SENSITIVITY ANALYSIS OF INJURY PATTERN FOR PASSENGER VEHICLE'S DRIVERS IN C2C COLLISIONS AT INTERSECTION

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ABSTRACT

Nearside occupants are at a higher risk for serious injury than far-side occupants in side impact collisions. Accidents where the driver is the only occupant accounts for more than 80% of all side impact injuries. This paper presents the results of study on sensitivity of serious injury outcome for drivers involved in nearside car to car (C2C) collisions, especially at intersection. In total, 865 intersection C2C crashes (NASS-CDS CY 2004-2014) are analyzed in detail to determine the injury level outcome based on different crash factors, such as delta-v, age, gender, striking vehicle type, impact location (F,Y,P,Z,B-regions) and impact angle. Injury sensitivity with respect to impact location was studied in detail. A univariate logistic regression was done to check the probability of a serious injury occurring between the center and end locations. A higher number of serious to fatal injuries (57%) occurred in the Y-region when compared to other impact locations. Additionally, a higher number of serious to fatal injuries (60%) occurred when the direction of impact is 10 o'clock. Injury occurrence for L-type offset impacts at both ends of the vehicle's-B and F regions, were quite low. In P and Y regions (T-type impact), the chances of having AIS3+ injuries were higher for an impact angle of 10 o'clock than those of 8 and 9 o'clock. The probability of having AIS3+ injuries was higher in senior (age>60) drivers than in younger drivers. When the striking vehicle changed from PV to SUV, a higher number of serious injuries were observed. AIS3+ injuries in head and lower extremity (including pelvis) injuries were increased, when the striking vehicle was a SUV as compared to a PV. But, there is not much change in the thorax region. Finally, the above real world accident results were also verified with barrier to car FE simulations. A certain amount of offset of the maximum intrusion point of the deformation profile from the occupant sitting position in both the forward direction (towards A-pillar) and backward direction (towards C-pillar) influences the outcome of the driver's injury level. Results of the present study provides opportunity for considering new interaction terms between impact locations, impact directions, occupant height, vehicle type and others in improving the accuracy of AACN ISP algorithm injury prediction in nearside lateral collision.

INTRODUCTION

In the National Automotive Sampling System [1], (NASS, US) real world field injury data are collected to obtain different crash and occupant related information such as vehicle/ crash data, impact vector, occupant exposure, incidence, risk, and injuries to different body regions of the occupants inside the vehicle. This information is essential for (i) the development and improvement of new anthropomorphic test devices with the help of various crashworthiness studies, and (ii) introduction of new or modifications of existing vehicle safety and traffic standards to meet the continuous demand of an ever-changing mobile society around the world. Side impact crashes are generally critical even at low impact speeds because of the energy absorbing capability of side structure, [2],[3]. Starting with the introduction of side impact regulation standards, side impact New Car Assessment Program (SINCAP, 1996) and consequent upgrades of new injury criteria and the specification of the side impact ATD device in the front and rear seating positions [4],[5],[6] the crashworthiness and occupant safety performance of new generation vehicles have been improved considerably, in last decade. These are the contributions of various valuable past research works [7],[8],[9] including those of full-scale vehicle MDB and pole tests conducted using different types of advanced internal instrumentation. With the introduction of the present IIHS's PV-vs-SUV C2C tests and future advanced biofidelic ATDs (50^{th}-ile World SID) for occupant safety evaluation, more studies are necessary to identify the remaining scopes of possible improvements and further reduction of fatalities based on real world accident analysis. A recent study indicates that approximately 40% police-reported rear-end crashes may have been prevented if all vehicles were equipped with FCW with AEB. Cicchino [10] mentioned that AEB systems that perform at a full range of speeds would likely prevent more crashes and injuries. Hence, in the near future, the present AEB market trend will lead to more attention and focus on C2C intersection crashes when the share of AEB in PV will reach 99% by 2022 in US [11]. The objective of this study is to focus on the sensitivity analysis of injury pattern in C2C side impact intersection collisions of passenger vehicles to indicate various effects, such as, impact location, impact angle, striking vehicle type, gender, and height of the driver. Using CY1995-2005 NASS-CDS data, Xinghua et.al, 2012 [12], indicated the importance of the consideration of the crash configurations beyond the scope of existing side-impact regulatory tests and stressed the necessity of vehicle crashworthiness and restraint system design to better protect occupants in real-world crash scenarios. However, this present study used more recent crash data (CY 2004-14 NASS-CDS) to capture the current trends of driver injuries in newer vehicles and also verified the accident analysis trend with numerical FE simulations.

DATA & METHODS

This study used National Automotive Sampling System Crashworthiness Data System (NASS-CDS) accident data from calendar year 2004 to 2014. Table 1 shows the assumptions used to prepare the input data set in this study. The accident samples are limited to car to car intersection side imact planar collisions (i.e., excluded crashes with primary general area of damage as top or bottom and rollovers). Values with unknowns have been removed. In total, 865 vehicles were extracted using criteria, to perform the accident analysis and logistic regression [13] analysis (details of which are described in later sections). Logistic regression is used to determine the effect of impact location on serious injuies occurring in side impact and results were calculated using XLSTAT software [14].

