COMPARISON OF UNIVERSITY OF MICHIGAN CIREN CASES TO EXISTING TYPES OF CRASH TESTS

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ABSTRACT

A comparison of U-M CIREN (University of Michigan Crash Injury Research and Engineering Network) cases to crash tests used in the automotive industry is presented in this paper. 442 U-M CIREN crashes were compared to crash test configurations used throughout the industry. Of those 442 cases, 49% were similar in crash configuration and crash extent to industry crash tests. 32% of the cases were similar to one of the industry crash tests in configuration but had greater extent. 20% of the cases did not match any of the current industry crash tests.

This analysis concluded that the majority of injuries in this study occurred in crash configurations similar to existing crash tests while only 20% of cases had crash configurations that were not represented by current crash tests. Any consideration of increasing test severity to address those crashes that produce a greater extent of crash deformation than that produced in crash tests must consider a broader spectrum of collisions including non-injury producing crashes. This analysis must be done in a way that does not increase the risk to the current uninjured population that is not included in the CIREN database.

INTRODUCTION

Studies have demonstrated that fatality rates from motor vehicle crashes in the United States have been reduced over the last several decades. As an example the fatality rate per 100 million miles driven was 5.5 in 1966 and steadily declined to 1.41 in 2006. In addition, injuries have been reduced from 169 injuries per 100 million miles driven in 1988 to 85 in 2006. Despite the significant improvements in automotive safety, there continues to be about 38,500 annual fatalities due to motor vehicle crashes [1]. Therefore there is benefit to investigating the remaining fatalities and serious injuries due to motor vehicle crashes.

The goal of this project was to compare the crashes in the U-M CIREN database to existing industry crash tests. CIREN is a multi-center research program involving a collaboration of clinicians and engineers in academia, industry, and government. There are currently eight CIREN centers around the United States that each pursues in-depth studies of crashes, injuries, and treatments. The UMPIRE (University of Michigan Program for Injury Research and Education) team specifically investigates crashes in Southeast Michigan in which the victims are brought to the University of Michigan Trauma Center in Ann Arbor, Michigan and serves as the CIREN center in Michigan.

BACKGROUND

Industry Crash Test Library

Auto manufacturers routinely conduct crash tests for a number of reasons. Tests are conducted to insure compliance to crash test regulations not only for the United States but for any country in which a vehicle may be marketed. In addition, tests may be conducted to evaluate a vehicle's performance to consumer metric tests such as those conducted at the Insurance Institute of Highway Safety (IIHS) or those conducted as part of the New Car Assessment Program (NCAP). Crash tests may also be conducted by a vehicle manufacturer to evaluate a vehicle's performance in crash tests which are neither government regulated nor consumer metric tests. Crash tests may be supplemented or replaced with component level tests, subsystem tests, math based computer modeling, or engineering judgment.

For the above reasons it is expected that different manufacturers may test to different matrices of crash

tests. However, certain impact test types are generally common throughout the industry. The majority of auto manufacturers who sell vehicles in the United States consider these configurations when designing vehicles.

Table 1 lists the crash test types that were chosen for comparison to the U-M CIREN cases for this study.

Table 1.
Included Industry Crash Tests

0 Degree Frontal (FMVSS 208 [2] and Frontal NCAP)
Left Angle (FMVSS 208 [2])
Right Angle (FMVSS 208 [2])
40% Offset Deformable Barrier (FMVSS 208 [2] and IIHS [3])
Frontal Center Pole
Frontal Offset Pole
Bumper Underride
IIHS Side Impact [4]
Side Impact (FMVSS 214 [5] and Side NCAP)
Side Pole [6]
Rollover

Limitations

It is important to acknowledge that this study is based solely on cases documented in the U-M CIREN database. As such, the uninjured population is not included for comparison. By the definition of the CIREN selection criteria (Appendix A), all of the case occupants are severely injured patients. Those crashes in which there are no injuries or only minor injuries are not included in the CIREN database or the U-M CIREN database, and are not referenced in this study. Thus it is not appropriate to use the CIREN database or the U-M CIREN database in isolation to estimate risk to the driving public.

To help put the CIREN database into context, Figure 1 shows a comparison of the data in the National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) to CIREN cases. More than half of the crashes in NASS-CDS are MAIS 0 crashes because the NASS selection criteria specifies a 'tow-away' crash whereas CIREN contains mostly MAIS 3, 4 and 5 cases.

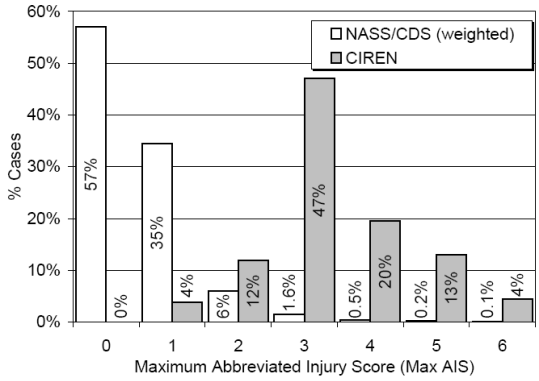

Figure 1. Comparison of CIREN to NASS-CDS . [7]

Figure 2 shows a comparison of AIS 3+ NASS-CDS cases to CIREN cases. Both databases show a similar distribution of Maximum AIS.

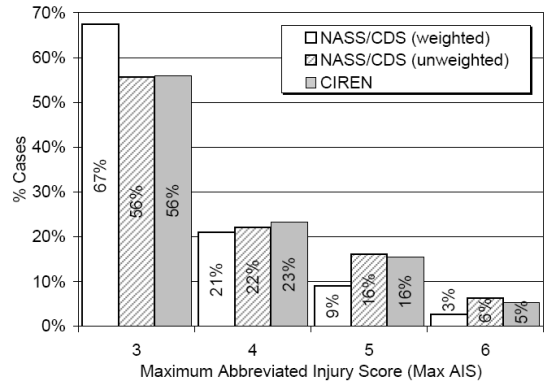

Figure 2. Comparison of AIS 3+ CIREN and NASS-CDS. [7]

Due to these database limitations, this study cannot be used to quantify the relative safety of vehicles, the effectiveness of government regulations, or the effectiveness of the vehicle design process. It has already been documented that motor vehicles have become much safer over the last few decades. This study did not attempt to quantify or verify that conclusion. Instead this study investigated the crash configurations of U-M CIREN cases and compared them to existing crash test configurations. This allowed for conclusions to be drawn about how the industry crash tests match to those injury producing crashes in the U-M CIREN database.

