An Improved Occupant Injury Severity Model for Rollover Crashes to Account for Advances in Ejection Mitigation

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I. INTRODUCTION

In 2019, 6,291 occupants of a passenger vehicle were fatally injured in a rollover crash accounting for 28% of all fatalities among passenger vehicle occupants [1]. Electronic Stability Control (ESC) is effective at preventing rollover crashes and has been shown to reduce first-event rollover crashes by 60% in passenger cars and by 74% in light trucks and vans (LTVs) [2]. This indicates that roughly one-third of first-event rollover crashes still occur. The development of a detailed injury model is therefore still important in predicting occupant injury from a rollover crash. Unlike planar crashes, a severity indicator, such as delta-v, does not exist in rollover crashes, making them difficult to characterize. As many factors contribute to injuries during a rollover, sometimes a seemingly severe rollover crash may result in only minor injuries. Ejection is a key contributor to occupant injury, although not every fatally injured occupant is ejected from the vehicle. The purpose of this study was to develop an ejection and injury prediction model for occupants in rollover crashes.

II. METHODS

Real-world rollover crashes were selected from the National Automotive Sampling System Crashworthiness Data System (NASS/CDS) database [3]. Every case in NASS/CDS is assigned a weight to represent the total number of similar crashes that occurred in the USA during that case year. The roof strength to weight ratio (SWR) for each vehicle was obtained from either the NHTSA Component Test Database or the IIHS Vehicle Ratings Dataset. The vehicle roof SWR is defined as the maximum force within the first 127 mm of roof deformation divided by the unloaded weight of the vehicle. The NHTSA Component Test Database follows the FMVSS 216 test procedure, which prescribes moving a rigid, unyielding test block at a rate of 13 mm/s to a maximum displacement of 127 mm [4]. IIHS measures the roof SWR following the same test procedures except the test block displacement is limited to 5 mm/s [5]. For vehicles with IIHS and NHTSA SWR measurements, the IIHS value was used since they represented the majority of the matched SWRs. The roof SWR was considered constant between corporate twins and the model years between component tests.

This study analysed rollover crashes within NASS/CDS case years 2006 to 2015. Cases with a case weight greater than 5,000 were removed from the case set [6]. To isolate injuries caused by the rollover, only pure rollovers were investigated. A pure rollover met the following criteria [7]: (1) the first event was a rollover or all events prior to the rollover must be contact with either a curb, the ground, a fence, a bush or shrub, or an object that fell from a vehicle; and (2) the rollover was the last event in the crash. This study only analysed drivers and right front passengers who were at least 12 years old.

A logistic regression model was constructed using the NASS/CDS sampling scheme to predict the probability of an occupant sustaining a moderate to fatal injury (MAIS2+F) according to the abbreviated injury scale (AIS). The covariates considered included occupant belt use, the number of half-turns, side airbag deployment, roof SWR, roll direction (near-side or far-side), occupant seat position, vehicle type, occupant age, occupant body-mass index, and the probability of ejection. Only statistically significant covariates ($p < 0.5$) were retained in the final model. The probability of ejection was estimated using a separate logistic regression model. Within the dataset, less than 0.1% of occupants were belted and ejected from the vehicle during a rollover. Therefore, we assumed that the probability of ejection was zero for belted occupants.

III. INITIAL FINDINGS

The logistic regression model for ejection was developed using the 89 unbelted front-seat occupants (Table I). Near-side rollover crashes and vehicles with higher roof SWR reduced the likelihood of occupant ejection. The

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logistic regression model for MAIS2+F injury was computed using the records of 395 drivers and right-front passengers (Table II). Occupants with a greater risk of being ejected from the vehicle were much more likely to sustain an MAIS2+F injury. The more vehicle rollover half-turns, the greater the risk of occupant injury. Occupants of light trucks were at an increased risk of injury compared to other passenger vehicle types for rollovers with less than three half-turns.

TABLE I
LOGISTIC REGRESSION FOR PROBABILITY OF EJECTION

	Estimate	Std. Error	p-value
Intercept	1.785	1.563	-
Far-side Rollover	2.817	0.691	0.006
Roof SWR	-1.581	0.546	<0.001

TABLE II
LOGISTIC REGRESSION FOR PROBABILITY OF A MAIS2+F INJURY

	Estimate	Std. Error	p-value
Intercept	-5.976	0.765	-
Age	0.031	0.011	0.006
Ejection Probability	4.557	0.947	<0.001
Half-Turns	1.047	0.228	<0.001
Light Truck	2.843	0.770	<0.001
Obese	1.054	0.466	0.026
Half-Turns: Light Truck	-0.985	0.257	<0.001

IV. DISCUSSION

Many of the passive safety systems for rollover events are designed to prevent the occupant from being ejected from the vehicle. Within the dataset, ejected occupants almost always sustained an MAIS2+F injury. Belt use was the most significant factor in predicting ejection, which agrees with Funk *et al.* [8]. Our study used roof SWR as a predictor of ejection since a stronger roof should prevent ejection paths from opening. In agreement with Funk *et al*., occupants in a far-side rollover were more likely to be ejected from the vehicle. Unlike our model, the Funk *et al.* injury model [9] and Flannagan [10] used ejection and belt use as a predictor of injury. Instead, we constructed a separate ejection model to account for seat belts, roof SWR, and side curtain airbags, which aim to prevent occupant ejection. This better reflects the injury prevention mechanism of seat belts and stronger roofs without any interaction between covariates. This is the first model that we are aware of to predict occupant injury during a rollover event that is based solely on the occupant, vehicle and rollover characteristics.

V. REFERENCES

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