed appropriate in this section. A simplified description of the CDC is shown in Figure 2. It is important to note that a CDC code for any given vehicle is based solely on contact damage; any damage that is induced to the vehicle structure as a result of an impact is specifically excluded from consideration. Essentially, the front end of a vehicle is divided into three sections- L, C and R. L covers the left one-third of the vehicle, R covers the right one-third of the vehicle and C covers the center one-third of the vehicle. By the definition of the IIHS test with only 25% overlap of the barrier all IIHS test like deformations should be in the L section (or R for right-front impacts). Since the overlap of the front-end of a test vehicle with NHTSA's barrier is 35%, the deformation of the front-end should be in the Y (or Z) section by definition. Therefore, all crashes that have CDC classification FY or FZ would contain the CDC observed in NHTSA's tests, and similarly all FL or FR crashes would contain the CDC observed in the SOI crashes conducted by the IIHS. Based on the definitions of FY and FL, given any error in the direct damage estimate, it is quite possible that some of the FY's could be FL's and some of the FL's could be FY's.

METHODOLOGY

Two crash test databases maintained by the IIHS and the NHTSA were interrogated. In the IIHS database there were results of 65 vehicle crashed in the SOI crash mode. In the NHTSA database results of 18 vehicles crashed in the Oblique RMDB mode were available. The damage patterns of the vehicles were assigned CDC classifications. The IIHS CDC classifications were 12FLXXXX and the NHTSA test vehicles 11FYXXXX. As shown in Figure 3, NASS frontal crash database was interrogated with the following restrictions: 3-point belted front-outboard occupants involved in planar impacts (i.e. no rollovers), airbags fitted on driver and passenger sides, direction of force 11, 12, 01, and all CDC extents. NASS calendar years were restricted to 1988 to 2010. The age of the front-outboard occupants was restricted to 15 years or older. This Subset of frontal crashes was referred to as Subset 03 in the two Prasad et al. papers. It contained 21,433 cases representing 9,793,461 cases when weighted. Hard copy reviews of all FL and FR crashes (not restricted by the PDOF) identified by the search in which a front outboard occupant had an MAIS3+F injury were conducted. Damage patterns of the involved vehicles were compared to those observed in the IIHS SOI tests and binned as "Good", "Moderate" or "poor" match with those observed in the SOI tests. The "Poor" matched cases were further examined to see if they could be classified in the Oblique RMDB crash bin. A similar process was followed for the FY and FZ classification of crashes as shown in Figure 3. Once again, the cases rated as "Poor" match with damage patterns observed in the Oblique RMDB were reviewed to verify if they could be classified in the IIHS bin. Details of the process can be found in the Prasad et al. papers. In this paper only the main results will be presented.