Another limitation of the study is that the vehicles included in the U-M CIREN database were designed at different times to different requirements. Government regulations have changed during the time span of the case vehicles. In addition, different manufacturers may have differing in-house, crash test requirements.

Database

The dataset used for this comparison included all of the 442 CIREN cases that resided in the U-M CIREN database as of August 2007.

To be selected as a CIREN case, the occupant needs to be air bag, or air bag and seat belt restrained and sustain serious injury (Abbreviated Injury Severity [AIS] 3 or greater, or AIS 2 injuries in two or more body regions with medical significance [8]). Currently, the case vehicle must be less than 6 years old and involved in a frontal, side, or rollover crash as described in Appendix A.

Figure 3 indicates that the case vehicles' age ranged from 1989 — 2006 model years with 63% of the vehicles from 1995 — 2000 model years. Most of the vehicles (84%) were produced by GM, Ford, or Chrysler.

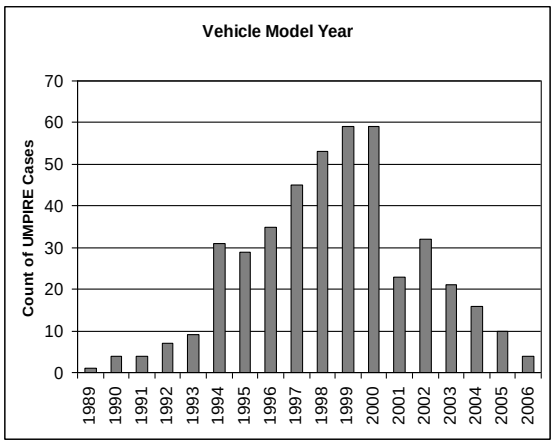

Figure 3. Case Vehicle Model Year Distribution.

METHOD AND RESULTS

The study consisted of two major tasks. First, crash tested vehicles were reviewed and Collision Deformation Classifications (CDCs) were assigned to the crash test types identified in Table 1. Next, U-M CIREN cases were reviewed and matched to test types and/or categorized into new crash categories.

CDC Coding of Crash Tests

<u>Assigning CDCs to laboratory tests from post-test photographs</u> CDCs were assigned to crash tests of midsized sedans, small sedans, small coupes, and large SUVs.

A variety of vehicles were evaluated to determine if there were differences in deformation patterns based on vehicle type. The team reviewed photographs of vehicles that had been crash tested in the laboratory according to standard test procedures and assigned CDCs as a team.

The method for assigning CDCs is defined in SAE recommended practice J224 [9]. The CDC is a method to classify the extent of residual vehicle deformation in a motor vehicle collision, and consists of three numeric and four alpha-numeric characters, arranged as shown in Figure 4.

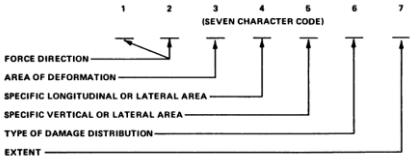

Figure 4. CDC Code

<u>Frontal Crash Test Types — CDCs from Post Test Photographs</u> Figure 5 shows a schematic of a 0 degree frontal crash test and an actual crash tested vehicle.

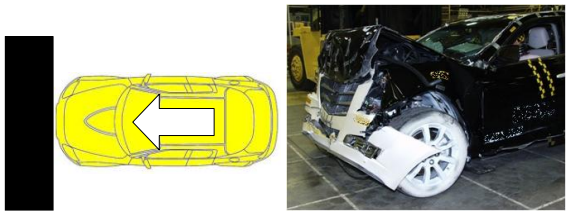

Figure 5. 0 degree Frontal Test.

The CDC for this crash test was 12FDEW3. 0 degree frontal crash tests conducted in the laboratory will always have a 12 o'clock Principle Direction of Force (PDOF). UMPIRE crash case PDOFs of 1 o'clock and 11 o'clock were also considered as similar to a 0 degree frontal laboratory tests. The remaining characters describe a crash that is front (F), distributed across the vehicle (D), everything below the beltline (E) and a wide damage distribution (W).

Figure 6 shows a schematic of a left angled frontal barrier crash test and an actual crash tested vehicle.

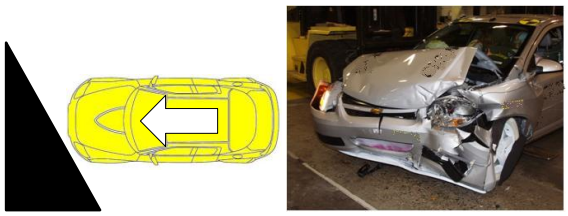

Figure 6 . Left Angle Barrier Test.

The CDC for this crash test is 12FYEW3. The principal difference between the 0 degree frontal crash test and a left or right angle crash test or offset deformable barrier tests is in the lateral area of deformation. The angled barrier crashes have a force direction of 11 or 12 o'clock force direction (left) or 12 or 1 o'clock force direction (right.) The angled barrier crash tests have a frontal (F) area of deformation but instead of the deformation being distributed across the entire front of the vehicle, it is more localized on the left or right side of the vehicle.

Figure 7 shows a schematic of a left offset deformable frontal barrier crash test and an actual crash tested vehicle.

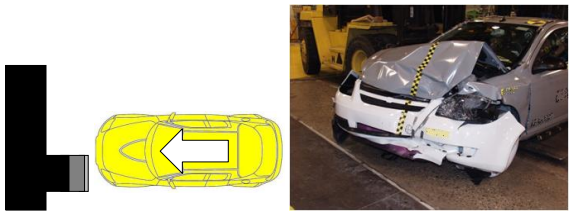

Figure 7. Offset Deformable Barrier Test.