Table 1.
List of criteria for input dataset

General Area Damage1=Left
Direction of Force DOF=8, 9, 10
Impact Location=F, P, Y, B, D, Z
Body Type PV (1-9,17)
Model Year>=2000
Driver Role=1, (Seat Position=11)
Age16+
V2V OBJCTD<=30
Towed Away Vehicles
No Ejection
No Rollover
No Fire Occurrence
Excluded AIS7 injury

Table 2 shows the final data set extracted from NASS CDS CY 2004-14 using the criteria mentioned in Table1. In total, 865 occupants with 3941 injuries involved in near side impacts were selected with six collision deformation codes(F, P,Y, Z, D, B) and three main impact angles (8, 9, 10 o'clock) as shown in Figure 1. A weighted count of the number of AIS injuries in six impact locations and three impact angles were mentioned in Table A1 of Appendix A. It is found from the data that serious AIS3+ and minor AIS1&2 injuries were 14.5% and 85.5%, respectively.

Table 2.
List of input dataset

	Weighted data	Raw data
Occupants	181,514	865
Injuries	3,057,702	3941

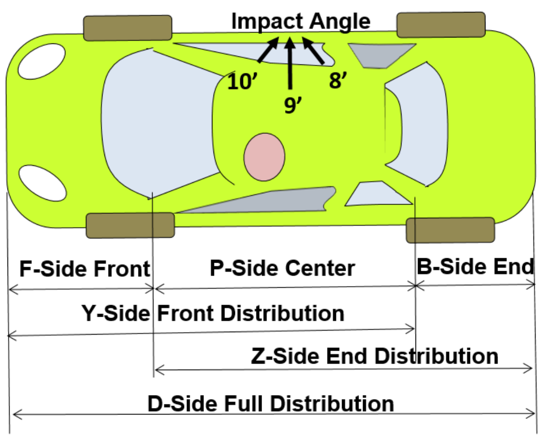

Figure 1. NASS-CDS collision deformation code (8, 9, 10 o clock are impact angles)

RESULTS

This section discuss the injury pattern of occupants involved in car to car collisions at intersection. The parameters considered in this study as folows: delta-v, age, gender, striking vehicle type, impact location, impact angle. Injury sensitivity with respect to impact location is studied in detail and verified with barrier to car FE simulations. A univariate logistic regression was carried out to check the probability of serious injury occurance between the center and end locations.

Variation of Serious Injuries in Individual Body Region

Figure 2 shows the AIS3+ serious injury distribution with respect to each body region for the occupants involved in near side impacts. It is observed that the thorax region has highest number of AIS3+ injuries (40%), follwed by the head (33%) and the lower extremities including the pelvis region (12%). It is evident that thorax and head are more likely to have AIS3+ injuries among all the regions in side impact collisions.

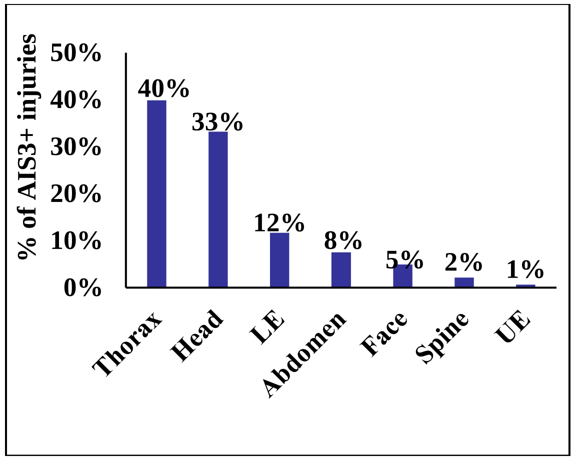

Figure 2. Distribution of AIS3+ injuries in side impact with respect to each body region

Variation of Serious Injuries with Delta-V and Max Crush Value

Figure 3 shows the variation of AIS3+ injuries with respect to delta-V. As the delta-v increases, the percentage of AIS3+ injured occupants increases. Figure 4 shows the variation of AIS3+ injuries with respect to the amount of deformation (maximum crush value). It should be noted that generaly the amount of deformation on external body depends on the impact velocity and strength of the vehicle. As the impact velocity increases, the level of AIS3+ injuries also increases and similar relationship exists with amount of external deformation value.

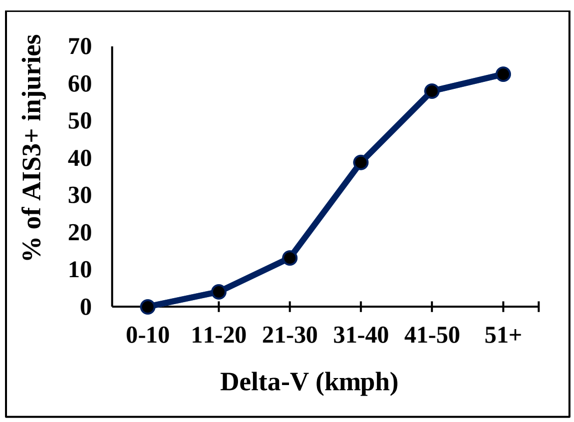

Figure 3. Variation of AIS3+ injuries with respect to Delta-V

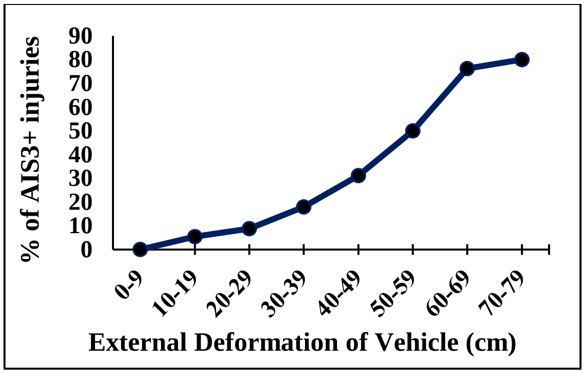

Figure 4. Variation of AIS3+ injuries with respect to deformation (cm)

