Introduction and Initial Analysis of New Side Impact Variables Captured in NHTSA Crash Databases

Mark Scarboro
Rodney Rudd
National Highway Traffic Safety Administration
U.S. Department of Transportation
Washington, D.C., USA

Paper Number 11-0371

ABSTRACT

Long-term data systems typically need to evolve to keep pace with changing elements in the data environment. The crash data systems developed and maintained by the National Highway Traffic Safety Administration (NHTSA) are not immune to such demands. Changes in the system may be driven by known fleet changes such as the need to expand air bag definitions when additional side and knee air bags were introduced into the fleet several years ago. Changes in the data capture may also arise from issues discovered during research. Prior to the 2008 data year NHTSA crash data systems lacked coding that would identify possible compatibility issues related to side impact configurations.

Beginning in 2008, NHTSA adopted new investigation protocols and data elements to improve the documentation of the aspects of a crash that aid in identifying compatibility issues and bear on the resolution of injury causation scenarios that occur in multivehicle crashes involving the interaction of the frontal-plane of one collision partner with the side-plane of the passenger compartment of the other. The new variables include damage measurements that are designed to enhance the research with respect to door intrusions, by documenting external damage to structures indicating the extent of override/underride in crashes where vehicle compatibility maybe an issue. This paper will review the case data that has been amassed in the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and the Crash Investigation Research and Engineering Network (CIREN) programs for side impact cases where the new techniques and data have been captured. Utilizing the data sets from NASS 2008 in conjunction with CIREN data (2008-10) 524 cases were extracted that indicated capture of the new variables.

This paper will explore the development of a correlation between the new side impact variables collected in NASS-CDS and CIREN and crash severity. The new side impact variables are expected to perform as desired by indicating crash severity and potential for injury causation. The new variables cover a wide array of issues related to side impact crashes. Issues related to compatibility between struck and striking vehicles can be better assessed. The role of door intrusion relevant to pillar and rocker involvement can be pursued as well as using the variables as another metric for crash severity. Do the new side impact variables captured in the NASS-CDS and CIREN aid in the identification of compatibility issues and severity of side impact crashes?

This study was limited to the first year of NASS data and two years of CIREN data collection on the new variables. This paper describes new variables available to research crashes involving the frontal plane of one vehicle and the side plane of the struck vehicle.

INTRODUCTION

The subject of vehicle compatibility related to crashes is not a new research subject. However, a majority of the work to date has focused on frontal impacts. When larger, heavier vehicles impact smaller vehicles in the side plane, the higher front bumper frequently overrides the sill of smaller cars [IIHS, 2005]. The Insurance Institute for Highway Safety (IIHS) has established a side impact vehicle test that attempts to recreate the compatibility issues of mass and geometry. The IIHS side-impact test utilizes a moveable deformable barrier (MDB) that is designed to be taller and heavier than a typical passenger car. The MDB is designed to mimic the size and shape of a larger and heavier sport utility vehicle (SUV) [IIHS, 2008]. This type of rigorous testing keeps automotive manufacturers endeavoring to find new ways to improve the performance of their products and protect occupants. There is a statistically significant higher risk of a serious injury for the driver of a passenger car when struck on the nearside by a larger utility vehicle. The risk is 50% higher when the larger vehicle is a minivan and three times higher when the larger vehicle is a standard pick-up truck [Austin, 2005].

The laboratory continues to be a good venue for exploring the performance of vehicles in crashes, but performance in the real-world must also be examined. Not only must real-world crash performance be studied, it must be measured in a robust manner that returns valid and applicable data in order to support successful research. The data captured from real-world crashes must be continuously screened to ensure it is properly classifying and adequately describing the crash event(s). The entire crash, including the environment, vehicle(s), impact(s), and injury outcome, must be captured and recorded appropriately.

NHTSA developed new variables and protocols to better measure and describe impact damage severity when the frontal plane of one vehicle interacts with the side plane of another vehicle. The design of the new variables needed to be both appropriate for applicable research and feasible from a crash investigation point-of-view.