The CDC for this crash test is 12FYEW3. In comparing the deformation pattern between angled frontal barriers to that in the offset deformable barrier test, although the shape of the barrier face differs in these two test modes, the deformation pattern, as defined by the CDC methodology cannot discriminate between the two. Using left angle tests and left offset deformable barriers as an example, the character in position 4 would be L if the area of deformation comprised up to 1/3 of the lateral area of the vehicle or Y if the deformation was between 1/3 and 2/3 of the left side of the vehicle. For a 40% overlap offset deformable barrier, the code for this position would, by definition, be Y as it would for a left angle crash test where the area of deformation is closer to 2/3 of the vehicle.

Figure 8 shows a schematic of a frontal center pole crash test and an actual crash tested vehicle.

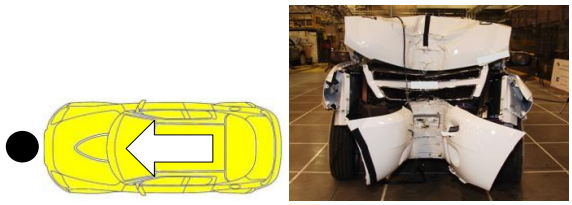

Figure 8. Frontal Center Pole Test.

The CDC for this crash test is 12FCEN3. A frontal center pole test has a 12 o'clock force direction and a frontal (F) area of deformation. The lateral area of deformation is in the center third of the vehicle (C), everything below the beltline (E) and narrow, less than 16", distribution.

Figure 9 shows a schematic of a bumper underride crash test and an actual crash tested vehicle

Figure 9. Bumper Underride Test.

The CDC for this crash test is 12FDMW3. The frontal underrride evaluation results in a deformation pattern that is described with a 12 o'clock force direction, front (F) distributed across the vehicle (D) crash, but the key difference between this crash test type and a 0 degree frontal barrier is that the vertical deformation is from the top of the bumper to the beltline/hood (M). This crash type engages the entire front of the vehicle for a wide damage distribution (W).

After the CDCs were assigned to the crash tests, cases in the U-M CIREN database were compared to the list of CDCs before evaluating the extent of deformation (CDC character 7). Table 2 shows the number of U-M CIREN cases assigned to each frontal crash test type and associated CDCs assigned to the tests.

Table 2.
Distribution of Frontal Cases by CDC

Crash Test Type	*CDC 1-6*	*Total*
0 degree frontal	12FDEW	78
	11FDEW	14
	01FDEW	6
left angle or offset	12FYEW	52
	12FLEW	12
	11FYEW	7
right angle or offset	12FZEW	16
	01FZEW	5
	12FREW	3
	01FREW	1
frontal center pole	12FCEN	10
bumper underride	12FDMW	3
Total		207

Side Impact Crash Types — CDCs from Post Test Photographs Figure 10 shows a schematic of an IIHS side impact crash test and an actual crash tested vehicle.

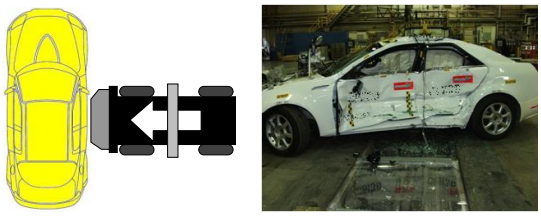

Figure 10. IIHS Side Impact Test.

The CDC for this crash test is 9LPAW3. IIHS side impact tests are conducted with a moving deformable barrier that strikes the vehicle on the side at a 90 degree angle leading to a force direction and area of deformation of 3 o'clock on the right (3R) or 9 o'clock on the left (9L). The moving deformable barrier is aligned with the goal of maximizing the contact with the passenger compartment leading to deformation of P (passenger compartment) or Y (passenger compartment and area forward of passenger compartment) for character 4. The vertical deformation in this crash type can extend above the beltline leading to an A or E for character 5. The lateral extent of the deformation in this crash type is greater than 16", or wide (W) for character 6.

Figure 11 shows a schematic of a side NCAP crash test and an actual crash tested vehicle.

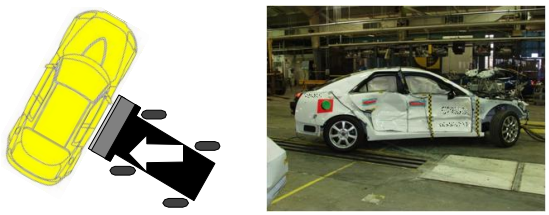

Figure 11. Side NCAP Test.

The CDC for this crash test is 10LPAW3. The key difference between the IIHS side impact test and the side NCAP test is that the side NCAP test uses a moving deformable barrier that is crabbed (at an angle of 27 degrees) with respect to the impacted vehicle. The crabbed impact results in a 10 o'clock left (10L) or 2 o'clock right (2R) as opposed to 3 and 9 o'clock for the IIHS test. The remaining characters are the same as for the IIHS test.

Figure 12 shows a schematic of a side impact pole crash test and an actual crash tested vehicle.

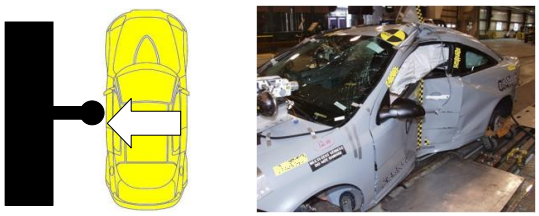

Figure 12. Side Impact Pole Test.

The CDC for this crash test is 9LPAN3. The side impact pole test that can be conducted as an evaluation for FMVSS 201 defines a perpendicular impact with a 254mm pole centered at center of gravity of the head of the Anthropomorphic Test Device (ATD, or test dummy). The differences in deformation pattern between this type and the IIHS side impact test type is that the pole impact results in a narrow (N), less than 16", deformation pattern in character 6, and has a vertical deformation pattern of the entire vehicle (A) in character 5.

Table 3 shows the number of U-M CIREN cases assigned to each side impact crash test type and associated CDCs assigned to the tests.