Variation of Serious Injuries in Senior and Non Senior Occupants

Table 3 summarizes the details of AIS3+ injuries for senior (age≥60) and non-senior (age<60) occupants. Senior occupants are more likely to sustain AIS3+ injuries than non-senior occupants in side impacts.

Table 3.
AIS3+ injuries in senior and non-senior occupants

Age	Senior (Age≥60)	Non Senior(Age<60)
Occupant count	187	678
AIS3+ / AIS1-6	17%	13%

Variation of Serious Injuries in Female and Male Occupants

Figure 5 shows the distribution of vehicles by the number of occupants. In the side impact accidents analyzed, 80% of the vehicles were driver alone and 20% had more than one occupant.

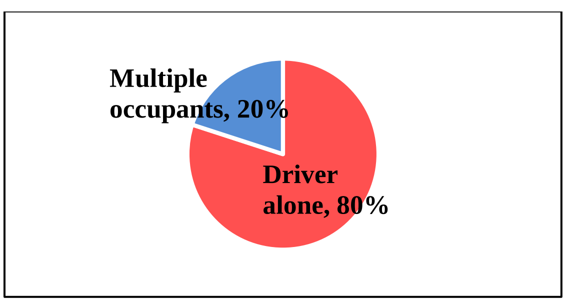

Figure 5. Distribution of vehicles with number of occupants present in side impact accidents

Within the driver alone population of PV, it is found that 64% of drivers were female and only 36% were male drivers. So the female drivers are more likely to get involved in side impact accidents at intersection than the male drivers in PV. The percentage of AIS3+ injuries corresponding to all six types of defomation locations and that of the combined P & Y regions corresponding to more cabin intrusion, are shown in Figure 6 for both male and female drivers. Female drivers suffered a higher number of AIS3+ injuries (57%) than male drivers (29%) in all regions. It is observed that the percentage of AIS3+ injury is more for occupants at P & Y locations (71%-female, 43%-male) when compared to that of all six regions (57%-female, 29%-male). It is observed that the percentage of AIS3+ injuries for females at P & Y locations when compared to that of all six regions. Percentage of AIS3+ injury is the ratio of number of AIS3+ injuries divided by total number of injuries (AIS1-6) in the specified regions for both male and female drivers.

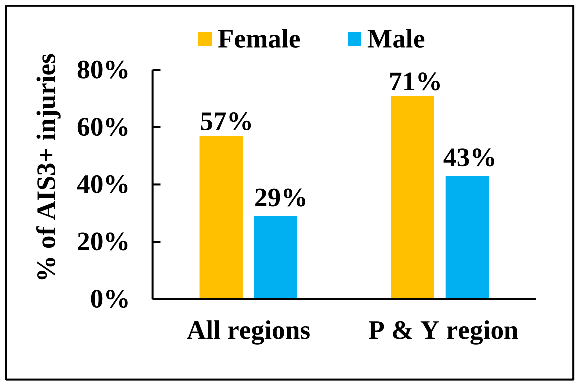

Figure 6. Percentage of AIS3+ injuries in all six deformation locations and P+Y regions alone

The variation of AIS3+ injuries is plotted with respect to the occupant height for both female and male drivers as shown in Figure 7. Using secondary axis of the right of this Figure 7, individual percentages of each category with respect to the total population (female and male drivers) are also overlayed on it for better visualization. First, the percentage of AIS3+ injuries is higher for shorter female drivers and as the height of the occupant increases, the percentage of AIS3+ injuries start to decrease. So, it is observed that the chances of having AIS3+ injuries are higher for shorter female drivers (corresponding to AF05, the 5th percentile female population which is around 151-155 cm in height).

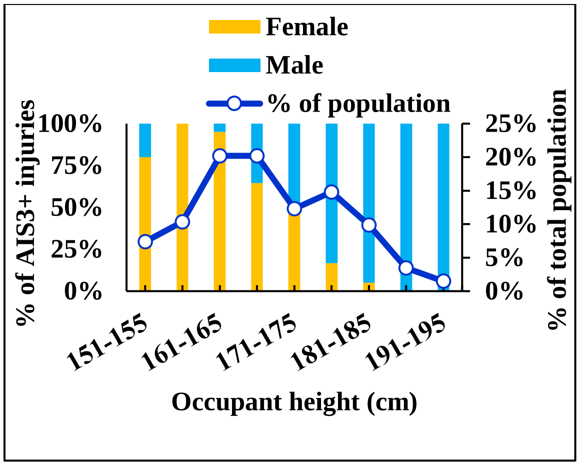

Figure 7. Variation of AIS3+ injuries with respect to height of occupant for both female and male and percentage of total population

Table 4 summarizes the average height of females and males for PV and SUV struck vehicle. Within the AIS3+ population, the average height of the female drivers (164 cm-PV, 165 cm-SUV) is less than that of the male drivers (177 cm-PV, 178 cm-SUV). The average hieght difference between female and male is 13 cm.