METHODS

The purpose of this paper is to introduce the new variables collected by NHTSA and also to conduct some initial analysis utilizing the new variables. This process will require a review of the definitions and methods for the new variables, which will be based on the NASS-CDS Coding Manual [NHTSA, 2009]. The analytical portion of this paper will be based on data extracted from the NASS-CDS and CIREN data repositories.

The NASS-CDS Coding Manual is a complete and thorough data manual on all the variables collected in the NASS-CDS system. The same manual applies to the Special Crash Investigation program (SCI) and the crash investigations performed by CIREN. The 2010 manual is over 1,200 pages in length, and contains a section for each variable captured, its attributes, technique for capture, SAS and ORACLE field name and also the name of the data table where the variable is stored. The process, procedure and definitions for the new side impact variables will be presented in summarized form, and the reader is asked to refer to the NASS-CDS manual for more information.

The extracted data was queried from both the NASS-CDS and CIREN repositories as of December 2010. The NASS-CDS data was queried for the initial year of new side impact variable availability, calendar year 2008. The CIREN data query covered all applicable cases up to the current year (2010) if the case had undergone multidisciplinary review and initial quality control. The exact inclusion and exclusion criteria will be discussed as part of the new variable review.

SIDE IMPACT DEFINITION

Since the new variables were designed for a certain type of side impact crash, it was necessary to properly define such crashes within the context of the current NASS-CDS investigation process and data architecture. At the highest level of the definition, the requirement for inclusion is that the crash must involve the case vehicle being struck in the right or left side plane by the frontal plane of another vehicle. The additional crash variables are collected only on the vehicle with side-plane damage. The next step of the inclusion requires use of the Collision Deformation Classification (CDC) [SAE, 1980]. The CDC is a uniform method used to document external sheet metal damage to a light passenger vehicle (see Figure 1). This classification is a fundamental variable in the NASS-CDS and CIREN crash investigation process. The next step in the definition utilizes the CDC to narrow the crash types down to only those impacts with direct damage to the occupant compartment by the striking vehicle. The direct damage in the side plane of the case vehicle must be in a zone classified by the CDC to include the passenger area or "P-zone" (see Figure 1). The zones included in the definition are D, P, Y and Z. Collection of the new variables in NASS-CDS, CIREN and SCI will only be conducted for vehicles meeting this definition.

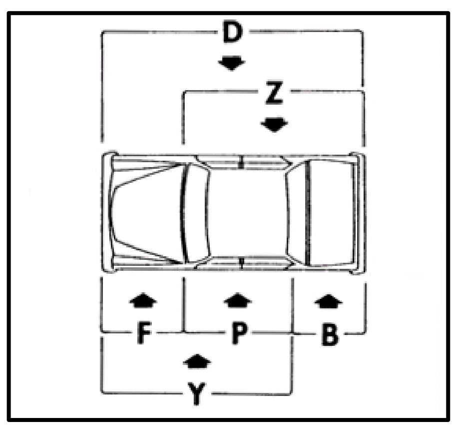

Figure 1: CDC zones for side impact crashes

NEW SIDE-IMPACT VARIABLES

To keep the task of collecting the new information manageable from a field investigation stand point, only four new variables were created. The new variables are Sill Height, Direct Damage to Pillars, Height of Max Door Crush and Door Sill Differential (DSD).

Sill Height: Sill height is a vertical measurement from the ground to the seam at the bottom edge of the door skin. This measurement should be taken at the B-pillar or as close as possible. Case vehicle inspection is the preferred source for this measurement. An exemplar vehicle or manufacturer specifications may be used if case vehicle inspection is not possible. Vehicles that have post-manufacturer modifications that affect the sill height, such as oversized tires, should not be measured and exemplar vehicles or manufacturer specifications are not substituted [NHTSA, 2009]. This variable aids in determining the structural geometry of the case vehicle. Figure 2 shows an example of sill height measurement.

Figure 2: Sill height measurement

Direct Damage to Pillar(s): This variable records the vehicle side pillar(s) that sustained direct damage from the impact of the striking vehicle. The variable is assessed visually by the crash investigator at the time of vehicle inspection [NHTSA, 2009]. This variable is intended to convey the extent of engagement the stiff vertical side structures of the case vehicle experienced.

