Opportunities for Injury Reduction in Rollover Crashes

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ABSTRACT

The NASS/CDS remains the best US data source for understanding the magnitude of the opportunities for reducing rollover injuries to the various body regions. However, judicious analysis techniques are required to address the many confounding factors, including but not limited to the consequence of recent safety improvements such as electronic stability control and increased roof strength. To better assess the effect of recent safety improvements, the population of drivers in rollovers in light vehicles model year 2000 and later was examined. To address crash severity, the number of quarter-turns was used. Injuries were separated by body region and the HARM method of aggregating injuries was used to provide added weighting to the more severe injuries. For belted drivers in near-side rollovers, the fourth quarter-turn contained the most HARM and the highest injury risk, especially for chest injuries. For belted drivers in far-side rollovers, most of the chest injury HARM is fairly uniformly distributed between quarter-turns 2, 4, 6 and 8.

INTRODUCTION

During the past 15 years there have been a number of changes in safety testing to encourage safety improvements in passenger vehicles. Improvements in the vehicle structure occurred in response to dynamic side impact testing and static roof testing for safety regulations and consumer information. Dynamic side impact testing was required by 1997 and the Insurance Institute for Highway Safety (IIHS) began consumer testing for side impacts in 2003. A continuing priority at NHTSA has been to increase the severity of the roof strength standard. The earlier standard required the roof to withstand a load of at least 1.5 times the vehicle weight when compressed 5 inches in a static test. In 2009, IIHS raised the requirement to 4 times the vehicle weight for a best score in their consumer information test that was based on the Federal Standard. The US Department of Transportation subsequently raised the standard to 3 times the vehicle weight. Electronic stability control (ESC) entered the market in 1995 and became standard on approximately 38% of the cars and SUV's by model year 2005. By MY 2009, the ESC was standard equipment on 100% of SUV's, 74% of cars and 38% of pickups (IIHS 2013). These structural and rollover avoidance countermeasures should result in improvements in rollover protection that will require continued monitoring and evaluation to determine what additional countermeasures may be effective and practical. In an earlier ESV paper, we examined the rollover safety performance of the passenger vehicle fleet documented in NASS years 1995-2005 (Digges 2007). A purpose of this paper is to examine how rollover injuries are occurring in recent models of vehicles, model year 2000 and later. Of particular interest is to determine the quarter-turns and the injuring contacts with the highest content of injury HARM in both near-side and far-side rollovers. Studies of this kind will assist in the search for the causes of rollover injuries and possible ways to mitigate them.

In an earlier paper, we examined safety changes in the vehicle fleet by model year (Eigen 2013). In that paper, we aggregated groups of vehicles my model year beginning with model year 1985 and examined how the injury rates had changed in all crash modes. The most recent model year grouping, model years 2000 to 2009, displayed a 40% reduction in serious injury rate compared with earlier model years. For that latest model year grouping, head and chest injuries each accounted for about 35% of the HARM to belted drivers in rollovers. The spine and upper extremities each accounted for about 10% and lower extremities about 5%. It is evident that head and chest protection offered the greatest opportunities for injury reduction and consequently they are a principal focus of this paper.

METHODS

The source for exposure and injury data was the NASS/CDS (National Automotive Sampling System/Crashworthiness Data System) years 1999 to 2012. NASS/CDS is a weighted estimate of tow-away crashes occurring in the United States. The NASS/CDS weighted data contains approximately 23 million drivers of passenger cars, SUV's, passenger vans or light trucks (pickups) who were exposed to crashes. NASS/CDS data were disaggregated by vehicle model year and crash mode.

Query Description

The Statistical Analysis System (SAS) was used to merge and extract NASS CDS data. The accident, vehicle, occupant, and injury files were merged. The filters, applied to each of the files, appear in Table 1.