Table 4.
Average of height of female and male

When the PV as struck vehicle	
AIS3+ population	Avg. Height (cm)
Female (110)	164
Male (83)	177
When the SUV as struck vehicle	
AIS3+ population	Avg. Height (cm)
Female (19)	165
Male (11)	178

Variation of Serious Injuries with Striking Vehicle Type (PV v/s SUV)

With increasing market share of SUV vehicles, the effect of the striking vehicle is also an important factor to be studied in side imapcts to check the sensitivity of injuryies. In this analysis, we studied the effect of injury sensitivity when a passanger vehicle was struck by either an SUV or PV. Looking at the percentages of vehicle types in total striking vehcile population of this study, it is also observed that PV has the highest share with 48% followed by the SUV with 23%. The percentage of AIS3+ injuries are given in Figure 8 for PV and SUV striking vehicles. The percentages of AIS3+ injuries are higher when the striking vehicle type is a SUV (70%) than when it is a PV (60%). The results compare the percentage of AIS+3 injuries when impact location is only P & Y regions with that for all the all the regions. It is evident that the chances of having AIS3+ injuries are more at the P & Y regions than that of all the regions for both types, PV and SUV striking vehicles. The percentage of AIS3+ injuries for female and male drivers are plotted in Figure 9 when the striking vehicle changes from PV to SUV. The chances of having higher AIS3+ injuries for female drivers are higher when struck by a SUV than those by a PV.

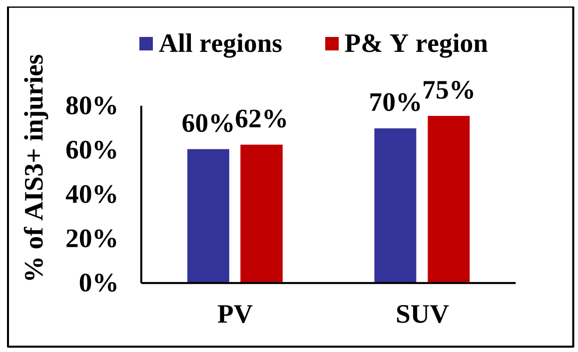

Figure 8. Variation of AIS3+ injuries with striking vehicle (PV v/s SUV) for all six regions and P & Y regions

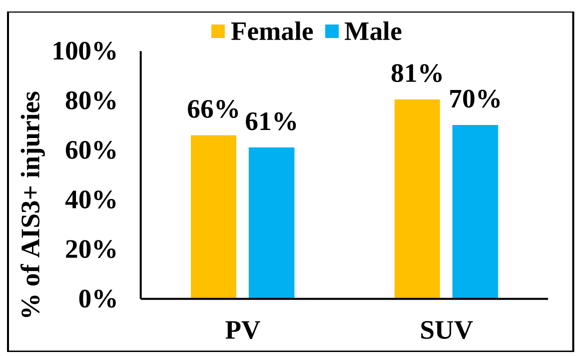

Figure 9. Variation of AIS3+ injuries with striking vehicle (PV v/s SUV) for male and female

Figure 10 shows the variation of AIS3+ injuries in four body regions (head, thorax, abdomen, lower extremities) for both PV and SUV striking vehicles. It is observed that the AIS3+ injuries in the head, lower extremity (including pelvis) and abdomen regions are increasing more than that in thorax when the type of striking vehcile is changed from PV to SUV. The following three mechanisms usually observed in IIHS side impact test conditions will explain the change in injury pattern related to SUV and PV striking vehicles[18].

(a) Matching of bumper height of SUV with the pelvis height of small females and less engagement of sill member of the struck vehicle with bumper of the striking vehicle may lead to more lower extremity injuries.
(b) Shorter females' upper torso, spinal cord and head will laterally bend more towards the window side due to higher input load near the pelvis and abdomen regions.
(c) More intrusion at the abdomen region for SUV striking vehicle will lead to more abdomen injuries.

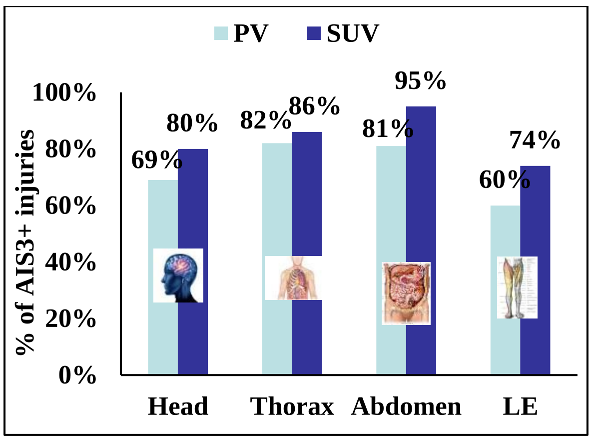

Figure 10. Variation of AIS3+ injuries for different body region in P & Y region (PV v/s SUV)