Height of Max Door Crush: This is a vertical measurement from the ground to the area of maximum crush sustained in the "P-zone" [NHTSA, 2009]. This variable was designed to give researchers an indication of the frontal plane geometry of the impacting vehicle relative to the side plane geometry of the struck vehicle. The variable also allows researchers to analyze door structure damage (see Figure 3).

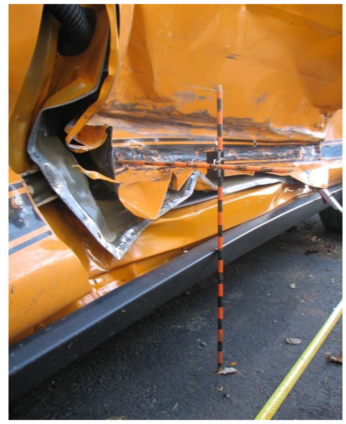

Figure 3: Height of Max Door Crush

Door Sill Differential (DSD): This variable is a post-crash lateral measurement of the difference between the sill or rocker panel level and the maximum crush in the "P-zone" [NHTSA, 2009]. This variable was designed to indicate the uniformity of crush in the side plane in the vertical direction of the case vehicle. A positive measurement indicates that the door has been crushed inboard beyond the outside edge of the sill or rocker panel. The DSD also serves as an indicator of override of the striking vehicle into the passenger compartment of the case vehicle (see Figures 4-6).

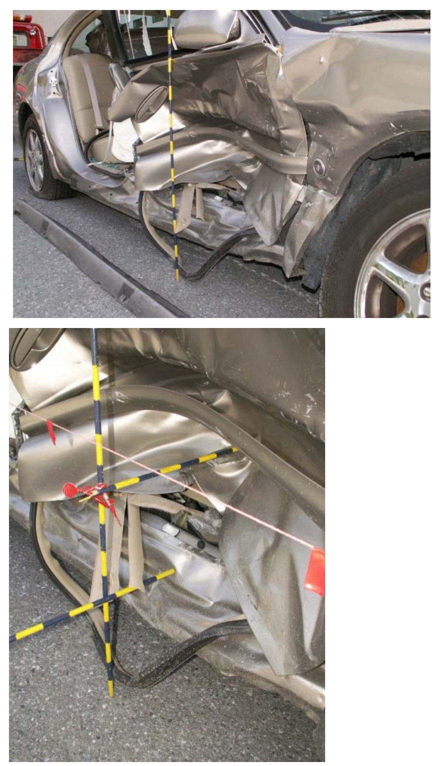

Figure 4: Door Sill Differential measurement

Figure 5: Uniform crush with a zero value for DSD

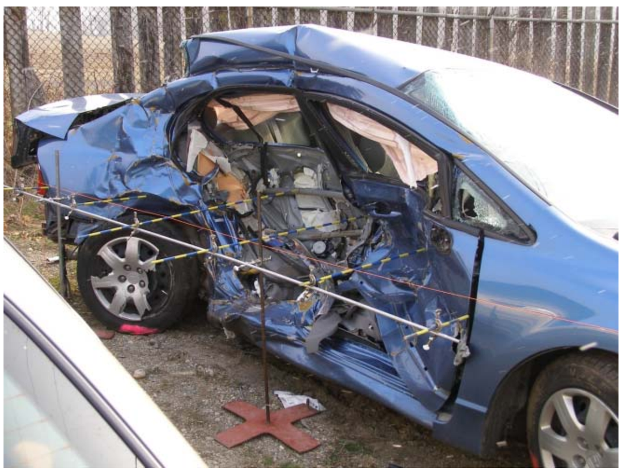

Figure 6: Vehicle exhibiting a large DSD

All of the new variables were designed to be easily integrated into the current NASS-CDS field investigation process.

RESULTS

The initial data extract captured 524 vehicles that were suitable for the analysis of the new side impact variables. The total occupant count for these vehicles was 702. After initial review of the data, seven vehicles were identified that needed to be removed from the dataset. One vehicle had the new side impact variables completed, but had been involved in a lateral crash with a tree. Another vehicle was removed due to being measured with oversized tires in place. The remaining five vehicles were removed due to recorded DSD appearing grossly in error when compared to images of the vehicle. The final data extract captured 517 case vehicles and 695 occupants. The model year breakdown of the case vehicles indicated in Figure 7, shows over seventy-five percent of the captured group were 1998 or newer.