Table 1: NASS CDS Data Files and Filters Applied

File Name	Variable with Filter	Rationale
Accident	1999<=***Year***<=2012	Crashes occurring in ***calendar years*** 1999 through 2012.
Vehicle	1<=***Bodytype***<=49	Passenger ***Vehicle body types***, including passenger cars, sport utility vehicles, pick up trucks, and vans
	Modelyr ge 2000	Vehicle model years greater than or equal to 2000 were retained, with 2013 as latest model year.
	1<=***Rollover***<=17 (pre-1998) 1<=***Rollover***<=21 (1998-onward)	***Rollover crashes*** about the longitudinal axis, 1 through 16, aggregating 17+, later 1 through 20, aggregating 20+.
Occupant	Role = 1	Occupant role was set to drivers only
	Manuse in(0,1,4)	Occupant restrained by a lap and shoulder belt (4) compared to unrestrained (0,1)
	3<=MAIS<=6	Maximum Abbreviated Injury Score serious (3), severe (4), critical (5), or maximum (6)
Injury	Region90=5	Occupants sustaining thoracic injuries
	3<=AIS<=6	Abbreviated Injury Scores 3 – 6, maximum per body region (BMAIS)

In order to capture all vehicles of model year 2000 and later, the calendar years1999 through 2012 were queried, resulting in vehicles through model year 2013. The vehicles were restricted to passenger vehicles, as the NASS CDS is a sample of tow-away passenger vehicle crashes. Larger vehicle types would fall outside the scope of NASS CDS and would not receive a full vehicle inspection, if impacting with a qualifying passenger vehicle.

The rollover quarter turn variable was modified in 1998. Previously, up to 16 quarter turns were quantified, aggregating 17 quarter turns and greater. In 1998, the quantified quarter turns were increased to 20, aggregating 21 quarter turns and greater. As this has been an on-going comparative study, the previous formatting was retained for comparative purposes. For future analyses, the 1998 rollover quarter turn formatting will be adopted.

Filters were applied to the occupant file. The occupant role was restricted to drivers. This has a normalizing effect, as vehicles inconsistently carried right front seat passengers. These drivers were further restricted to unrestrained, those not using a factory-installed restraint or seated in a position without a factory-installed restraint, and restrained, those using lap and shoulder belt combination. Only occupants sustaining at least a serious injury were considered in this study. Additional review of drivers sustaining thoracic injuries suggested the need for additional future analyses. This review was based upon the severity of the maximum thoracic injury sustained, eliminating the possibility of double counting and misstating the effects of more pervasive, concomitant injury types.

Interpretation of Queried Data

There are a variety of ways to examine the frequency and rate of injuries in the available databases. Frequently, Maximum Abbreviated Injury Scale (MAIS) 3 and above injuries are combined. Alternatively, the HARM weighting scheme is applied to injuries of different severity. The latter has the advantage of weighting injuries in proportion to their cost (Malliaris 1982). The HARM method will be the primary method used in this paper to assess the magnitude of the injuries suffered by the populations under consideration.

The HARM calculations for the body regions were based on the approach introduced by Fildes and Digges [Fildes 1992]. This methodology applies a weighting factor to each AIS 2+ injury in the database. The weighting factor is proportional to the cost of the occupant's most serious injury. In general, minor injuries (AIS 1) are high frequency, events that tend to cloud the analysis of serious injury reduction by safety systems. For this reason, AIS 1 injuries were excluded from the HARM calculations. The AIS 2+ HARM, measured in equivalent fatalities, was based on NHTSA's data on average cost of injuries. The equivalent fatality measurement is obtained by normalizing the average cost of a given injury by the cost of a fatality. The average cost of each injury severity was obtained from a Table E-1 in the 1995-1997 NASS/CDS Summary (NHTSA 2001). The injury cost values are: MAIS 2, 3,600; MAIS 3, 98,011; MAIS 4, 221,494; MAIS 5, 697,533; and MAIS 6, 822,328. The Mean HARM for each category was calculated by dividing the HARM suffered by drivers by the number of drivers exposed to that category. The Mean HARM results were multiplied by 100 to simplify the presentation.

RESULTS

The distribution of drivers in model year 2000 and later light vehicles who were involved in NASS/CDS rollover crashes is displayed in Figure 1. This Figure also displays the distribution of AIS 2+HARM for the same population. The weighted driver population consisted of 318,376 belted and 29,781 unbelted drivers. The unbelted population suffered 37% of the AIS 2+ HARM. The unweighted population consisted of 926 of which 78.5% were belted. The unbelted sustained almost half of the unweighted AIS 2+ HARM.