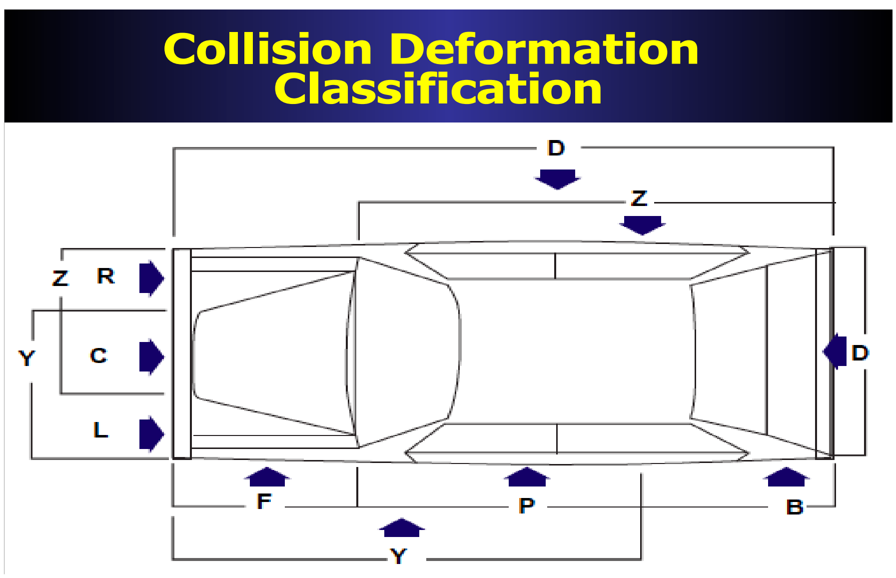

***Figure 2**. Schematic Of the Collision Deformation Classification*

Prasad et al.(2014a) have reported the results of the CDC-FL branch shown in Figure 3 for all MY vehicles, MY2000+ vehicles and the 2000+ MY vehicles that were rated "Good" in the IIHS Moderate Offset tests to be consistent with the Brumbelow and Zuby study. Both the FIT analysis and hard copy reviews of the NASS cases were performed. The FIT analysis indicated that 7.5% of all frontal crashes could be represented by the IIHS SOI tests. The frequency of occurrence of the NHTSA test like deformations was estimated by Prasad et al (2014b) as 1.24%. Therefore, the two small overlap corner crashes account for approximately 9% of all frontal crashes. The IIHS test condition also accounted for 6.1% of all MAIS3+F injuries to the front outboard occupants. These proportions were similar for the 2000+ MY vehicles as shown in Table 1. Note that Table 1 contains data for paired driver and passenger, i.e. driver side and passenger side crashes with occupants on the side impacted. Considering that the Samaha et al. study included "small offset side" also, the results of the FIT analysis in the two studies are similar. Samaha et al. also found little difference in injury distribution between all MY vehicles and 2000+ MY vehicles. Based on the above, hard copy reviews of the NASS cases in FY or FZ branch in Figure 3 was limited to the 2000+ MY vehicles. The results of the hard copy analysis are shown in Figure 4.

Table 1. Summary of Estimated Contribution of IIHS SOI- like Crashes

	All MY	MY2000+	MY2000+ & Good
SOI % MAIS3+F	2.9% to 6.8%	3.9% to 7.1%	3.0% to 7.5%
SOI %MAIS3+F	6.1% FIT Analysis 5.2% to 9.3%	4.5% to 8.8%	4.7% to 9.2%