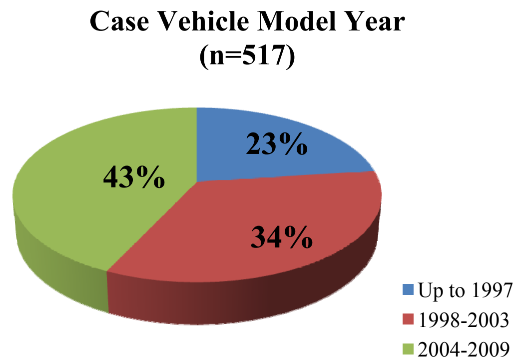

Figure 7: Case vehicle model year breakdown

For the purposes of this paper, the twelve different vehicle class categories utilized by NASS-CDS in this dataset were merged into three simpler categories. The revised classifications are passenger vehicles (PC), compact utility vehicles (CLTV) and large utility vehicles (LLTV). The details of the vehicle class merging are displayed in Table 1.

Table 1 – Revised Vehicle Class

NASS-CDS Vehicle Class	Revised Vehicle Class*
Subcompact/mini (wheelbase < 254 cm)	PC
Compact (wheelbase >=254 but < 265 cm)	PC
Intermediate (wheelbase >=265 but < 278 cm)	PC
Full size (wheelbase >=278 but < 291 cm)	PC
Largest (wheelbase >=291 cm)	PC
Minivan (<=4,536 kgs GVWR)	CLTV
Compact utility vehicle	CLTV
Compact pickup truck (<=4,536 kgs GVWR)	CLTV
Large van (<=4,536 kgs GVWR)	LLTV
Large utility vehicle (<=4,536 kgs GVWR)	LLTV
Large pickup truck (<=4,536 kgs GVWR)	LLTV
Utility station wagon (<=4,536 kgs GVWR)	LLTV
***-PC-Passenger Vehicle, CLTV-Compact Utility Vehicle, LLTV-Large Utility Vehicle**	

Table 2 displays an overview of the crash configurations for the entire dataset using the revised vehicle class. There were nine vehicles that were outside the scope of the revised vehicle class, such as a semi tractor-trailer, and were labeled as unknown. Seventy-one percent of the applicable crashes involved a PC as the struck vehicle. The majority of those were struck by either a CLTV or LLTV. The 367 crashes where the case vehicle (struck vehicle) was a PC will be the primary focus for the remainder of this paper.

Table 2: Crash configurations (all cases)

Case Vehicle Class	Striking Vehicle Class	N=517	%
PC	PC	179	35
PC	CLTV	105	20
PC	LLTV	83	16
CLTV	PC	58	11
CLTV	CLTV	31	6
CLTV	LLTV	23	4
LLTV	PC	16	3
LLTV	CLTV	9	2
LLTV	LLTV	4	1
Unknown		9	2

It should be noted that the model year breakdown for the dataset of crashes where the PC was struck in the side plane mimicked the larger group as depicted in Figure 7. Twenty four percent were model year 1997 or older, thirty two percent were model year 1998 to 2003 and forty four percent were model year 2004 to 2009.

The mass ratio (striking vehicle curb weight/case vehicle curb weight) between the crash partners was explored to establish if the majority of the CLTV and LLTV striking vehicles were indeed heavier than the case vehicle (PC). As indicated in Figure 8, the CLTV crashes indicated greater than 1:1 mass ratio in more than eighty percent of the cases. Large LTV crashes indicated a ratio greater than 1:1 more than ninety-five percent of the time.

