ACCURACY OF WINSMASH IN REAR CRASHES USING EVENT DATA RECORDERS

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ABSTRACT

Vehicle change in velocity, often referred to as delta-V, is a widely used measure of crash severity. The National Highway Traffic Safety Administration (NHTSA) uses the WinSMASH computer code to estimate delta-V in several of its in-depth crash databases. This study examined the accuracy of WinSMASH longitudinal delta-V estimates in 140 rear crashes by comparison with direct measurements of delta-V recorded by EDRs. In the entire dataset, WinSMASH longitudinal delta-V was 4.5% lower on average than the delta-V based on direct measurements of acceleration from EDRs.

WinSMASH accuracy varied widely by the degree of overlap. WinSMASH was only 2% lower than EDRs in full engagement rear crashes, but 18-22 % lower in small and moderate overlap rear crashes. WinSMASH accuracy appears to be a function of struck vehicle type. WinSMASH delta-V estimates were only 3-4% lower for rear-struck LTVS, but were 10% lower than EDRs for passenger cars. The lower accuracy of WinSMASH car delta-V estimates did not appear to be the result of LTV-to-car or car-to-LTV structural incompatibilities. The lowest agreement between WinSMASH and EDRs occurred in car-to-car crashes.

This paper is the first of a kind assessment of rear-struck vehicle delta-V reconstruction accuracy when using energy-based methods, e.g. WinSMASH. In our dataset, WinSMASH delta-V estimates were within 5% of EDR recorded direct measurements. However, this level of accuracy was unevenly distributed across both crash overlap and struck vehicle type, and suggests opportunities for further improvements in WinSMASH accuracy.

INTRODUCTION

Vehicle change in velocity, often referred to as delta-V, is a widely used measure of crash severity. The National Highway Traffic Safety Administration (NHTSA) uses the WinSMASH computer code to estimate delta-V in several of its in-depth crash databases including the National Automotive Sampling System Crashworthiness Data System (NASS CDS), the newer Crash Investigation Sampling System (CISS), the Crash Injury Research and Engineering Network (CIREN) study, and the NHTSA Special Crash Investigations (SCI) study. WinSMASH estimates of delta-V are based on post-crash vehicle deformation measured by crash investigators, and vehicle stiffness values derived from staged crash tests [Sharma et al, 2007].

WinSMASH stiffness values in rear crashes are obtained from NHTSA's FMVSS No. 301 Fuel System Integrity compliance tests. Prior to model year (MY) 2007, the Federal Motor Vehicle Safety Standard (FMVSS) No. 301 test consisted of a 1814 kg (4000 lbs) movable rigid impactor which struck the rear of the subject vehicle at 48 km/hr (30 mph). The impact involved full engagement of the rear of the subject vehicle. In December 2003, NHTSA amended FMVSS No. 301 to increase the severity of the test [68 FR 67068]. Phase-in of the higher-severity FMVSS rear crash test occurred from MY 2007 to MY 2009. The upgraded FMVSS No. 301 rear crash test requires striking the rear of the subject vehicle at 80 km/h (50 mph) with a 1,368 kg (3,015 lbs) moving deformable barrier at a 70% overlap with the subject vehicle.

Previous studies have used Event Data Recorders (EDRs) to investigate the accuracy of WinSMASH in both frontal and side collisions [Niehoff and Gabler, 2006, Hampton and Gabler, 2009, 2010; Johnson and Gabler, 2014]. However, the accuracy of WinSMASH in rear crashes has never been examined using EDRs. The earliest generation of EDRs, introduced by General Motors Company (GM) in MY 1995, only recorded longitudinal delta-V when the vehicle was struck in the front. Beginning in MY 2004, GM EDRs began to record longitudinal delta-V as well when struck in the rear. This practice of recording delta-V in rear crashes has since also been implemented by several other automakers. The availability of EDR delta-V measurements in rear crashes provides a unique opportunity to examine the accuracy of WinSMASH in rear crashes.

OBJECTIVE

The objective of this study is to determine the accuracy of WinSMASH delta-V estimates in rear crashes.

APPROACH

The study was based upon cases extracted from NASS CDS 2006-2015 involving rear-struck vehicles with EDR downloads. The study examined all EDRs imaged in NASS CDS from 2000-2015. However, there were no EDRs in our dataset which recorded rear crashes prior to MY 2004, and no cases from NASS CDS earlier than NASS CDS 2006.

Cases included in the study were restricted to collisions in which the most harmful event for the subject was a rear impact. In this study, a rear impact was defined to be a crash in which the general area of damage was to the rear plane of the vehicle. Collisions were included in which the rear crash was the only event, or a two-event crash in which a rear impact was followed by a frontal impact, or a two-event crash in which a frontal impact was followed by a rear impact. Rollovers were excluded. Any case involving a side impact was excluded as the longitudinal component of a side crash pulse could potentially be misinterpreted as a frontal or rear crash pulse depending on the sign of the delta-V.