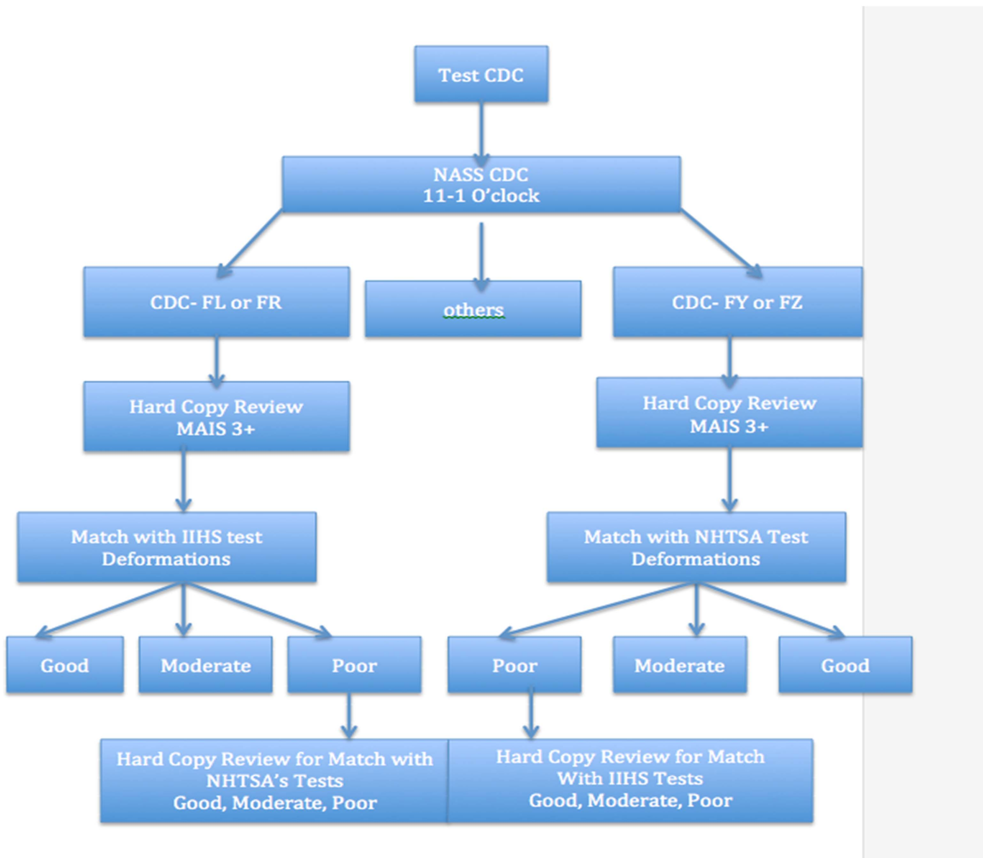

Figure 3: *Schematic of the process used to identify NASS Frontal crashes that could be represented by NHTSA's Oblique RMDB Tests or by the IIHS SOI*

NASS cases involving MY 2000 and newer vehicle and MAIS ≥ 3 or fatal belted driver reviewed for similarity to NHTSA 35% overlap, 15º angled frontal RMDB Impact and the IIHS SOI Tests

