The Injury Risk from Objects Impacted Before and During Rollovers

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ABSTRACT

The number of quarter-turns is one widely used metric for rollover severity. However, this metric does not adequately recognize the consequences of impacts with fixed objects or with other vehicles that may occur before or during the rollover. Since 1995, the NASS/CDS includes a measurement of the extent of vehicle damage. The database permits rollovers to be grouped according to whether or not a harmful crash event preceded or succeeded the rollover. Groupings can also include the extent of vehicle damage and the number of quarter turns. In NASS/CDS 1995-2003, belted occupants in rollover crashes that were preceded by impacts with fixed or non-fixed objects and with severe extent of damage had injury risk three times higher than all other rollover groupings. This high risk group requires the extent of damage as a rollover severity metric. When higher injury risk cases with severe damage were removed, chi square tests showed significance of the relationship between the number vehicle inversions and the occupant injury outcome.

KEYWORDS: Rollover Accidents, Crashworthiness, Injury Severity, Occupants, Statistics

In 1995, the NASS/CDS introduced a number of additional data elements to its rollover data. These included vehicle damage measurements that permit the assessment of the severity of contacts from fixed or non-fixed objects, including the ground. Another improvement was the categorization of rollover crashes is according the sequence of impact events, including impacts prior to and subsequent to rollover. Also in 1995, NASS improved the discrimination of the quarter-turns. Up until 1995, the quarter-turns were designated as 1, 2, 3 and 4+. After 1995, up to 16 quarter-turns were enumerated. There are also categories for 16+ quarter-turns and end-over-end rollovers. The purpose of this paper is to examine how these new categories can be used to develop more precise severity metrics and to assess the distribution of injuries by body region in the various categories.

DATA SOURCES

NASS/CDS 1995-2005 forms the basis for the analysis. During the period NASS/CDS documented 60,671(n=562 unweighted) belted adult occupants who sustained MAIS3+ injuries during rollover crashes. The belted occupants were those whose restraint selection would have potentially provided protection against the forces imparted during a rollover crash. Those occupants protected by a lap belt, lap and shoulder belt combination, or a three point automatic belt were considered ”belted” for purposes of rollover.

METHODS

Analysis variables were created based upon those reported in the NASS CDS. NASS CDS is a sample of tow away passenger vehicle crashes occurring on United States public roadways. Measures of injury occurrence and severity, restraint usage, crash severity, and rollover sequence were used for this study. A brief description of each follows.

Injury severity was reported based upon the maximum abbreviated injury scale (MAIS) score reported for each involved occupant. As dictated by NASS CDS, the treatment variable was consulted to distinguish fatally injured occupants. This was especially important in cases where an autopsy report or medical reports were not available to the researcher. Occupants were assigned to four injury categories: uninjured (MAIS 0), minor injury (MAIS 1), moderate injury (MAIS 2), or serious through fatal injury (MAIS 3+F). The MAIS 3+F group consisted of occupants sustaining serious

(MAIS 3) through maximum (MAIS 6) injuries or fatally injured occupants, as conveyed by the treatment variable.

A measure for crash severity has been adapted from the NASS CDS. Delta-v readings are calculated, where the algorithm supports, and the delta-v associated with the most severe event is reported. The most severe event may be a planar event preceding or following the rollover. For these cases, a calculated delta-v may exist. If the vehicle damage inputs violate the algorithm logic, then the NASS CDS investigator may make a quantitative delta-v estimate, based upon his experience. If however, the damage pattern is in complete violation of the algorithm, as in the case of rollover, or classification defies experience, a qualitative severity estimate may be made. A combined metric considering calculated and estimated delta-v has been designed for three severity classes. These are minor (less 24 kilometers per hour), moderate (24 to 55 kilometers per hour), and severe (55 kilometers per hour or greater). The calculated and estimated values were analyzed separately and were found to behave in a similar fashion when aggregated and disaggregated. Collectively, these were defined as extent of damage and were not meant to be equivalent to the NASS CDS terminology.