Variation of Serious Injuries with Respect to Impact Location and Impact Angle

Figure 11 shows the percentage of AIS3+ serious to fatal injury distribution with respect to the impact location and impact angle, respectively. A higher number of serious to fatal injuries (57%) occurred in Y-region when compared to other impact locations and a higher number of serious to fatal injuries (60%) occurred when the direction of impact is 10 o'clock. Injury occurrence for L-type offset impacts at both ends, B and F regions, were the lowest of all locations studied. In P and Y regions (T-type impact), the chances of having AIS3+ injuries were higher for an impact angle of 10 o'clock than for angles of 8 and 9 o'clock. Figure 12 shows the variation of AIS3+ injuries with respect to impact angle. A 10 o' clock impact has a higher number of AIS3+ injuries (60%) than other impact angles.

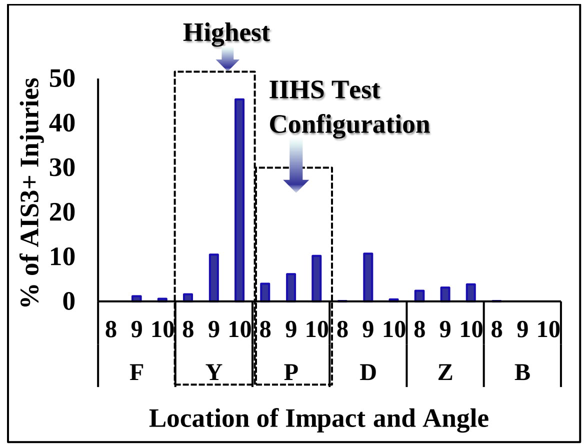

Figure 11. Distribution of AIS3+ injuries in side impact with respect to impact location and angle

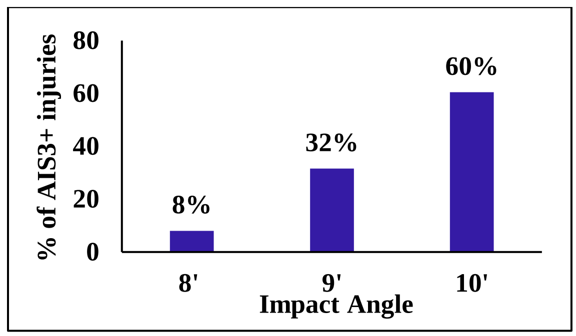

Figure 12. Variation of AIS3+ injuries with respect to impact angle

Though the current IIHS side impact test configuration is mainly focused for P-region to reduce compartment intrusion, from this accident analysis it is observed that the Y-region is having higher number of AIS3+ injuries than the P-region.

Logistic Regression Test

A statistical test was performed to determine the probability of AIS3+ injuries with respect to impact location. Out of 865 vehicles, 550 vehicles were considered. To understand the sensitivity of injuries with respect to impact location, the side regions of the vehicle area is divided into two separate categories i.e. both ends as one category and the central region as another category, as shown in Figure 13. The cases whose impact location is in front (F region) and back (B region) were combined into one (end region) and the cases whose impact location is other than the front and back are considered as impact happening at the center. It is observed that 30% and 9% of AIS3+ injuries were happening at the center and end regions respectively.

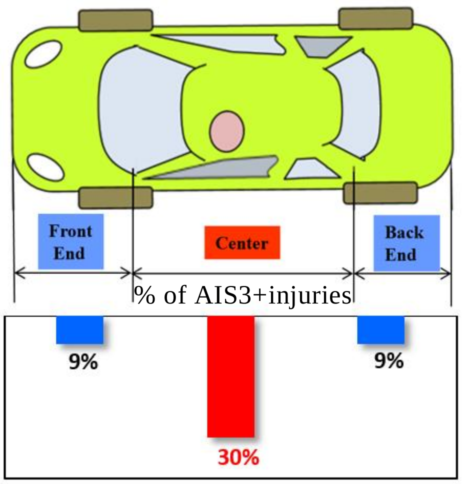

Figure 13. Classification of impact location into two: 1) center and 2) end regions

A univariate binary logistic regression test was carried out to test the significance of being impacted at center than at the two ends away from A and C pillars. As shown in Table 4, a statistical significance ($p<0.05$, chi square test) is found between the AIS3+ injury (dependent variable) and impact location (independent variable). The results also show that the odds ratio between the impact at center and impact at two end locations is 6.08. Hence, impact at the side center location is 6 times as likely as impact at vehicle side end locations leading to AIS3+ injuries. Impact locations at the side front (away from A pillar) and the side end (away from C pillar) regions may be safer than that at side central region (close to driver seating position) to cause comparatively less serious AIS3+ injury in near side collisions.

Table 4.
Logistic regression test

AIS3+ prediction	Value	Wald Chi-Square	*p > Chi²	Odds ratio
Constant	-3.81	43.96	< 0.0001	
Impact @end (reference)	0.000			
Impact @centre	1.80	9.19	0.002	6.08

Statistically Significant *p<0.05

Verification of Serious Injury Sensitivity by FE Simulations

This section discuss the results of AIS3+ injury sensitivity obtained from a series of full vehicle FE simulations. The above real world accident results were also verified with barrier to car digital simulation.