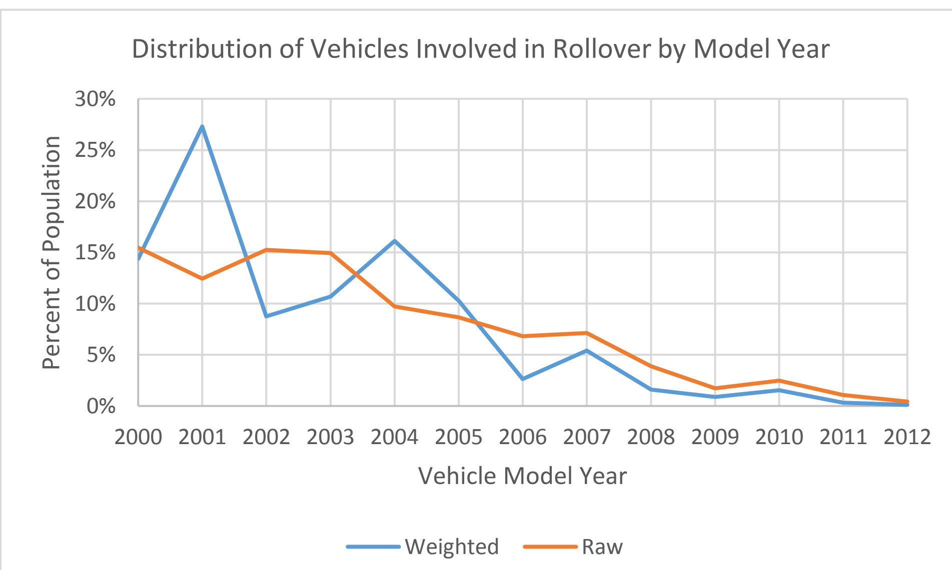

Figure 1. Distribution of rollover involved light vehicles in 2000-2012 NASS/CDS by model years

Figure 2 shows the exposure of rollover involved vehicles, model year 2000 and later, by vehicle type. The corresponding distributions of AIS 3+ injuries and AIS 2+ HARM are also shown. It may be noted that the HARM generally tracks the AIS 3+ injuries. However, HARM allows for the representation of AIS 2 injuries and gives additional weight to AIS 4+ injuries.

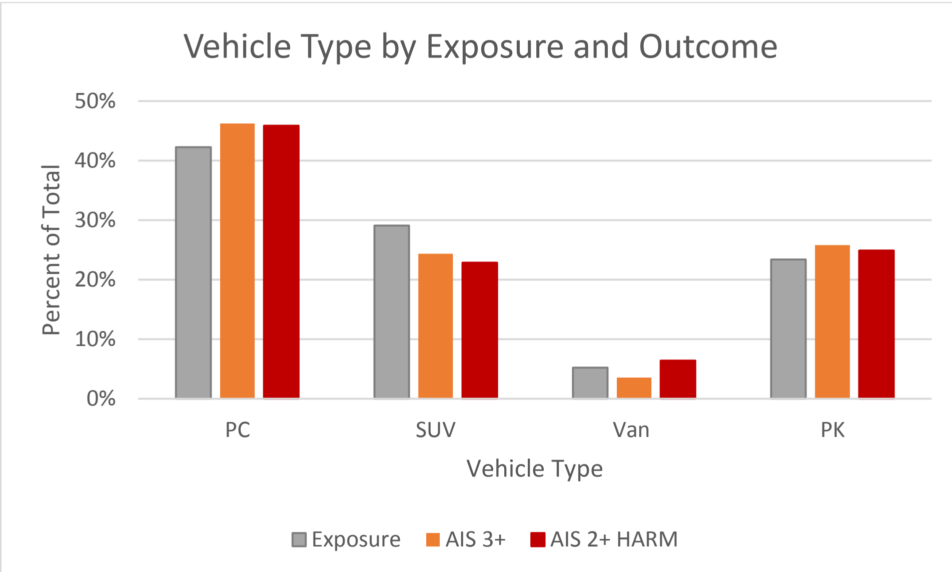

Figure 2. Distribution of rollover involved MY 2000+ light vehicles in 2000-2012 NASS/CDS by vehicle type

Figure 3 examines the distribution of vehicle quarter-turns and compares weighted and raw data. The weighting factors reduce the populations exposed to 2, 4 and 6 quarter-turns and increase the populations exposed to 1 and 5 quarter-turns.