Finally, rollover sequence was considered. Crashes in which a rollover event occurred were disaggregated by number of events. Pure rollovers were characterized by the rollover occurring in the first and only crash event. These rollovers, however, could result in any number of quarter turns since the complete rollover is considered to be one event and not reflective of the number of quarter turns. A second category considered multiple event rollover crashes in which the rollover was the first event followed by other crash events. The third category described a rollover crash in which a non-fixed object contact preceded the rollover event. The fourth category described a rollover crash in which a fixed object contact preceded the rollover event. The fixed and non-fixed object definitions are consistent with those found in NASS CDS.

The NASS/CDS rollover exposure and MAIS 3+ injury data were partitioned according to the object contacted prior to rollover and subsequent to rollover. The data was further partitioned according to damage severity measures that are available in NASS/CDS after 1995. The damage severity categories include “minor”, “moderate”, and “severe” damage from contacts with vehicles and other non-fixed objects, and fixed objects, including the ground. Cells with similar injury risks were grouped and served as the basis for a metric that considers both the rollover and the planar crash severity.

In analyzing body regions, the following three groupings were made:
Head-The head grouping was comprised of the head, face, and neck categorization of injured body regions;
Trunk-The trunk grouping contemplated injuries to the chest, abdominal, back, and shoulder;
Other-Finally, other considered all other injuries.

RESULTS

Earlier studies found two combinations of rollover conditions that substantially increased injury risk (Digges, 2006). The first combination was an impact with a fixed or non-fixed object prior to rollover in which severe damage was recorded. The second condition was rollovers that are arrested during the first quarter-turn by an impact with a fixed or non-fixed object.

Table 1 shows groupings of rollover conditions that illustrate how risk varies for different combinations. The columns in the Table are labeled “Roll 1st”, “Obj 1st”, and “Total”. Roll 1st includes all rollovers in which the rollover occurs first, including those with subsequent impacts. Obj 1st refers to all rollovers that are preceded by an impact with fixed and non-fixed objects, including other vehicles. Total is the sum of the two other columns. The Table shows the distribution of MAIS 3+ injuries and the MAIS 3+ injury rate by damage severity.

A review of rollover cases in NASS found that frequently an impact before rollover could contribute to the cause of the rollover but was inconsequential with regard to the injuries from the initial impact (Eigen, 2004). However, when the initial impact caused severe damage it was more likely to contribute to the injury severity. In Table 1, the crashes with severe damage were separated from those with minor and moderate damage.

The data in Table 1, shows that the cells with "minor or moderate" damage have about the same injury rate for all rollover categories. For "Roll 1st" and "severe" damage, the injury risk is somewhat higher. For "Obj 1st" and "severe" damage the injury rate is much higher.

Earlier research has shown that the number of vehicle inversions is a good severity metric for belted occupants in rollovers when rollover is the first event (Digges, 2005). However, statistical significance was not achieved for this metric.

Table 1. Distribution of Injuries and Injury Rates for Belted Relevant Occupants in Rollovers by Vehicle Damage Severity and Characteristics of the Crash

	Distribution of MAIS 3+		
Damage Extent	Roll 1st	Obj 1st	Total
Minor & Moderate	28.2%	38.7%	66.8%
Severe	10.9%	22.3%	33.2%
Total	39.1%	60.9%	100.0%
	MAIS 3+/100 Exposed		
Damage Extent	Roll 1st	Obj 1st	Total
Minor & Moderate	2.34	2.88	2.63
Severe	3.39	10.26	6.16
Total	2.56	3.91	3.24

A series of chi square tests were performed to test the significance of the relationship between the number vehicle inversions and the occupant outcome. Occupants greater than 12 years, of any restraint status, with known injury severity, MAIS zero through six, were considered as the baseline case. Three rollover classes were tested: (1) baseline, (2) all rollovers with severe damage extent excluded, (3) non-fixed or fixed object prior to the rollover crash but with severe damage cases excluded.

P-values less than 0.05 were considered statistically significant. The analysis was done using SUDAAN. For the various rollover classes, p-values were produced via chi-square test for occupant injury severity and vehicle inversions. Occupant injury severity indicated presence of MAIS 3+F injury or not. The vehicle inversions was considered in two ways. Vehicle inversion either included the one quarter turn and classified them as zero vehicle inversion or omitted the first quarter turn and started the classification at one vehicle inversion. Selected significant relationships have been included in Table 2.