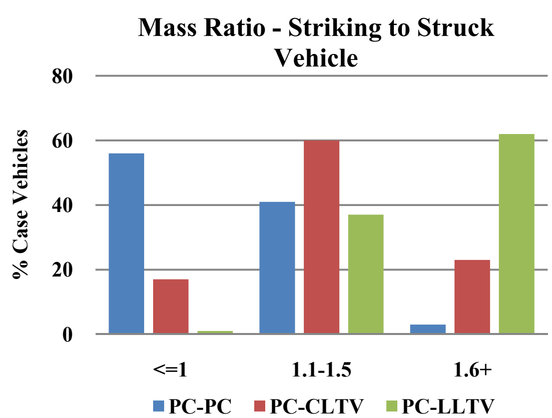

Figure 8: Mass ratio for PC cases

Since geometry is also a key component for compatibility, we wanted to evaluate the bumper height of the striking vehicle for the three different crash configurations. The results of the average bumper height comparison are indicated in Figure 9. Although there is an increase in bumper height as vehicle class goes from PC to LLTV, the difference is minor. The striking vehicle bumper height data is surprising, since the difference in mean height between a striking PC and LLTV is only 1.5 cm. However, it should be noted that the missing data rate for this variable was as high as 33% (in the LLTV group), which could result in inaccurate mean measurements for a vehicle class.

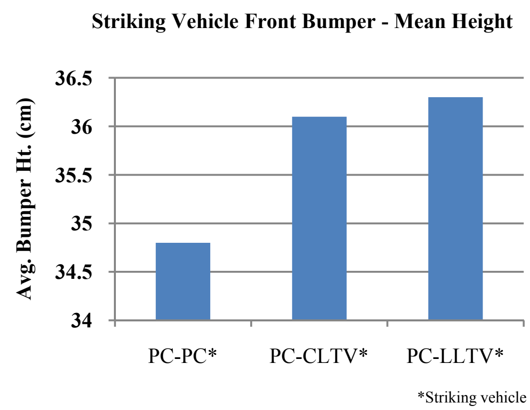

Figure 9: Striking vehicle bumper height

The principal direction of force (PDOF) was evaluated to determine the angle of impact for all crashes. The percent of crashes are plotted by the PDOF of the case vehicle in Figure 10. Using 90° +/- 10° for right side impact impacts and 270° +/- 10° for left side impacts, we discovered that less than thirty percent of the crashes in any combination were at or near a perpendicular impact. The majority of the study case vehicles experienced a PDOF with some amount of obliquity.

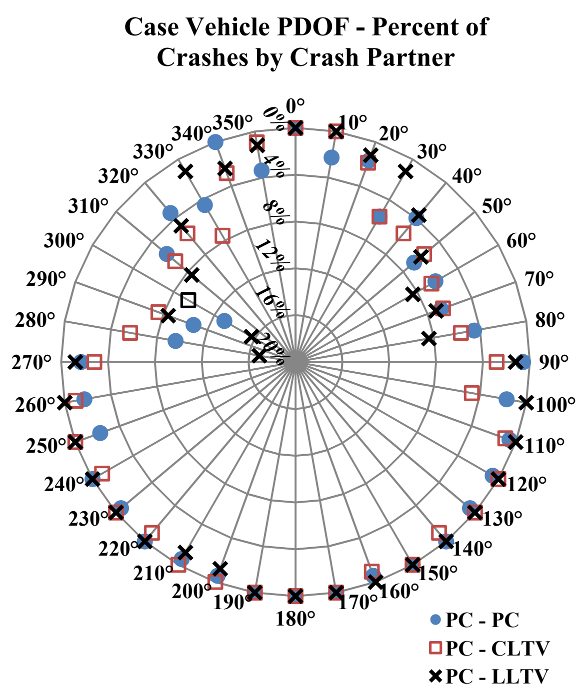

Figure 10: Case vehicle PDOF

Table 4 shows a summary of the new variables from the captured dataset where the vehicle being laterally impacted was a PC. The table also includes the delta-V data for the population as calculated by the Winsmash algorithm. Delta-V has long been a standard metric for crash severity. The mean delta-V in this dataset increases in magnitude as the mass, and possibly even stiffness, of the striking vehicle increases with the categories of CLTV and LLTV. There is a 9 kph difference between the mean delta-V in the PC/PC crash and the PC/LLTV crash. The mean sill height for the struck vehicle (PC) in the different crash partner configurations varies less than 1 cm, which lends additional confidence to the measurement techniques developed and utilized in the field. The mean height of maximum door crush increases as the striking vehicle transitions from PC to CLTV to LLTV, with the LLTV mean value being over 4 cm higher than that of a PC. The mean DSD in each group follows a similar trend, with PC/LLTV crashes having a mean DSD that is 8.2 cm larger than that for the PC/PC impacts. This data review also indicates a more than satisfactory capture rate for the new variables by researchers in the field. The worst missing rate for capture in the field of the new variables is only 4% (sill height of PC vehicles in CLTV crashes).