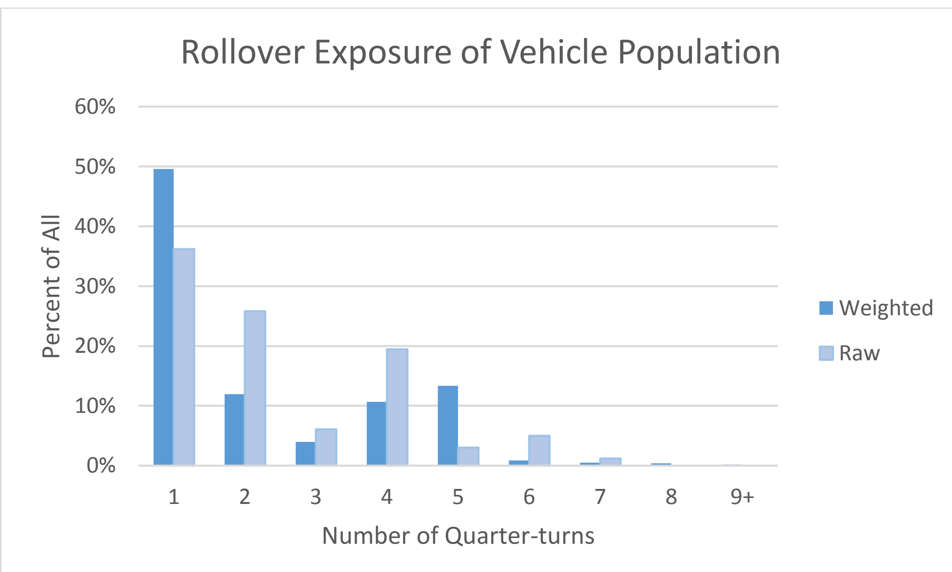

Figure 3. Distribution of rollover involved MY 2000+ light vehicles by number of quarter-turns

Figure 4 examines the distribution of AIS 2+ HARM by vehicle quarter-turns and compares weighted and raw data. Although the weighting factors reduced the populations exposed to 2 and 4 quarter-turns, the HARM level remained high for those quarter-turn groups.

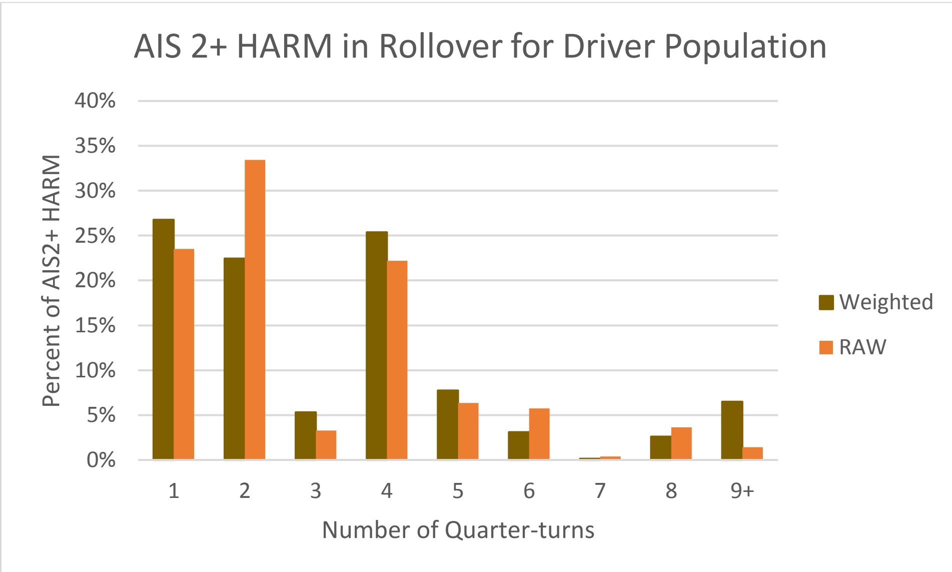

Figure 4. Distribution of driver AIS 2+ HARM in rollover involved MY 2000+ light vehicles by number of quarter-turns