Table 3.
Distribution of Side Impact Cases by CDC

Crash Test Type	*CDC 1-6*	*Total*
IIHS side impact	09LPAW	12
	09LYAW	9
	03RPAW	9
	09LPEW	5
	03RPEW	4
	03RYAW	3
	09LYEW	3
	03RYEW	1
side NCAP	10LYAW	13
	02RPAW	8
	02RYAW	7
	02RYEW	3
	10LPAW	3
	10LYEW	3
	02RPEW	1
	10LPEW	1
side pole	09LPAN	2
	03RPAN	1
	09LPAW	1
Total		89

Table 4 shows CDCs from non-arrested rollover crash cases that have deformation patterns that are similar to those generated in laboratory crash tests.

Table 4.
Non-arrested rollover crash CDCs

Crash Test Type	CDC 1-6	Total
rollover	00TDDO	6
	00TYYO	1
	00TYZO	1
Total		8

Laboratory rollover crash tests [10] are used in developing rollover sensor calibrations. These tests focus on the initiation portion of the rollover and therefore often involve tethered vehicles so there is no body damage, or the vehicle rolls one full roll or less. These kinds of tests result in a CDC that is defined as non-horizontal (00) for the force direction and an area of deformation of top (T). Deformation in laboratory rollover tests is typically distributed over the vehicle (D) or skewed slightly forward (Y) due to the location of the engine in the front of the vehicle. Character 5 can be either distributed (D) or the left (Y) or right (Z) 2/3 of the vehicle. Finally, character 6 is always O for a rollover. An example of a rollover laboratory tested vehicle is shown in Figure 13 (a) with a comparable U-M CIREN case in Figure 13 (b)

(a) **(b)**

Figure 13. Laboratory Rollover Crash Tested Vehicle and Non-Arrested Rollover Case Vehicle-00TDDO3.

Additional Case CDCs Matched to Front and Side Impact Crash Test Types during In-depth Review

The next step was an in-depth case-by-case review of the remaining U-M CIREN cases to determine if the cases had deformation that appeared visually to match that generated in crash tests. Table 5 shows the number of additional U-M CIREN frontal cases that had deformation patterns that were determined to be similar to frontal crash test types and the associated CDCs.

Table 6 shows the number of additional U-M CIREN side impact cases that had deformation patterns that were determined to be similar to side impact crash test types and the associated CDCs.

Table 7 shows examples of additional frontal and side impact crashes. These examples are explained in the following section.

Table 5.
Distribution of Additional Frontal Impact Cases by CDC

Crash Test Type	CDC 1-6	Total
frontal offset pole	12FZEN	5
	12FYEN	4
	12FLEN	3
	12FZAN	1
	12FRAN	1
	12FREN	1
left angle or offset	11LYEW	6
	11LYAW	5
	12FYAW	1
	11FYAW	1
0 degree frontal	11FDAW	5
	12FDAW	3
	01FDAW	1
right angle or offset	01RZEW	2
	12FZAW	1
frontal center pole	12FCEW	2
Total		42

Table 6.
Additional Side Impact Cases by CDC

Crash Test Type	CDC 1-6	Total
IIHS side impact	09LZAW	4
	08LZAW	1
side NCAP	10LZAW	3
	01RPAW	1
side pole	09LPEN	1
Total		10

Table 7.
Examples of Additional Frontal and Side Impact Crash Types

Frontal Impact	Side Impact
(a) Offset Pole - 12FZEN3	**(d) IIHS Side Impact - 09LZAW4**
(b) 0 Degree Frontal - 12FDAW5	**(e) Side Pole – 09LPEN3**
(c) Left Angle - 11LYEW4	**(f) Side NCAP - 10LZAW3**

Table 7 Figure (a) shows an example of a 12 o'clock frontal (12N) narrow impact (N, character 6) that was similar to a frontal pole test. Table 7 Figure (b) demonstrates a vertical deformation area that extends above the beltline (A, character 5) was similar to the deformation that is generated in a 0 degree frontal crash but coded as everything below the beltline (E, character 5). Table 7 Figure (c) is an example from the left angle or offset category. There was an overlap between the deformation defined by an 11 o'clock frontal (11F) and an 11 o'clock left side (11L) and therefore the 11 o'clock left impacts were added to this category. A similar overlap was noted on the right side of the vehicle. In addition, for angled impacts that engaged up to 2/3 of the lateral vehicle structure (Y or Z, character 4), vertical deformation that extended above the beltline (A, character 5) was also similar to that seen in the frontal angle and offset crash tests, everything below the beltline (E, character 5).

The two additional CDCs assigned to the IIHS side impact test type reflect a slight shifting of the impact rearward in the vehicle so that the area of deformation includes the passenger compartment but extends rearward (Z, character 4) as demonstrated in Table 7 Figure (d). In addition there was one case with an 8 o'clock force direction that had deformation similar to that generated in an IIHS side impact test.

For the side NCAP test type, the additional CDCs were assigned in a similar fashion — a slight rearward shifting in deformation area (Z, character 4) shown in Table 7 Figure (e) as well as a force direction that that was one 'hour' different than assigned from crash test pictures (1 o'clock versus 2 o'clock).

For the side pole test, one case, Table 7 Figure (f), had a deformation pattern of everything below the beltline (E, character 5) instead of extending up above the beltline as is typical in a side pole crash test.

Cases with Crash Configurations Different from Laboratory Tests

The remaining cases which could not be matched to existing crash tests were grouped into new crash configuration categories. In this step, 77 cases were assigned to these additional crash configurations without a matching crash test and 9 cases were so unique that they could not be categorized into any crash category.

The distribution of frontal crash cases without a corresponding crash test is shown in Table 8.

Table 8.
Distribution of Frontal Crash Cases without an Associated Crash Test by CDC

Crash Type	*CDC 1-6*	*Total*
left small overlap	12FLEE	9
	12FLAE	8
	11FLEE	3
	12FLAW	3
	11LFEW	2
right small overlap	12FREE	5
	02FREE	1
underride	12FDAA	3
	12FZAA	1
high undercarriage	12FDLW	2
	12FRLN	1
sideswipe	12LDAS	1
corner underride	12FRAE	1
offset underride	12FLME	1
Total		41

The distribution of side impact cases without a corresponding laboratory crash test is shown in Table 9.