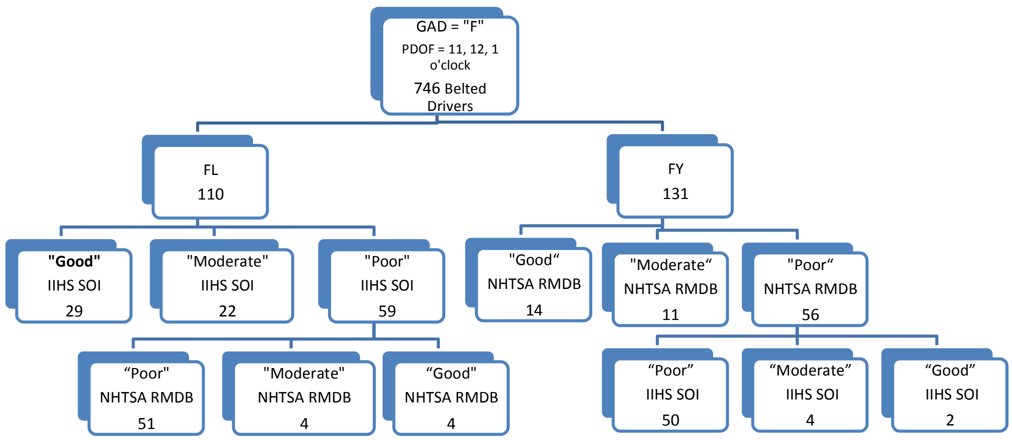

Figure 4: Distribution of Driver MAIS3+F Injuries by FL and FY Damage Locations

Figure 4 shows that there were 746 drivers with MAIS3+F injuries in 2000+ MY vehicles that were involved in frontal crashes. Of these, 110 were in crashes with frontal damage classified as FL. Hard copy analysis of these 110 cases showed that 29 had a "good" match with the IIHS tests and 22 had "moderate" match with the IIHS tests. Out of the 59 cases with poor match with the IIHS tests, 4 were considered to be a "Good" match with NHTSA's Oblique RMDB tests. There were 131 cases with FY classification. Out of these, 14 were considered to be "Good" match with the RMDB tests and 11 had a "moderate " match. Out of the 56 with "Poor" match with the RMDB test, 2 were considered to have "Good" match with the IIHS test and 4 had "Moderate" match with the IIHS tests. Adding up, there are 31 "Good" matches with the IIHS tests and 18 "Good" matches with the Oblique RMDB tests. The total number of "Good" matches is assumed to indicate the lower bound of the estimated proportion of all frontal crash MAIS3+F injuries. There are 31 "Good" matches with the IIHS SOI test yielding 31/746 or 3.9% of all frontal MAIS3+F injuries. Similarly there are 18 "Good" matches with the NHTSA RMDB test yielding 2.4% of all frontal injuries considered. The two tests together address 6.3% of all MAIS3+F frontal injuries to belted drivers. If the sum of the "Good" and "Moderate" matches is assumed to be the upper bound of injuries addressed by either test, the IIHS test represents approximately 7.6% and the RMDB test represents approximately 4.4% all MAIS3+F driver injuries in frontal crashes. Therefore, an upper-bound of approximately 12% is estimated as being addressed by the two small overlap corner tests discussed in this paper. Therefore the two small overlap corner tests address 6.3% to 12% of all driver frontal MAIS3+F injuries. The authors believe that a point estimate closer to the lower bound is more likely outcome of the current analysis described in the paper, since the upper estimates contain cases with "Moderate" match with the test data several of which have extent 9 with massive damage not seen in the IIHS tests. The estimates made by Sullivan et al. and Samaha et al. are within the range of estimates in this analysis.

Distribution of injuries by damage location

With insights gained from the hard copy reviews, further interrogation of the Subset 03 reported in Prasad et al. was conducted to estimate MAIS3+ injury rates by damage locations for belted Front Outboard Occupants (FOO). Particularly, AIS3+ head/face and chest injuries were investigated as a function of seating position, Direction of Force and Damage Extent.

RESULTS of NASS Data Analysis:

The overall composition of frontal crashes being considered in this paper is shown in Tables 2. In Tables 2, numbers in parentheses give the percentage of the total of the individual cell, e.g. 12.8% of the drivers are involved in crashes whose damage location is coded as FL. Table 3 contains the injury rates for the drivers and passengers based on weighted data. The raw counts are also shown. Note that in order to have increased raw sample size, all MY's counts were used. In spite of that, the raw numbers for the passenger side are relatively small.

Table 2: Involved Driver and Passenger By Damage Location (All MY) Subset 03 Prasad et al.

Subset 03 Drivers GAD/SHL1	Driver Raw count	Driver weighted	Passenger Raw count	Passenger weighted
FL	2154	1,066,113 (12.8%)	448	200,952 (13.7%)
FY	2586	1,137,490 (13.7%)	499	173,508 (11.8%)
FD	8873	3,929,359 (47.2%)	1798	708,527 (48.2%)
FC	273	91,581 (1.1%)	60	18701 (1.3%)
FZ	2187	1,122,328 (13.5%)	455	173,517 (11.8%)
FR	1739	976,964 (11.7%)	361	194,421 (13.2%)
All	17,812	8,323,834 (100%)	3621	1,469,626 (100%)

Table 3: MAIS3+F Injury rates by Damage Location (All MY)

Subset 03 Drivers GAD/SHL1	Driver Raw count	Driver weighted (%)	Passenger Raw count	Passenger weighted (%)
FL	224	2.0	28	0.9
FY	285	2.0	34	4.1
FD	832	1.6	160	1.6
FC	48	2.3	8	11.4
FZ	148	1.0	42	1.2
FR	83	1.0	38	0.8
All	1620	1.6	310	1.7

Examination of table 3 indicates that the driver injury rates in the near-side frontal impacts, i.e. in the FL and FY damage locations, are nearly two times those in far-side damage locations, i.e. in FR and FZ locations. This trend does not appear to be true for the passenger, especially when the far-side is the FY location. The FY location is slightly over three times more injurious than the FZ location for the passenger. The passenger injuries in the FY damage location were examined further in terms of the demographics of those injured.