Figure 5 focuses on belted drivers and displays their exposure and AIS 2+ HARM distributions by vehicle quarter-turns. It may be noted that 4 quarter-turns is especially harmful.

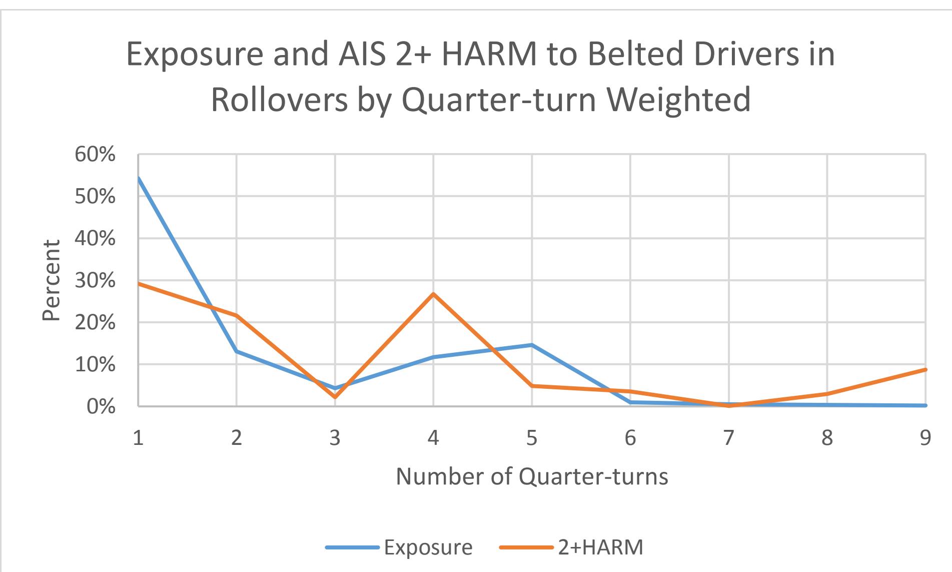

Figure 5. Distribution of rollovers and AIS 2+ HARM for belted drivers of rollover involved light vehicles in 2000-2012 NASS/CDS by number of quarter-turns (weighted)

Figure 6 examines the distribution of AIS 2+ HARM by vehicle quarter-turns and compares near-side and far-side rollovers. Populations exposed to 1, 2 and 4 quarter-turns sustain the largest percentage of HARM in both roll directions.