Table 9.
Distribution of Side Crash Cases without an Associated Crash Test by CDC

Crash Type	*CDC 1-6*	*Total*
side imp. non-occ. comp.	10LFEW	2
	02RFEW	2
	09LFEW	1
	09LBEW	1
	03RBEW	1
IIHS side - shifted rwd	03RZAW	2
	02RZAW	2
	09LZEW	2
oblique side	01RDAW	2
	11LDAW	1
IIHS side - distributed	09LDAW	2
side NCAP - shifted rwd	02RZEW	2
IIHS side - shifted fwd	01RYAW	2
side oblique pole	10LPAN	1
side NCAP - distributed	02RDAW	1
Total		24

The rear impact crash cases are shown in Table 10

Table 10.
Distribution of Rear Crash Cases without an Associated Crash Test by CDC

Crash Type	*CDC 1-6*	*Total*
full overlap rear impact	06BDEW	3
partial overlap rear impact	06BZAW	1
	06BYAW	1
rear angle	07BLAW	1
narrow overlap rear impact	06BRAE	1
Total		7

Table 11 shows examples of cases without a corresponding crash test. These examples are explained in the following section.

The left and right small overlap crashes (Table 11 Figure (a)) had deformations that were typically outside of the longitudinal rails. These were primarily frontal crashes (F, character 3) with damage limited to the left (L, character 4) or right (R, character 4) 1/3 of the vehicle. The vertical damage ranged from the entire vehicle (A, character 5) or everything below the beltline (E, character 5) with a corner (from corner to 16" inboard) (E, character 6) type of damage distribution. In addition, the overlap seen between the FL and the LF (characters 3 and 4) resulted in an additional CDC and two cases assigned to this crash type.

The corner underride case (Table 11 Figure (b)) was different from a right angle or offset test in that although there was deformation below the beltline, the majority of deformation was above the beltline. This is a detail that is not evident in the CDC but was visible during review of the post-crash photographs.

The high undercarriage cases (Table 11 Figure (c)) had deformation that was from the top to the bottom of the vehicle frame (L, character 5), which discriminated these cases from 0 degree frontal and pole tests which have residual deformation from the beltline down (E, character 5).

The one offset underride case (Table 11 Figure (d)) was distinguished from other case types by the M for character 4, meaning from the top of the frame to the beltline. The sideswipe crash (Table 11 Figure (e)) was categorized by the S in character 6 which is defined as a sideswipe with 0 to 4" of lateral overlap. The underride crash types (Table 11 Figure (f)) were categorized by the A in character 6 defined as an overhanging structure or inverted step.

The side impact cases without a corresponding crash test type primarily involved damage that involved either more of the side of the vehicle (D, character 4, as shown in (Table 11 Figure (g)) or was shifted forward or rearward of the occupant compartment. In addition, there were variations in the force direction (characters 1 and 2) as compared to laboratory tests.

The oblique side impacts (Table 11 Figure (h)) were defined by the somewhat frontal force directions of 11 and 1 o'clock combined with a distributed loading along the side of the vehicle. The side impacts that did not involve the compartment (Table 11 Figure (i)) were either in front of the occupant compartment (F, character 4) or behind the occupant compartment (B, character 4). The side oblique pole was characterized by a non-perpendicular 10 o'clock impact with a

Table 11.
Examples of Cases Without a Corresponding Crash Test

(a) Left Small Overlap - 12FLEE9	**(g) IIHS Side Impact - Distributed - 09LDAW4.**
(b) Corner Underride - 12FRAE7	**(h) Oblique Side Impact - 01RDAW3**
(c) High Undercarriage - 12FDLW1	**(i) Side Impact Non-Occupant Compartment - 10LFEW3.**
(d) Offset Underride - 12FLME5	**(j) Side Oblique Pole Impact - 10LPAN4**
(e) Sideswipe – 12LDAS2	**(k) Full Overlap Rear Impact - 06BDEW3**
(f) Underride - 12FDAA6	

narrow damage distribution (N, character 6, Table 11 Figure (j)).

The rear impact cases were characterized by force directions from the rear of the vehicle (6 and 7 o'clock) and a rear area of deformation (B, character 3, Table 11 Figure (k)). Although rear impact crash test evaluations are performed to evaluate vehicle structural performance, occupant performance is not evaluated in these tests.

The arrested rollover crash cases are shown in Table 12. Cases with deformation patterns that are so unique that they could not be categorized are shown in Table 13 and Table 14.

Table 12.
Distribution of Arrested Rollover Crash Cases without an Associated Crash Test by CDC

Crash Type	*CDC 1-6*	*Total*
arrested rollover	00TZDW	1
	00TYDN	1
	00TPDN	1
	00TFDO	1
	00TZZO	1
Total		5

Table 13.
Non-categorized Crash Cases by CDC

Crash Test Type	*CDC 1-6*	*Total*
not categorized	02FDEW	3
	12LYAW	2
	00FCEN	1
	00LZAW	1
	11LFEN	1
	12FDHW	1
Total		9

Table 14.
Examples of Crash Damage in U-M CIREN Cases Non-categorized Cases by CDC

02FDEW3	00LZAW9
12LYAW3	**11LFEN3**
00FCEN2	**12FDHW9**

<u>Extent (CDC Character 7)</u> After categorizing the U-M CIREN cases by crash configuration and crash category, the CDC extent, character 7, was analyzed. The maximum extent for the laboratory crash test types is shown in Table 15. The maximum extent was consistent across laboratory tests of different vehicle types.

Table 15.
CDC Extent for Crash Tests

Crash Test Type	*Maximum Extent in Laboratory Testing*
0 degree frontal	3
bumper underride	3
frontal center pole	4
frontal offset pole	4
left angle or offset	3
right angle or offset	3
IIHS side impact	3
side NCAP	3
side pole	3
rollover	3

Appendix B shows the distributions of U-M CIREN crash types by CDC characters 1-6 and CDC extent above or below that generated in laboratory crash tests.

DISCUSSION

In many cases, crash damage in U-M CIREN cases closely resembled deformation from laboratory crash tests. Table 16 shows a comparison of three crash types to the associated case vehicle where the pattern of deformation is visually similar.