Figure 11 shows the relationship of the mean DSD and the mean height of maximum door crush for each crash configuration. This relationship indicates increasing override into the door, and increasing height of damage, as the class of striking vehicle grows. This is another indicator that the new variables are doing a good job of identifying cases where side sill override is occurring and generating encroachment on the passenger compartment of the struck vehicle.

Table 4 – Summary data on new side-impact variables

Crash Type	**PC/ PC (n=179)**		**PC/CLTV (n=105)**		**PC/LLTV (n=83)**	
Sill Height (cm)	Missing n=5		Missing n=4		Missing n=0	
	Min	7	Min	10	Min	15
	Max	37	Max	37	Max	38
	Mean	25.5	Mean	25.8	Mean	26.2
Height of Max Door Crush (cm)	Missing n=4		Missing n=2		Missing n=2	
	Min	19	Min	17	Min	14
	Max	81	Max	89	Max	84
	Mean	48.3	Mean	50.1	Mean	52.6
DSD (cm)	Missing n=0		Missing n=0		Missing n=0	
	Min	0	Min	0	Min	0
	Max	60	Max	55	Max	101
	Mean	13.1	Mean	18.6	Mean	21.3
Delta-V * (kph)	Missing n=14		Missing n=7		Missing n=7	
	Min	5	Min	6	Min	6
	Max	65	Max	72	Max	83
	Mean	26.6	Mean	32.3	Mean	35.6

*- Winsmash derived

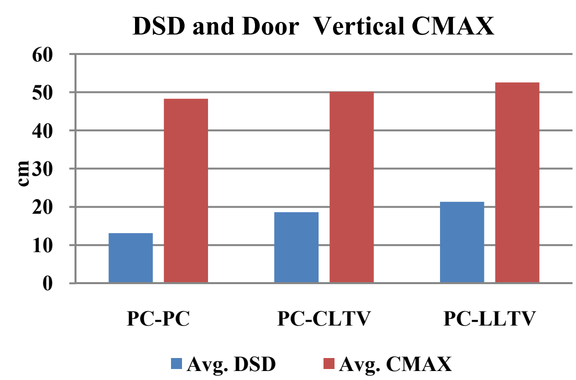

Figure 11: DSD and Height of Max Door Crush

The last variable of the new set we reviewed was the Direct Damage to Pillars variable. The initial expectation of this variable was to be a good inverse-correlate for DSD. We made the assumption that increasing the direct damage associated with the vertical structures would increase the effective stiffness for the side plane and potentially result in a decrease in the DSD and crush values. However, the data did not support our initial theory. Figure 12 indicates that as the number of pillars that are directly contacted by the striking vehicle increases, the DSD, on average increases, as well.

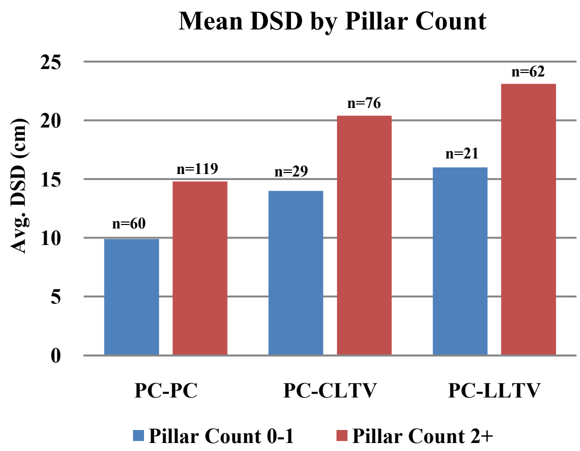

Figure 12: Direct pillar contact and mean DSD

Since the pillar count to DSD correlation finding was in contrast with the expected outcome, we reviewed the crash severity for each of the pillar count groups. The average delta-v for all of the crash partner groupings, where it was known, was higher for all pillar damage counts of two and greater as displayed in Figure 13. Therefore, it can be ascertained that the higher DSD results in the two plus pillar group are likely related to the crash severity.