For the FE simulation, a Movable Deformable Barrier (MDB) is used to hit the passenger vehicle fitted with AM50% dummy in driver seating position. This test is (was) done with an impact angle of 270 degrees (9 o'clock) and with an impact speed of 62 km/h. The MDB hits the vehicle at different impact locations as shown in Figure 14. First, it was hit at the center (close to the driver seating position) and injured values were measured. This injury value were used as a reference to compare with those of other locations. Barrier impact position was changed by 250 mm of several increments for both forward and rear side of the center reference position.

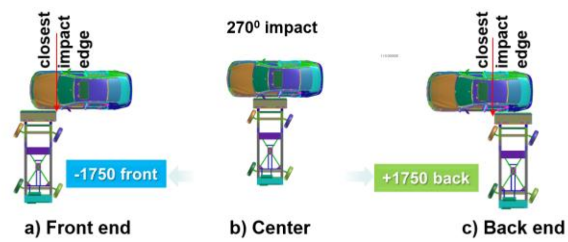

Figure 14. FE simulation test configurations with center (base): SINCAP

As shown in Figure 15, the chest injury values decrease as the closest impact edge of the barrier moves away from driver. There is a significant reduction of injuries (40%) as the impact location moves away from the center to end regions. To determine the probability of AIS3+ injury at different impact locations, the US-NCAP side impact chest injury risk curve for dummies, as mentioned in Equation 1 [15], has been considered here. All of the serious injury probabilities were calculated and shown in Figure 16. It is observed that the probability values of AIS3+ injuries are decreasing rapidly as the impact location moves away from the center, the reference position. But the injuries at 250 mm and 500 mm were increasing because they are very close to B pillar (driver's seating position). Both accident analysis and FE simulation results confirm that higher number of injuries at center and lower number of injuries at end locations. Hence, from driver's seating position and injury occurrence point of view, the impact locations in F (front end) and B (back end) regions are safer than those at P and Y (at center) regions.

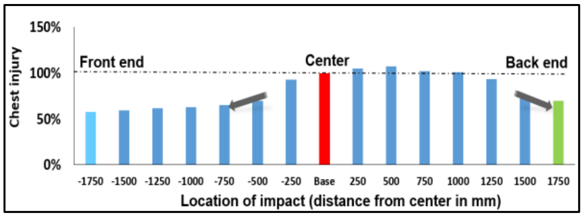

Figure 15. Chest injury sensitivity w.r.t location of impact (base: SINCAP)

$$P_{(Chest)}\ (AIS3+) = \frac{1}{(1+\exp(5.3895-0.0919 * max.rib\ deflection\ in\ mm))} \quad (1)$$

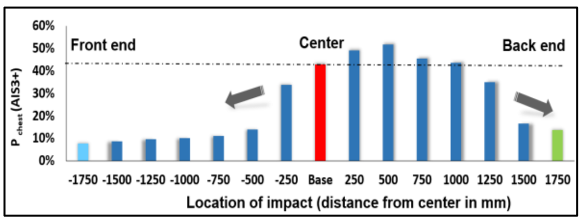

Figure 16. Probability of AIS3+ chest injury w.r.t location of impact (base: SINCAP)

DISCUSSION

Similar injury reduction is observed in other body regions (abdomen and pelvis) and the results are mentioned in the Appendix. Injury sensitivity is also verified with 10 and 8 o'clock impact angles. All of the injury values decrease quickly as the impact location changes from center to end. Please note that only 9 o'clock impact angle FE simulation results are explained in detail in this paper but not the results of other angles. Similar changes in injury patterns with respect to different impact locations were observed when the AM50 was replaced with the AF05 dummy in IIHS test condition. This was done to verify the changes in injury patterns in both average males and shorter females. Since the serious injury outcome is changing with position of impact location, the results of this analysis provides some indications how to consider different interaction terms between impact locations, impact directions, gender, height etc., in improving the Injury Severity Prediction (ISP) algorithm related Advanced Automatic Collision Notification (AACN). It is discussed in detail in reference [16]. So adding an interaction terms to a model drastically changes the interpretation of all of the coefficients [16, 17]. If there were no interaction terms, the angle of impact would have unique effect of ISP. But the interaction means that the effect of each variable on ISP is different for different values of other independent interacting variables such impact locations, gender and others.

LIMITATIONS

Please note that all the above mentioned results were verified for only PV struck vehicles in C2C intersection accidents but not for other vehicle types. A limited number of cases were studied in this research work. However, considering all possible accident scenarios, more detailed verifications are needed by using various combinations of physical C2C experiments and simulations using different dummies and types of vehicles in order to make any generalized statement as stated above. It is also necessary to do similar accident analysis for other countries for verification.