Table 16.
Examples of Crash Damage in U-M CIREN Cases Similar to Crash test Damage

Laboratory Crash Test	U-M CIREN Case CDC
0 Degree Frontal	**12FDEW3**
Frontal Center Pole	**12FCEN4**
IIHS Side Impact	**9LPAW3**

In some cases, crash damage within a CDC category varied from crash test deformation. Table 17 shows a comparison of two crash types to the associated crash test types where the pattern of deformation is not visually similar. The first example, shows a U-M CIREN case coded 12FYEW3, or similar to a left angle or offset laboratory test. There is an obvious difference in deformation patterns, but because the impact in the U-M CIREN case engaged part of the left and center thirds of the front of the vehicle and was wider than 16", the case must be coded as wide (W, character 6) as opposed to narrow (N, character 6).

The second example shows a 0 degree frontal laboratory crash test coded as 12FDEW3. Visually, the deformation pattern in the U-M CIREN case looks more similar to a frontal angle test, but because the damage is distributed across the front of the vehicle, this case is categorized as a 0 degree frontal.

There were cases in which the 'classic' picture of a given CDC did not exactly match the actual vehicle deformation. These examples demonstrate the coarseness of using CDCs to describe vehicle deformation.

Table 17.
Examples of Crash Damage in U-M CIREN Cases Different from Crash test Damage

Laboratory crash test	U-M CIREN Case CDC
Left Angle Frontal	**12FYEW3**
0 degree Frontal	**12FDEW3**

SUMMARY

As shown in Figure 14, 48.9% of the 442 U-M CIREN cases studied matched an existing crash test configuration with an extent less than or equal to the test, 31.7% of the frontal cases matched an existing crash test configuration but with greater extent, and 19.5% did not match an existing crash test configuration.

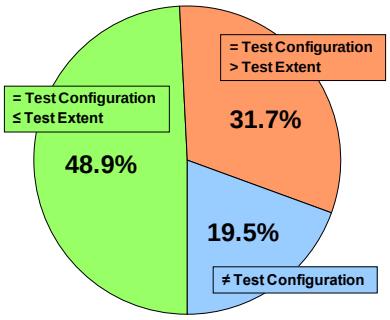

Figure 14. Distribution of U-M CIREN Cases.

A comparison was made to determine if the distribution of the U-M CIREN cases was consistent with the entire set of cases from all of the CIREN centers. Of the 2089 CIREN cases analyzed, the CDCs placed 47.5% in the groups which matched an existing crash test type with an extent less than or equal to the test, 25.8% of the cases matched an existing crash test configuration but with greater extent, and 14.4% did not match an existing crash test configuration. There were 12.3% of the CIREN cases that had CDCs that did not match those found in U-M CIREN cases (Figure 15). Those cases were not analyzed further in this study. The distribution of cases was similar between the U-M CIREN and CIREN datasets, which gave confidence that the U-M CIREN dataset is reasonably representative of the entire CIREN dataset.

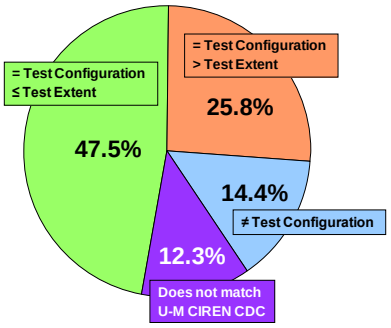

Figure 15. Distribution of all CIREN Cases.

Cases Matching Test Configuration and Extent

Figure 16 shows the distribution of the 48.9% of U-M CIREN crash cases that had configurations similar to current laboratory tests with extents less than or equal to the test. For frontal crashes, the 0 degree frontal impact category was the most represented followed by the left angle or offset category. For side impact crashes, the percentage of cases in the Side NCAP and IIHS Side Impact categories were similar. These categories were the most prevalent type of side impact configuration. There were a limited number of rollover cases in the CIREN database which is influenced by the CIREN selection criteria.

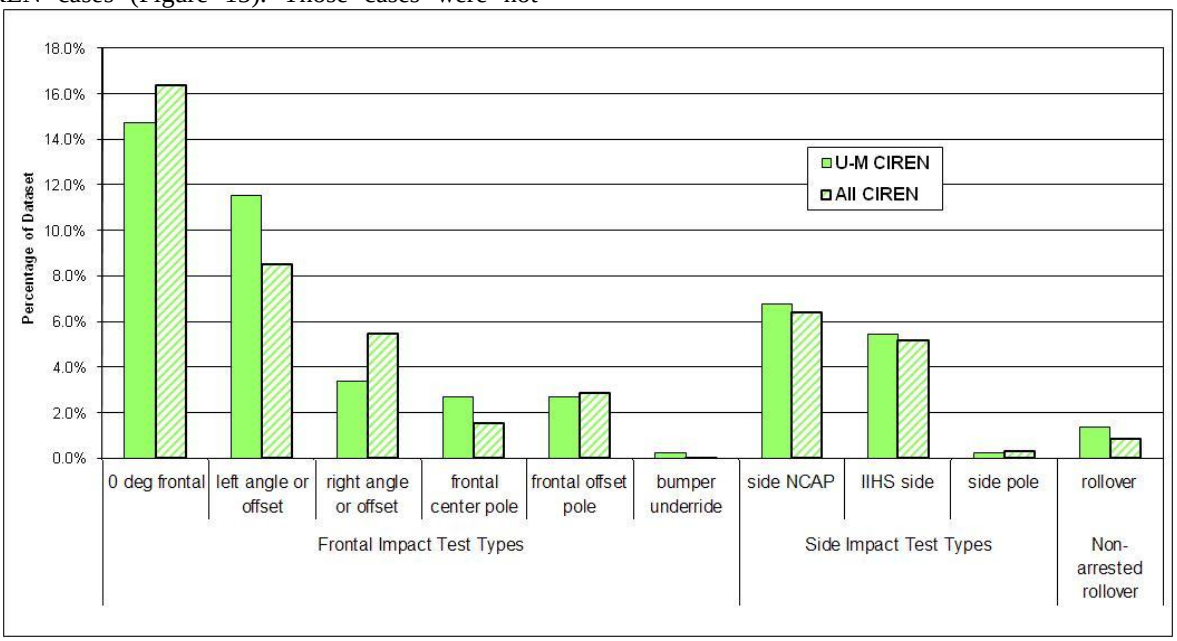

Figure 16. Distribution of U-M CIREN and CIREN cases versus Crash Test Type for crashes with similar configurations and extents less than or equal to a current industry crash test