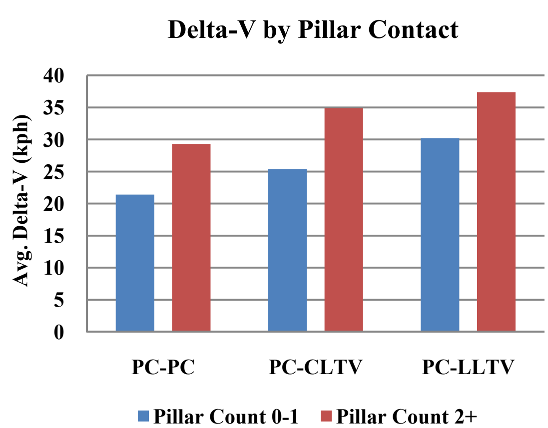

Figure 13: Direct pillar contact and delta v

Finally, we wanted to see how delta-V, a standard metric for crash severity, compared to DSD. The simple assumption was made that as delta-V increased, DSD would increase as well. We have already established increased mass and bumper height with both the CLTV and LLTV as striking vehicles when compared to the struck PC. This would also suggest that LLTV, and to some extent CLTV, would result in larger DSD as well. The scatter-plot in Figure 14 shows the delta-V and DSD relationship for each crash configuration where both delta-V and DSD were available. In general, the plot exhibited a correlation of DSD to delta-V as the crash partner gained mass and height from PC to LLTV. The plot did indicate a few puzzling points. There are approximately 13 struck PC vehicles that have DSD measures of zero yet have delta-V measures of 20 kph and higher. One crash involving a LLTV has a delta-V of greater than 60 kph and a DSD of zero. These cases were reviewed closer to check for potential data errors. It turns out that the issue is actually with the shortcomings of the CDC and when minimal "P-zone" is involved. If any part of the "P-zone" is directly involved with the impact, the new measurement variables must be recorded. But, as can be seen in Figure 15, there are occasions where the "P-zone" experiences a minimal direct contact, while other parts of the side plane that are in direct contact experience more significant crush.