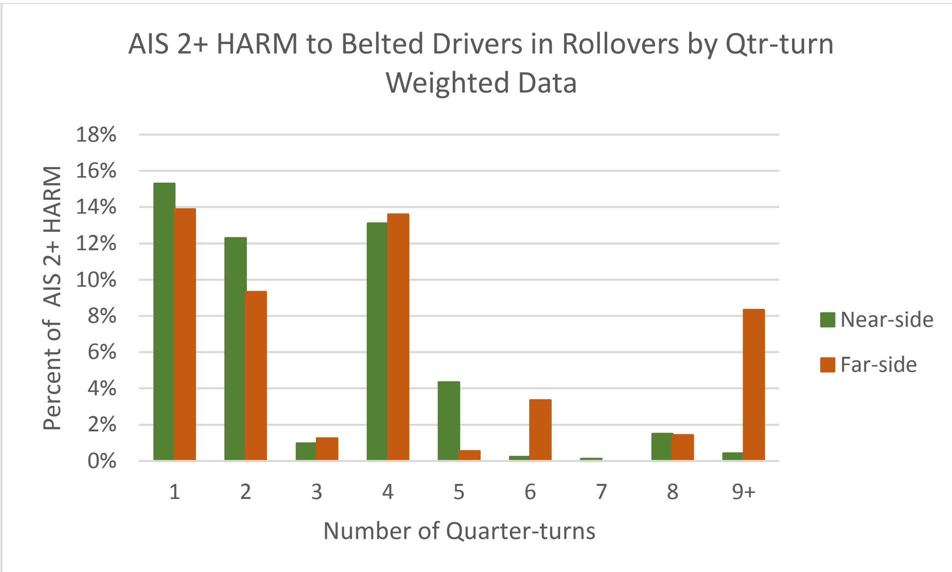

Figure 6. Distribution of belted driver AIS 2+ HARM in rollover involved MY 2000+ light vehicles by direction of rollover and number of quarter-turns (weighted data)

Figure 7 examines the distribution of AIS 2+ HARM from chest injuries by vehicle quarter-turns and compares near-side and far-side rollovers. For near-side rollovers, 1, 2 and 4 quarter-turns sustain the largest percentage of AIS 2+ HARM. Quarter-turn 4 appears to be particularly harmful, with about 30% of the total chest HARM. For the far-side rollover, the HARM is more uniformly distributed among the even number of quarter-turns – 2, 4, 6 and 8.

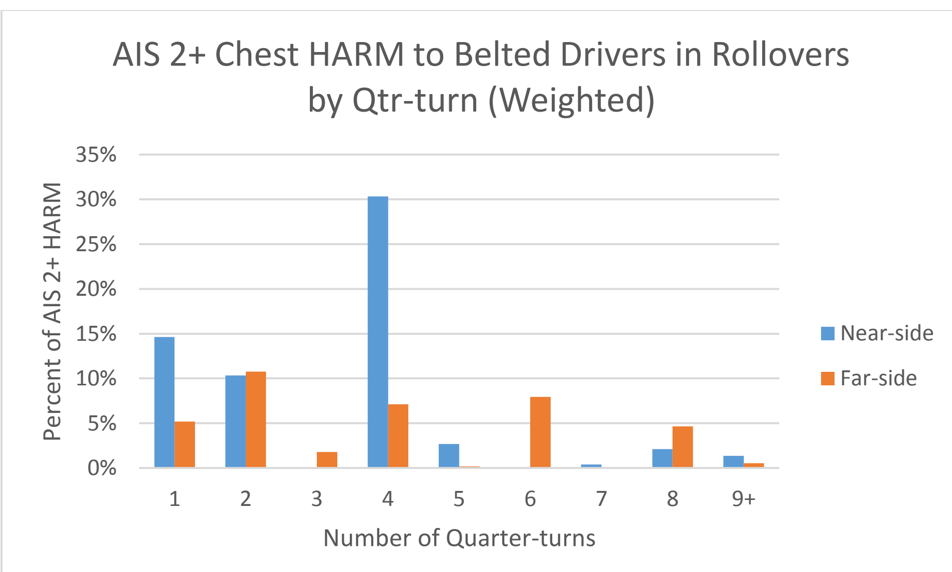

Figure 7. Distribution of belted driver AIS 2+ HARM from chest injuries in rollover involved MY 2000+ light vehicles by direction of rollover and number of quarter-turns (weighted data)

To better understand what parts of the vehicle are causing injuries in rollovers, an analysis of injuring contacts was conducted. NASS CDS allows the coding of more than 100 possible injuring contacts for occupant injuries. To clarify the location of occupant contacts in rollovers, it was necessary to aggregate the possible contacts according to location within the vehicle. The following contacts were included: roof, near-side compartment, far-side compartment, center compartment (including seat), frontal compartment, floor, other occupant and all other (including safety belt). The resulting distribution of contacts by injuring contacts by body region are shown in Tables 2 and 3. In Table, injuries at all AIS levels are included. In Table 3 only serious injuries (AIS 3+) are included. In both tables multiple injuries per occupant are allowed. Both near-side and far-side rollovers are included in these tables.