Passenger Head and Chest injuries in FY damage location crashes

There were only six passengers with MAIS3+ head injuries and all were females. Three of the six were in multiple impact crashes. One had a head contact coded as Center IP and below, one contacted the right B-pillar, one the right Grab Handle, one had contact with the passenger airbag and one showed only belt contact, one had an unknown contact. Based on the small numbers other more detailed analysis was not conducted.

There were 18 cases of MAIS3+F chest injuries. All except one were female occupants whose average age was slightly over 65 years. The source of injury for all except one was coded as the belt restraint and hardware. One injury source was coded as Floor or console. Based on the chest injuries and source, there is no evidence of passenger occupant slipping out of the shoulder belt in the far-side crashes.

Driver Head and Chest Injuries by Damage Location:

The distribution of driver head and chest injuries by frontal damage location was studied next and is shown in Table 4. Nearly half of all MAIS3+F head injuries occur in crashes with damage location coded FD, i.e. both rails were engaged. The corner impacts would include a subset of the FL and FY damage locations that account for nearly 27% of all head injuries. However, not all FL crashes are represented by the IIHS test and not all FY crashes are represented by the Oblique RMDB test. Based on Figure 4, approximately 26.4% to 46% of MAIS3+F injury producing FL crashes are like the IIHS SOI, and 10.7% to 19% of all FY crashes are like the Oblique RMDB crash. Applying these to the numbers in Table 4, one would estimate that the two crash modes together address 4.6% to 8.2% of all MAIS3+F head injuries. Similarly, the proportion of all frontal MAIS3+F chest injuries addressed by the two small overlap or corner tests is estimated to be 6% to 10.6%.

Table 4. Composition of Frontal Sample by Damage Location (Drivers Only)

(From Prasad et al. 2014b)

Subset #03	Sample Counts		% Composition by GAD1/SHL1					
Drivers			Head/Face AIS>=3		Chest AIS>=3		Fatality or MAIS>=3	
GAD/SHL1	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted
FC	273	91,581	2.4%	3.4%	3.3%	1.7%	3.0%	1.6%
FD	8,873	3,929,359	48.1%	49.9%	53.7%	49.7%	51.2%	48.3%
FL	2154	1,066,113	17.4%	11.0%	12.7%	15.1%	13.8%	16.4%
FR	1739	976,964	6.1%	12.9%	5.0%	6.9%	5.4%	7.5%
FY	2586	1,137,490	20.5%	15.9%	16.3%	19.4%	17.5%	17.6%
FZ	2187	1,122,328	5.5%	7.0%	9.0%	7.3%	9.1%	8.6%
All	**17,812**	**8,323,834**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

The MAIS3+F head, chest and overall are shown in Table 5 for the driver. These rates are for frontal crashes in which the damage extent is between 3 to 6 which is the range of extent of frontal damage produced in the regulatory and public domain tests (IIHS 40% and 25% Overlap, the NCAP and RMDB Small Overlap tests). Examination of Table 5 shows that the head injury rate in highest in FD crashes and lowest in the FR and FL crashes. Similarly, the chest injury rate is highest in the FD crashes and lowest in the FR and FL crashes.

Table 5. Frontal Injury Rates by Damage Location Drivers only/ CDC Damage Extents: 3 to 6
(From Prasad et al, 2014b)

Subset #03 Drivers CDC Exts: 3-6	Sample Counts		Injury Rates (%)					
			Head/Face AIS>=3		Chest AIS>=3		Fatality or MAIS>=3	
GAD/SHL1	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted
FC	82	11,538	4.88%	1.08%	15.85%	4.14%	32.93%	8.22%
FD	1,528	262,248	5.82%	2.09%	13.74%	5.32%	32.79%	14.36%
FL	872	350,921	1.83%	0.19%	3.44%	1.15%	12.50%	2.97%
FR	732	397,919	0.96%	0.12%	1.91%	0.41%	6.56%	1.13%
FY	595	139,669	7.90%	1.86%	11.76%	2.53%	33.61%	10.53%
FZ	367	110,873	1.91%	0.44%	8.17%	1.33%	22.62%	5.56%
All	**4,176**	**1,273,167**	**4.07%**	**0.77%**	**8.79%**	**1.97%**	**23.18%**	**5.84%**