The data from all EDRs were examined to ensure that delta-V was completely recorded. In previous studies which analyzed the accuracy of EDRs in frontal crash tests, the longitudinal delta-V recorded by EDRs has been shown to be, on average, within 6-7% of the delta-V computed from crash test instrumentation [Niehoff et al, 2005; Tsoi et al, 2013]. In the current study, the longitudinal delta-V recorded by the EDR in each case was compared with the WinSMASH longitudinal delta-V coded in NASS CDS. The difference between WinSMASH and EDR delta-V was examined as a function of percent overlap, (i.e. small overlap, moderate overlap, or full engagement), struck vehicle body type, striking-struck vehicle pairing, and the reconstruction algorithm, e.g., the missing vehicle algorithm. Struck vehicle body type was categorized as either a car or LTV (light truck or van). LTVs included pickup trucks, sport utility vehicles (SUVs), minivans, and full-sized vans.

Crash mode was based on the specific horizontal damage location (SAE J224, 1980). As illustrated in Figure 1, the specific horizontal location divides the struck plane of the vehicle into 3 approximately equal regions. A small overlap was defined as an impact to the “L” or “R” region of the rear of the struck vehicle, or approximately 1/3 engagement. A moderate overlap was defined as an impact to the “Y” or “Z” region of the rear of the struck vehicle, or roughly 2/3 engagement. Finally, a full engagement impact was defined as an impact to the “D” region. Note that the upgraded FMVSS No. 301 rear test corresponds approximately to the moderate overlap crash mode under this definition.

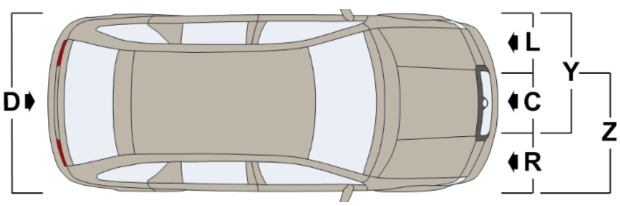

Figure 1. Definition of Specific Horizontal Damage Location

RESULTS

Composition of Data Set
The resulting dataset contained EDR downloads from 140 rear-struck vehicles. Table 1~~Table 1~~ presents the composition of the dataset by vehicle make, model year, crash mode, struck vehicle type, WinSMASH reconstruction method, the presence of potential structural mismatch both in terms of car vs. LTV collision pairing and override assessment by the crash investigator.

Most crashes involved full structural engagement, i.e. in which the damage to the struck vehicle was distributed across the entire rear of the vehicle. Over half of the EDRs in our sample were from GM vehicles. This is because GM was the first automaker to widely deploy EDRs in their vehicles. Most cases (68%) in the dataset were MY2009 or later, and would have been subject to the revised FMVSS 301. Over 2/3 of the struck vehicles were cars. Investigators performed a large fraction (42%) of the WinSMASH estimates based only on crash damage estimates from one vehicle i.e. the missing vehicle algorithm. Nearly half of all collisions were car-to-LTV or LTV-to-car collisions with the potential for mismatch of structural frame elements. However, investigators only explicitly noted one case of structural override. In this case, a 2003 GMC Sonoma pickup truck struck the rear of a 2004 Chevrolet Malibu.

Table 1. Composition of the Dataset

	Number of Cases	% Cases
All Vehicle Cases	140	100%
Vehicle Make		
Chrysler	12	9%
Ford	19	14%
GM	73	52%
Toyota	36	26%
Model Year		
2004	2	1%
2005	8	6%
2006	10	7%
2007	14	10%
2008	11	8%
2009	13	9%
2010	12	9%
2011	27	19%
2012	14	10%
2013	18	13%
2014	8	6%
2015	3	2%
Crash Mode		
Distributed(Full Engagement)	75	54%
Moderate Overlap	34	24%
Small Overlap	21	15%
Unknown	10	7%
Struck Vehicle Type		
Car	91	65%
LTV	49	35%
Collision Pairing		
Car->Car	51	36%
Car->LTV	26	19%
LTV->Car	40	29%
LTV->LTV	23	16%
Override/Underride		
None	133	95%
Override	1	1%
Unknown	6	4%
WinSMASH Algorithm		
Crash Damage of Both Vehicles Known	81	58%
Missing Vehicle Algorithm	59	42%

Comparison of WinSMASH and EDR delta-V

Figure 2 compares the longitudinal delta-V recorded by the EDR and the corresponding WinSMASH longitudinal delta-V estimate for each case. Points on the solid diagonal line represent cases in which there was perfect agreement between the EDR and WinSMASH. The dashed line is a linear regression fit to the data with the intercept set to zero. On average, the WinSMASH delta-V was less than 5% (4.5%) below the EDR recorded delta-V. However, there was a substantial amount of dispersion about the fit.