CONCLUSION

This paper discussed the sensitivity of the injury patterns of C2C side impact accidents at intersection for PV vehicles using NASS CDS CY 2004-2014 data. The following specific conclusions can be drawn from this study:-

a) More than 80% of C2C side crash intersection accidents are driver-alone cases and within that population, female are more likely to have AIS3+ injuries than male drivers. Shorter females (AF05) are most likely to have AIS3+ injuries. Further detail study with more accident data is necessary to identify the effect of gender difference (male and female) for shorter populations.

b) SUVs produces a higher number of AIS3+ injuries than PVs as the striking vehicle. AIS3+ injuries in head and lower extremities (including pelvis) injuries increases when the striking vehicle is an SUV, when compared to PV. But there is not much change observed in thorax region.

c) A higher number of AIS3+ injuries occur in side distribution Y location than the side center P location. Crashes which occur at a 10 o'clock impact yield a higher number of AIS3+ injuries than at the 9 o'clock impact angle in both P and Y regions. Injury probability occurance with impact at the center is 6 times more than the end regions(F&B). The level of injuries decreases rapidly as the closest impact edge of the striking vehicle moves away from the side center location to the side-end locations in barrier to car simulations.

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NOMENCLATURE:

NASS CDS: National Automotive Sampling System Crashworthiness Data System
AIS: Abbreviated Injury Scale (1998 version)
AM50: 50th percentile American male
AACN: Advanced Automatic Collision Notification
ISP: Injury Severity Prediction
AF05: 5th percentile American female
IIHS: International Institute of Highway Safety
NCAP: New Car Assessment Program

PV: Passenger Vehicle
SUV: Sport Utility Vehicle
C2C: Car to Car

APPENDIX A.

Table A1. Weighted count of AIS injuries with respect to different impact locations and impact angles (Percentage of injuries mentioned in bracket)

AIS Count Number (%)		Impact Location And Impact Angle: B			D			F			P			Y			Z			Total
		8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	
Minor	1	749 (0.02)	8989 (0.29)	9845 (0.32)	15777 (0.52)	92553 (3.03)	59675 (1.95)	43598 (1.43)	40363 (1.32)	154546 (5.05)	31883 (1.04)	112872 (3.69)	246761 (8.07)	32072 (1.05)	342155 (11.19)	635380 (20.78)	51117 (1.67)	150363 (4.92)	214234 (7.01)	2242934 (73.35)
	2	81 (.003)	541 (0.02)	652 (0.02)	221 (0.01)	47287 (1.55)	5540 (0.18)	5526 (0.18)	3609 (0.12)	4329 (0.14)	15444 (0.51)	27416 (0.90)	29715 (0.97)	7821 (0.26)	31835 (1.04)	138125 (4.52)	11073 (0.36)	22590 (0.74)	21433 (0.70)	373238 (12.21)
Serious	3	81 (.003)	-	-	213 (0.01)	33138 (1.08)	1606 (0.05)	-	4595 (0.15)	2032 (0.07)	12901 (0.42)	20402 (0.67)	23427 (0.77)	3471 (0.11)	41068 (1.34)	164213 (5.37)	4935 (0.16)	8617 (0.28)	8921 (0.29)	329619 (10.78)
	4	-	-	-	-	10353 (0.04)	391 (0.01)	-	528 (0.02)	330 (0.01)	2371 (0.08)	6197 (0.20)	11376 (0.37)	2678 (0.09)	4588 (0.15)	26278 (0.86)	1581 (0.05)	757 (0.02)	5322 (0.17)	72750 (2.38)
	5	-	-	-	-	2352 (0.08)	-	-	-	165 (0.01)	2371 (0.08)	439 (0.01)	10373 (0.34)	848 (0.03)	771 (0.03)	9350 (0.31)	3463 (0.11)	4199 (0.14)	2036 (0.07)	36368 (1.19)
	6	-	-	-	-	1330 (0.04)	-	-	-	-	-	-	-	-	-	391 (0.01)	484 (0.02)	-	589 (0.02)	2793 (0.09)
	3+	81 (0.03)	-	-	213 (0.01)	47172 (1.54)	1997 (0.06)	-	5124 (0.16)	2527 (0.09)	17643 (0.58)	27038 (0.88)	45176 (1.48)	6997 (0.23)	46427 (1.52)	200232 (6.55)	10463 (0.34)	13572 (0.44)	16868 (0.55)	441530 (14.55)
AIS 1-6		912 (0.02)	9530 (0.31)	10497 (0.34)	16211 (0.54)	187012 (6.12)	67213 (2.20)	49124 (1.61)	49096 (1.61)	161402 (5.28)	64970 (2.12)	167326 (5.47)	321652 (10.52)	46891 (1.53)	420417 (13.75)	973738 (31.85)	72652 (2.38)	186526 (6.10)	252534 (8.26)	3057702