DISCUSSION

A historical review of various studies aimed at examining the real world relevance of frontal corner crashes as represented by the IIHS 25% overlap and the NHTSA RMDB test conditions has been presented. The estimated proportion of serious-to-fatal injuries addressed by the corner impacts varies substantially depending on the sampling scheme of the different datasets studied and reported. Some studies in Europe show high proportions of fatal frontal crashes that could be explained by the small overlap tests and some show very little if any. In the US, NASS-CDS is a nationally representative accident sampling scheme from which the field relevance of these crashes can be estimated for the US. Towards this end, the authors of this paper have estimated the frequency of occurrence and the proportion of frontal crash injuries addressed by the tests simulating frontal corner impacts. The estimates are similar to those by other authors who have attempted to estimate the frequency of occurrence of these crashes and the population affected by them using the NASS-CDS database.

Comparison of the Results With Current Test Data

The results shown in Table 5 indicate good correlation with the results of the IIHS 25% overlap tests. Prasad et al. (2014a) have reported their analysis of the 25% overlap IIHS crash test data that indicate head and chest injury risks predicted by dummy responses to be low but lower extremity injury responses to be higher than those observed in the 40% overlap tests. The NHTSA tests also indicate lower extremity injuries in the RMDB tests to be important. However, very little data with the THOR dummy exist in other frontal crash modes to evaluate the relative importance of the RMDB tests conducted so far. Based on the analysis of Samaha et al. the corner tests (IIHS and the RMDB tests together) potentially address slightly less than 10% of all AIS3+ lower extremity injuries. When the limited existing test data from the RMDB tests are examined, the projections from the tests do not agree with the field data as analyzed in this report or others by Prasad et al. (2014b), Samaha et al., Sullivan et al. and Scullion et al.. The serious head injury risks predicted by the dummy responses are substantially higher than those observed in the field. This prediction is traced to be due to the utilization of the new rotational injury criteria, BrIC (Takhounts et al.), to predict head injury risk in the tests. The brain injury risk predicted by the dummy head responses for the passenger in driver-side RMDB tests are substantially over-predicting head injury risks. As discussed earlier in this paper, only six serious head injuries were identified in all serious injury producing FY crashes and all were to females and some were in multiple event crashes. Similarly, chest injury of passengers in FY type of corner crash appears to be an issue with elderly females (average age 65+ years) with injury source identified as the belt system. In the RMDB tests, the dummy kinematics is such that it slips out of the belt. This slipping out of the shoulder belt is not supported by the field data. It is not clear if the passenger dummy kinematics is due to artifacts of the dummy design, the RMDB or the initial test conditions.

CONCLUSIONS

1. The frontal corner impacts as represented by the 25% Small overlap frontal and the Oblique RMDB tests together address slightly less than 9% of all frontal crashes and 6% to 12% of all MAIS3+F injuries to the drivers in these crashes.

2. The two crash modes together address 4.6% to 8.2% of all MAIS3+F head injuries. Similarly, the proportion of all frontal MAIS3+F chest injuries addressed by the two crash modes or corner tests is estimated to be 6% to 10.6%.

3. The available data for the passenger involved in driver-side frontal corner crashes indicate that female occupants predominantly incur serious head and chest injuries. All, except one, injured passengers were females. The average age of injured females who had chest injuries was slightly over 65 years.

4. Injury risks in far-side frontal corner crashes are lower than those in near-side frontal corner crashes.

5. The field data do not support the RMDB test data in terms of predicted head injury risks and observed kinematics of the passenger dummy in far-side frontal crashes.

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