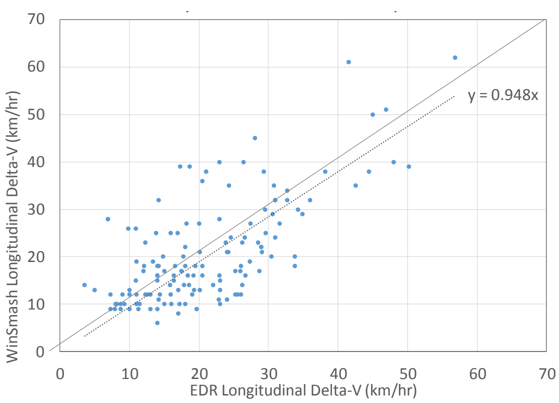

Figure 2. Overall Comparison of EDR and WinSMASH Delta-V

Figure 3 examines whether WinSMASH accuracy may be affected by the degree of structural engagement. As described earlier in this paper, the study considered three different levels of structural engagement, i.e. full engagement, moderate overlap, and small overlap. In full engagement crashes, in which crash damage was distributed across the entire rear plane of the struck vehicle, WinSMASH delta-V on average was only 2% lower than the EDR recording. In contrast, in moderate overlap, WinSMASH underestimated longitudinal delta-V by nearly 20% (18.5%). Similarly, in small overlap cases, WinSMASH underestimated EDR delta-V by 22%. This finding is consistent with the manner in which WinSMASH stiffness coefficients were computed. The WinSMASH stiffness coefficients were developed from the older full-engagement FMVSS No. 301 rear crash tests. This result indicates that WinSMASH may be less accurate as the crash diverges further away from the test mode used to develop the stiffness coefficients.

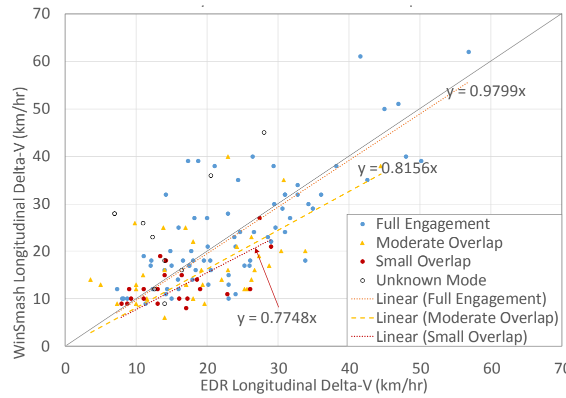

Figure 3. EDR vs. WinSMASH Delta-V as a function of Crash Mode

Figure 4 indicates that WinSMASH accuracy is a function of struck vehicle type. The sample in this figure has been divided into a set of struck cars and struck LTVs. In our dataset, WinSMASH overestimates longitudinal delta-V for rear struck LTVs by only 3-4%. However, WinSMASH underestimates delta-V for cars by nearly 10%. Figure 4 also shows that the delta-Vs of cars were much larger in general than the delta-Vs of LTVs. With only one exception, all LTV delta-Vs were below 31 km/hr. In contrast, over 20% of the car delta-Vs (19 of 91 cases) were over 31 km/hr.

Higher delta-V crashes would involve large deformations which may be beyond the deformation observed in FMVSS No. 301 tests from which the stiffness coefficients were derived. The average maximum crush observed in crash tests was 38 cm for cars and 28 cm for LTVs. The average delta-v in crash tests was 27 km/hr (17 mph) and 24 km/hr (15 mph) for cars and LTVs, respectively.

The higher delta-Vs of struck cars could be due to a mismatch in mass between cars and their collision partners. The higher car delta-Vs in car-to-LTV impacts are consistent with the fact that cars are on average lighter than LTVs, and would likewise have a higher delta-V on average. Note however that these higher delta-V values could also occur if cars were being struck at a higher speed than were LTVs. However, it is not obvious why rear-struck cars might experience a higher impact speed than LTVs.