Cases matching Test Configuration but with Greater Extent

Figure 17 shows the distribution of the 31.7% of U-M CIREN crash cases that had configurations similar to current laboratory tests with extents greater than current crash tests. Similar to the cases with lesser extents, the 0 degree frontal was the most prevalent frontal impact, followed by the left angle or offset category. Side NCAP was the most represented side impact category, followed by the Side IIHS configuration. There were very few frontal pole crashes with extents greater than the industry crash tests.

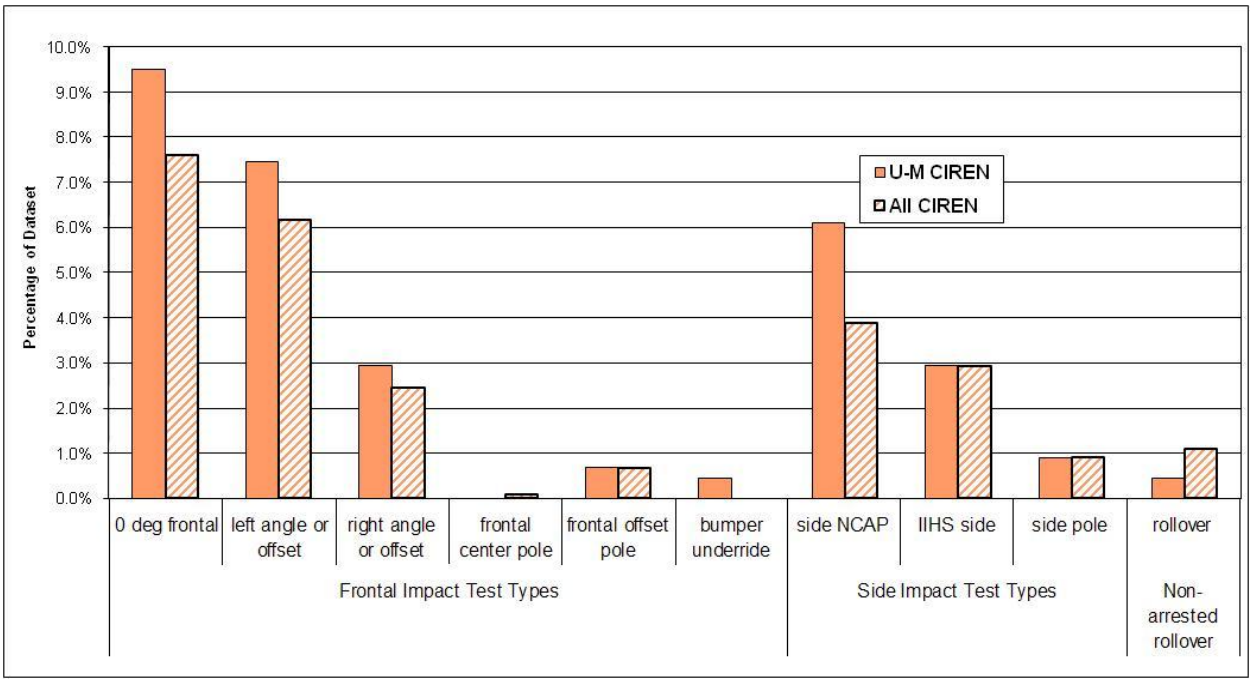

Figure 17. Distribution of U-M CIREN and CIREN cases versus Crash Test Type for crashes with similar configurations and extents greater than a current industry crash test.

There are several possible measures of crash severity including delta V, Equivalent Barrier Speed (EBS), and Extent of Deformation. CDC extent (Character 7), or extent of crash deformation, was used in this analysis as an indicator of crash severity because delta V and EBS were not available for all cases. Overall, the distribution of cases that had an extent greater than the crash test extent was very similar to the distribution of cases that had an extent less than or equal to the crash test extent. The maximum regulated frontal crash test speed is currently 35 mph which encompasses 99% of all frontal tow away crashes by delta V as illustrated by Figure 18.

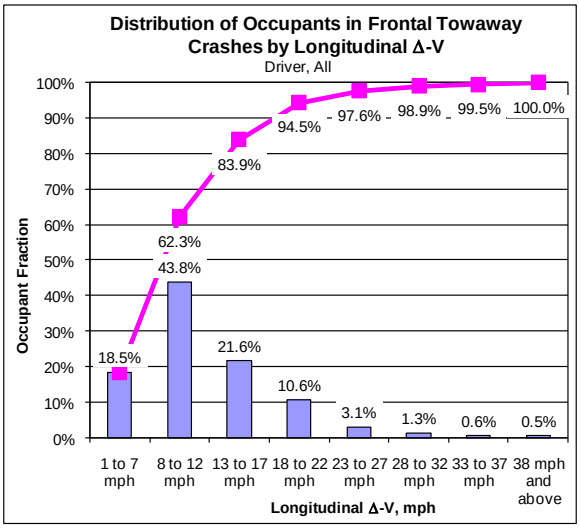

Figure 18. Frontal Crash Severity Distribution - 1997-2006 NASS CDS.

Cases Not Matching Test Configuration

Figure 19 shows the distribution of the 19.5% of U-M CIREN crash cases that did not match a current industry crash test configuration. The majority of these cases were Left or Right Small Overlap crashes. Left (FLEE) and right (FREE) small overlap crashes totaled 10.7% of all frontal cases in the U-M CIREN database. The next largest category contains crashes with deformation patterns that were so unique that they could not be categorized. The majority of side impacts in this group were similar to current industry side impact crash tests, but with the impact location shifted more forward or rearward of the occupant compartment.