The number of injuring contacts were equally divided between near and far-side rollovers. The head and trunk contacts with the near-side compartment accounted for 59% of the contacts for near side-rollover compared to 27% for far-side rollovers. The all other contacts for head and chest injuries was much larger for far-side rollovers (52% vs 23%). Other contacts were generally similar.

Table 2. Distribution of injuring contacts in rollover crashes by injured body region (all injury levels)

Contact Location	Head & Trunk	Upper Ex.	Lower Ex.
roof	13%	5%	0%
near-side compartment	27%	62%	57%
far-side compartment	1%	2%	0%
center compartment	3%	1%	3%
frontal compartment	1%	2%	0%
floor	2%	0%	22%
other occupant	1%	1%	0%
all other	52%	25%	17%

Table 3. Distribution of injuring contacts in rollover crashes by injured body region (AIS 3+ injury levels)

Contact Location	Head & Trunk	Upper Ex.	Lower Ex.
roof	11%	0%	0%
near-side compartment	66%	90%	93%
far-side compartment	6%	1%	0%
center compartment	2%	2%	1%
frontal compartment	0%	5%	0%
floor	3%	0%	7%
other occupant	1%	0%	0%
other	10%	3%	0%

DISCUSSION

The separation of NASS CDS data by vehicle model year 2000 and later, and the aggregation of injuries by the HARM weighting scheme provides new insights into the opportunities for further reducing injuries in rollovers. The historical method of analysis uses NASS data years for longitudinal studies and AIS 3+ injuries for measuring casualties. This approach obfuscates the presence of new vehicles in the fleet and inflates the effect of AIS 3 injuries. Separation of rollovers by crash severity (number of quarter-turns), rollover direction and injured body region is rarely done. This paper presents an innovative approach to rollover casualty analysis and highlights opportunities for further safety improvements.

Figures 3 and 4 show that the most frequent number of quarter-turns for both the exposure and the AIS 2+ HARM are 1, 2 and 4. The NASS weight factors for quarter-turn categories 5 and 9 may result in an unreliable prediction of the frequency of these events. Figure 5 shows that quarter-turns 2 and 4 carries the highest rate of AIS 2+ HARM.

A comparison of near-side and far-side rollover AIS 2+ HARM is displayed in Figures 6 and 7. Figure 6 addresses the HARM from all injuries and indicates that far-side rollovers have a higher percentage of HARM at the higher (6+) quarter-turns compared to near-side rollovers.

A further breakdown of HARM by the chest body region is displayed in Figure 7. The near-side chest HARM tends to track the overall HARM distribution with peaks at 1, 2 and 4 quarter-turns. However, the far-side chest harm is more uniformly distributed between quarter-turns 1, 2, 4, 6 and 8.

As shown in Table 2, the near-side compartment is the most frequent injuring contact for belted drivers. It accounts for 27% of the head and trunk injuries, 62% of the upper extremity injuries and 57% of the lower extremity injuries. When considering only AIS 3+ injuries these contact percentages are even higher (Table 3).

We need further study to better understand the causes of the high frequency of chest injury in near-side rollovers with 4 quarter-turns. For far-side rollover, chest injuries at 2 and 6 quarter-turns require further investigation. Explanations of chest injury causation in far-side rollovers with 4 and 8 quarter-turns were offered in an earlier ESV paper (Digges, 2013; Tahan, 2013).

CONCLUSIONS

The number of rollover quarter-turns with the highest exposure and AIS 2+ HARM are 1, 2 and 4.

Far-side rollovers have a higher percentage of HARM at the higher (6+) quarter-turns compared to near-side rollovers.

The near-side chest HARM tends to track the overall HARM distribution with peaks at 1, 2 and 4 quarter-turns. However, the far-side chest harm is more uniformly distributed between quarter-turns 1, 2, 4, 6 and 8.

One cause of chest injuries in far-side rollovers with 4 and 8 quarter-turns has been proposed in earlier papers [Digges 2013, Tahan 2013]. Additional studies may be required to determine the high rate of chest injuries in four quarter-turn near-side rollovers.

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