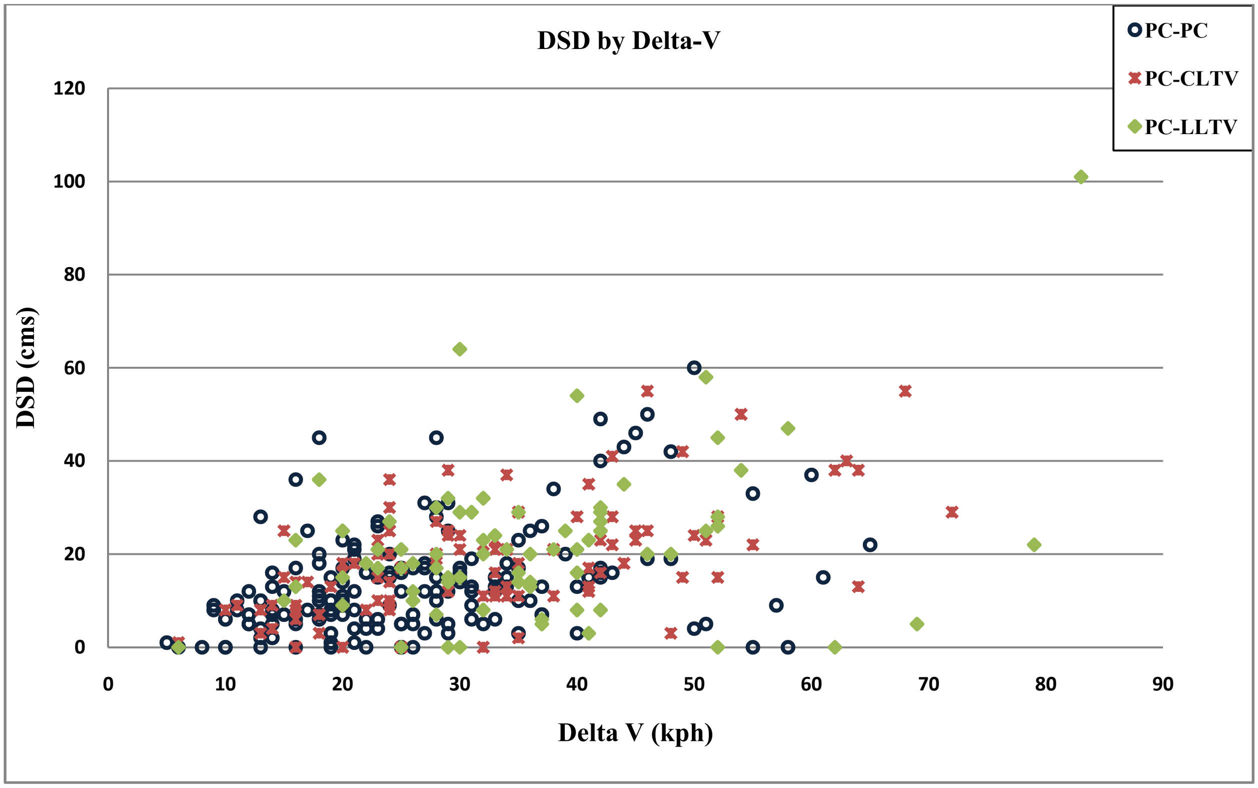

Figure 14: Plot of DSD vs. delta v for PC case vehicles

Figure 15: Example high delta v with low DSD (PC-LLTV)

CONCLUSION

In 2008, NHTSA began collecting newly developed variables as part of its field crash investigation programs. The variables were designed to help identify override and compatability issues related to side impact crashes. This paper discusses an initial review of the new variables to assess if they are achieving the goal for which they were designed.

Although over 500 cases have been coded, we concentrated this review on the cases where the vehicle impacted in the side plane was a passenger car (n=367). This enabled us to focus on the population most vulnerable to side impact compatibility issues.

Sill Height is a new variable that is a simple measurement in the field, but can be compromised due to vehicle damage. The data indicate that the measurements vary little in different crash configurations and are missing less than four percent of the time from the study population. Direct Damage to Pillars is a field observation determined by the crash investigator. The variable assesses the direct damage contact of the striking vehicle on the vertical side pillars of the struck vehicle. Review of this variable yielded unexpected results. More significant override, or DSD increase, was expected to be seen in cases with fewer pillars contacted and larger crash partner involvement. The data actually indicated the opposite, with more pillar involvement in cases with greater override. Additional analysis indicated the cases with the greater pillar involvement also had much higher delta-v results on average. Height of Maximum Door Crush was developed to determine the extent of crush and how high over the sill structure a vehicle was being struck on the side of the passenger compartment. Initial review of this variable indicates good field collection and accurate assessment of the role the frontal geometry of the impacting vehicle is having on passenger compartment deformation of the struck vehicle. The final new variable in the assessment is the DSD, or Door Sill Differential. This variable was designed to give insight into the amount of deformation a vehicle door experiences as compared to the sill or rocker panel. Large positive DSD measurements should indicate side plane override. The analysis of DSD shows it does a good job of identifying override and potential compatibiltiy issues. DSD and delta-V correlate reasonably well throughout this dataset in predicting crash severity. The DSD to delta-V correlation did indictate that DSD is only a good metric for side-impact crash severity where a significant portion of the passenger compartment is involved. Otherwise, delta-V becomes the more efficient indicator. The results of this review indicate the new variables to be of good quality and the majority are yielding the type of results that were anticipated.

References

[1] – IIHS, “Status Report: Special Issue – Vehicle Inncompatibility in Crashes”, Vol. 40. Number 5, April 2005, Arlington, Virginia, pg. 4.

[2] – IIHS, “Side Impact Crashworthiness Evaluation Crash Test Protocol”. Version 5, 2008.

[3] – Austin, R., Proceedings of the Nineteenth International Conference on Enhanced Safety of Vehicles, Paper No. 248, Washington, D.C., June 2005.

[4] – Crash Deformation Classification, SAE Surface Vehicle Standard – J224, Rev Mar80, Warrendale, Pa.

[5] – NASS-CDS 2009 Coding and Editing Manual, NHTSA, 2009, pp. EV158-EV166.