Table 2. Sample Size and p-values for Test Populations that Produced Statistical Significance for the Number of Vehicle Inversions

Roll Class	Restrictions	Raw	Weighted	p-value
Baseline		7,313	2,693,082	0.0103
Object 1st & Roll 1st	No Severe Damage	4,320	2,062,151	0.0103
Object 1st -Only	No Severe Damage	2,838	1,021,567	0.0220

BODY REGIONS AND HARM DISTRIBUTION:

Table 3 shows the distribution of MAIS 3+ HARM by body region. HARM provides a metric for both the frequency and severity of injuries. When multiple injuries are recorded for an occupant, all injuries above the AIS 3 level are included in the calculation. HARM is calculated by multiplying each weighted AIS 3+ injury by a factor that is proportional to the average cost of an injury of the same severity. The HARM factors are: AIS 3-98,011 AIS 4-211,494, AIS 5-697,533 and AIS 6-822,328. The factors are from a publication from NHTSA (NHTSA 2001)

Table 3. Distribution of AIS 3+ HARM in Baseline Rollover Crashes by Body Region and Rollover Grouping

Roll Grouping	Head	Trunk	Other	Total
Roll 1st, Min & Mod	8%	9%	1%	18%
Roll 1st, Severe	8%	4%	1%	13%
Obj 1st, Min & Mod	12%	13%	10%	35%
Obj 1st, Severe	12%	14%	9%	35%
Total	40%	39%	21%	100%

DISCUSSION

Table 1 shows that the highest injury rate is the cell – "severe damage and object struck before rollover". The other cells have much lower injury rates. This high rate suggests that the planar crash that occurred before rollover may have influenced the injury severity. For the cells with "minor and moderate damage" the injury rates are generally similar for both types of rollovers – Roll 1st and Obj 1st. Consequently, the use of damage severity may not be a necessary component of a rollover severity metric for these groups of rollovers. By exclusion the severe damage conditions above, statistically significant relationships between number of roof inversions and injury rate were achieved for all groups of rollovers and for rollovers preceded by impacts with fixed and non-fixed objects.

About 61% of the MAIS 3+ injuries and 70% of the AIS 3+ HARM occurs in rollovers that are preceded by an impact with a fixed or non-fixed object. It is interesting to note that 22.3% of the population with MAIS 3+ injuries were in the Obj. 1st, severe damage category. However, this population is more likely to have multiple injuries and more severe injuries as noted by the 35% HARM fraction associated with this group.

The HARM distribution between the head and trunk was about equal for all damage severities. The HARM to the "other" body regions was largest in Obj 1st rollovers.

CONCLUSIONS

The vehicle planar damage data collected in NASS/CDS rollover cases since 1995 is very useful in assessing the degree to which planar crashes add risk to rollovers. The NASS characterization of damage severity permits the separation of rollovers into categories that carry higher injury risks than would be expected from the rollover alone.

Rollover was the first event in 39% of the rollover crashes with belted occupants and MAIS 3+ injuries. The remaining 61% of the MAIS 3+ injuries were in rollovers where an impact with a fixed or non-fixed object was the first event. Rollovers with severe damage that were preceded by an impact with a fixed or non-fixed object accounted for 23.3% of the MAIS 3+ injured. The injury rate for these rollovers was three times higher than for the other groups.

The HARM to the head and trunk was about equal for all damage severities and each constituted about 40% of the total.

For belted occupant involved in rollover crashes, the relationship between occupant injury outcome and vehicle inversions was found to be significant When higher injury risk cases with severe damage were removed, chi square tests showed significance of the relationship between the number vehicle inversions and the occupant outcome.

REFERENCES

Digges, K., and Eigen, A., Classification of Rollovers According to Crash Severity Proceedings of AAAM, 2006.

Digges, K., and Eigen, A, "Severity Measurements for Rollover Crashes", IRCOBI, Prague, 2005.

Eigen, A, "Characterization of Attributes Applicable to a Rollover Severity Metric", Dissertation, The George Washington University, Ashburn, Virginia 2004.

NHTSA, "1995-1997 National Automotive Sampling System" DOT HS 809 203, Feb 2001, page 152.