AIS3+: 14.5% injuries, AIS1&2: 85.5% injuries

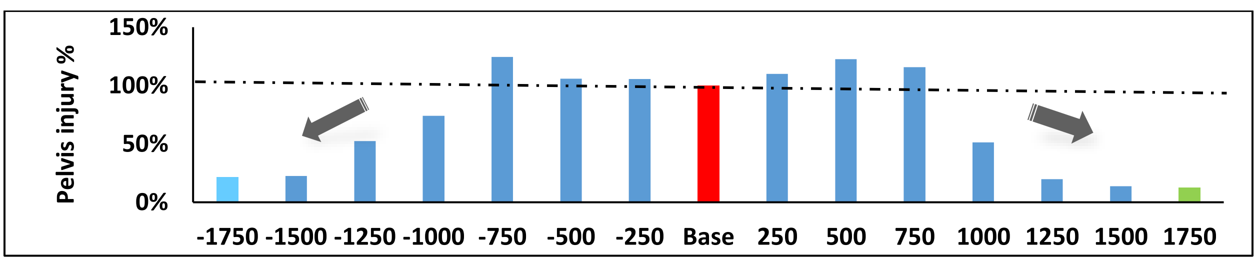

Figure A1. Pelvis injury sensitivity with respect to location of impact

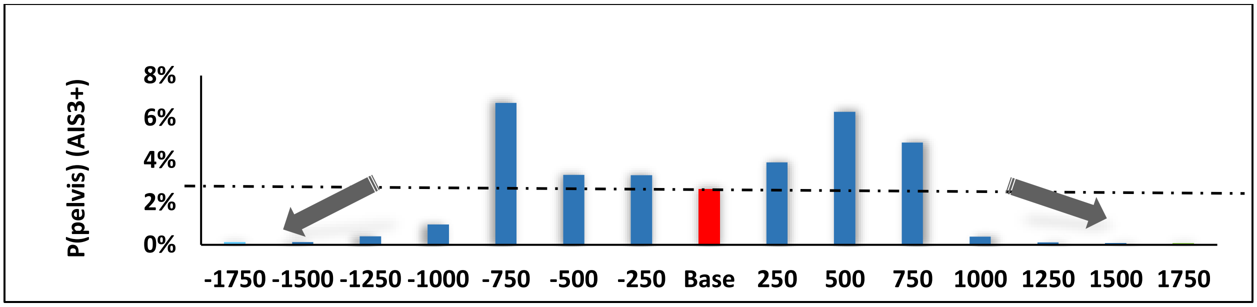

Figure A2. Probability of AIS3+ pelvis injury with respect to location of impact

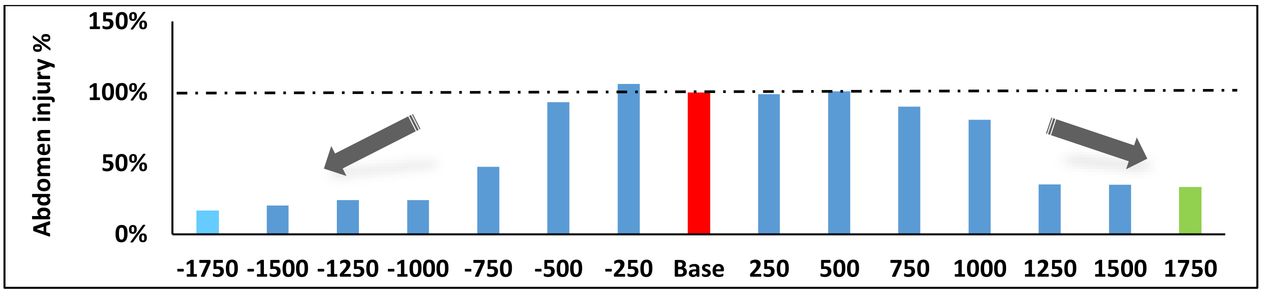

Figure A3. Abdomen injury sensitivity with respect to location of impact

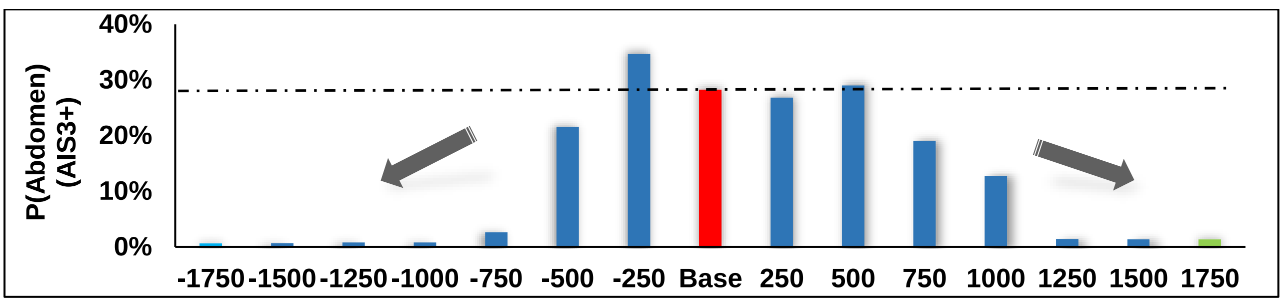

Figure A4. Probability of AIS3+ abdomen injury with respect to location of impact

Equation 2 shows the probability of pelvis AIS3+ injury

$$\mathbf{P}_{\mathbf{pelvis}}\,(\mathbf{AIS3+}) = \frac{\mathbf{1}}{(\mathbf{1+exp}(\mathbf{7.5969-0.0011}*\boldsymbol{pelvis\ force\ in\ N}))} \quad (2)$$

Equation 2 shows the probability of abdomen AIS3+ injury

$$\mathbf{P}_{\mathbf{abdomen}}\,(\mathbf{AIS3+}) = \frac{\mathbf{1}}{(\mathbf{1+exp}(\mathbf{6.04044-0.002133}*\boldsymbol{Abdomen\ force\ in\ N}))} \quad (3)$$