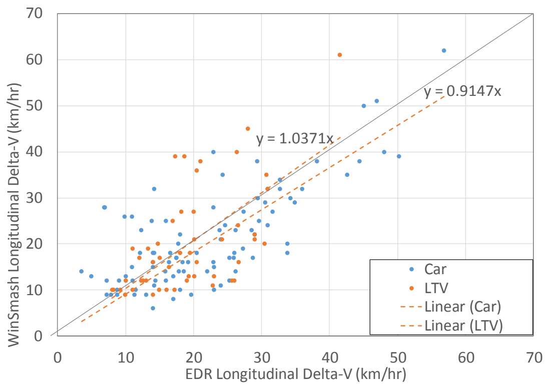

Figure 4. EDR vs. WinSMASH Delta-V as a function of Struck Vehicle Type

One possible explanation for the difference in accuracy is that in collisions between cars and LTVs there can be a mismatch between the height of the front and rear structures of these vehicles. These geometric mismatches can lead to one vehicle overriding or underriding the collision partner. As the FMVSS No. 301 tests do not involve override/underride, the associated stiffness values derived from these tests may not properly characterize the actual stiffness in a real world crash.

Figure 5~~Figure 5~~ examines WinSMASH accuracy as a function of collision partner pairing. Interestingly, WinSMASH exhibits the worst underestimation of delta-V (12%) in car-to-car crashes. Car-to-car impacts should be the collisions with the best geometric compatibility, but exhibit the highest WinSMASH inaccuracy. In contrast, WinSMASH underestimated car-to-LTV struck vehicle delta-V by only 4%, and underestimated LTV-to-car struck vehicle delta-V by only 5%. In our dataset, structural incompatibility did not appear to be a major factor in WinSMASH accuracy.

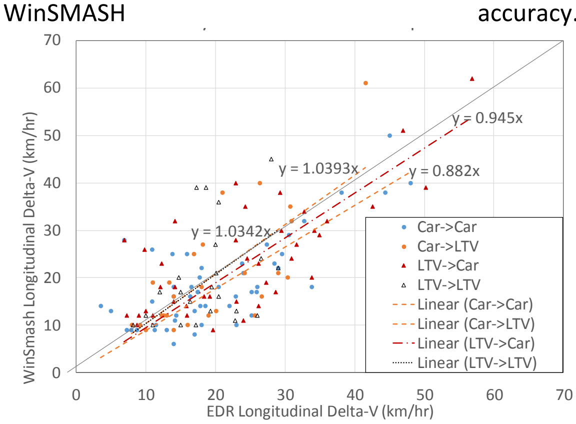

Figure 5. EDR vs. WinSMASH Delta-V as a function of Collision Partner Pairing

Figure 6 examines the accuracy of WinSMASH as a function of the WinSMASH algorithm used in the reconstruction. WinSMASH computes delta-V based upon post-crash deformation measurements. Ideally, the post-crash measurements are available for both vehicles. In some cases, however, crush measurements are only available for one of the vehicles. In these cases, investigators can use the WinSMASH missing vehicle algorithm to estimate delta-V [Prasad, 1991]. In our dataset, investigators used the missing vehicle algorithm in 42% of cases. With less information, the missing vehicle algorithm would be expected to provide a less accurate estimate. However, in our dataset the missing vehicle algorithm overestimated delta-V by only 1.6%. In contrast, when crash damage measurements from both vehicles were available, WinSMASH underestimated delta-V by nearly 10%.

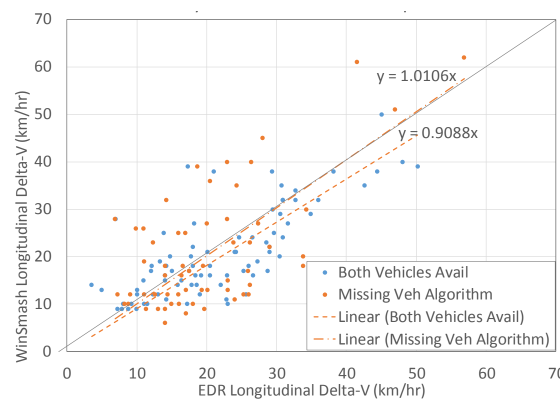

Figure 6. EDR vs. WinSMASH Delta-V as a function of WinSMASH algorithm

Limitations

Older full engagement FMVSS No. 301 tests were the basis for many of the WinSMASH stiffness values and may explain the higher accuracy in full engagement. FMVSS No. 301 tests conducted to the recent test upgrade are moderate overlap tests, and collection of this stiffness data should improve WinSMASH accuracy in the future. The conclusions of this study are limited by the small dataset and the study should be revisited when additional EDRs from rear-struck vehicles are available.

WinSMASH only calculates the delta-V up to the point of maximum crush ignoring the restitution effects. The EDR delta-V is the total delta-V at separation which includes restitution. Therefore, some difference is expected between the WinSMASH estimates and EDR delta-V.

CONCLUSION

This study has examined the accuracy of WinSMASH longitudinal delta-V estimates in 140 rear crashes by comparison with direct measurements of delta-V recorded by EDRs. In the entire dataset, WinSMASH longitudinal delta-V was 4.5% lower on average than the delta-V based on direct measurements of acceleration from EDRs.

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