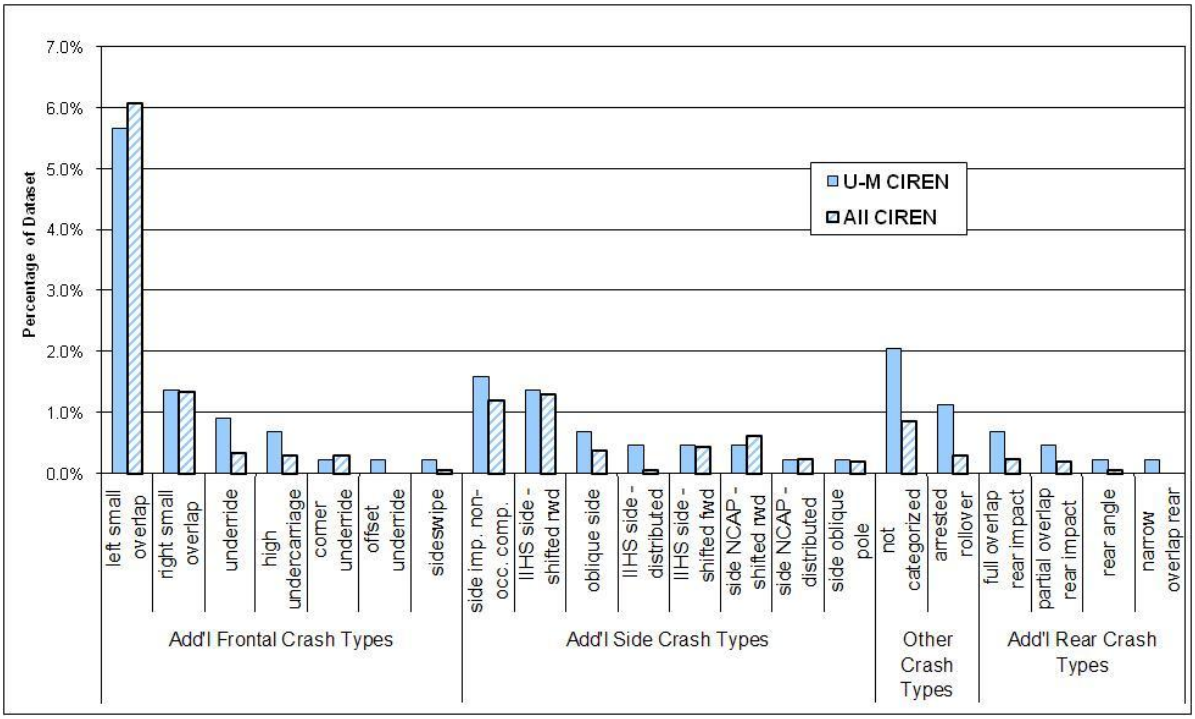

Figure 19. Distribution of U-M CIREN and CIREN cases versus Crash Test Type for crashes that do not match a current industry crash test.

Figure 20 shows the distribution of frontal crash test extents for cases with frontal crash configurations that were different from existing test types. Figure 21 shows the distribution of frontal crash test extents for cases with configurations similar to current test types.

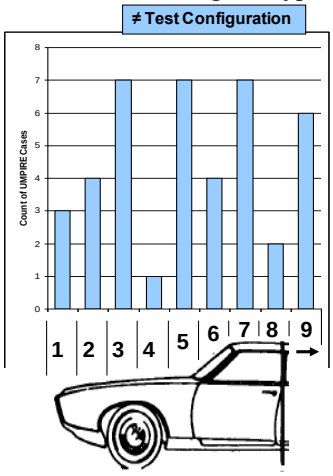

Figure 20. Extent Distribution ≠ Test Configuration.

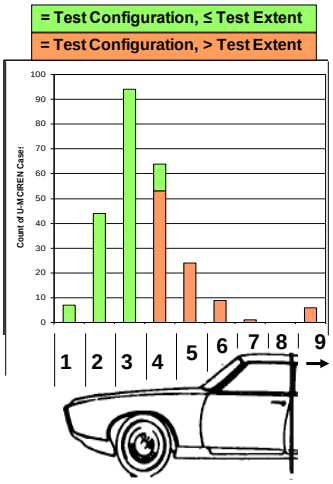

Figure 21. Extent Distribution = Test Configuration.

Frontal crashes that had configurations different from current laboratory tests tended to involve localized vehicle deformation. The concentrated loads engaged less of the vehicle's front structure and resulted in maximum crush extending farther rearward on the vehicle. Measures of crash severity other than the extent of maximum crush, such as delta V, are less likely to show the same increase and may even decrease.

CONCLUSIONS

The conclusions of this research are:

- The majority of cases in this study had crash configurations similar to existing industry crash tests.
- Only 19.5% of cases had crash configurations that were not represented by current crash tests.

Any consideration of increasing test severity to address those crashes that produce a greater extent of crash deformation than that produced in crash tests must consider a broader spectrum of collisions including non-injury producing crashes. This analysis must be done in a way that does not increase the risk to the current uninjured population that is not included in the CIREN database.

ACKNOWLEDGMENT

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APPENDIX A: CIREN ADULT INCLUSION CRITERIA (OCTOBER 2006)

Case Type	Crash Direction	Vehicle Criteria	Restraint Criteria	Occupant Positions	Injury Thresholds
Frontal	10 to 2 o'clock Full frontal Offset frontal	CY-6 yrs* *(Priority on newest vehicles)*	Air bag, Air bag and 3-point belt	Row 1	AIS≥3 or **
			Must be in 3-point belt and gross misuse **not** documented	Rows 2+	
Side	8 to 10 o'clock 2 to 4 o'clock	CY-6 yrs* *(Priority on newest vehicles)*	Any and all, including unrestrained on struck side and far side	Any	AIS≥3 or **
Rollover	All	CY-6 yrs* *(Priority on newest vehicles)*	Any and all, including unrestrained (EXCEPTION = 100% EJECTION)	Any	AIS≥3 or **
Pregnant Occupant (total enrollment limited)	10 to 2 o'clock Full frontal Offset frontal	CY-8 yrs* *(Priority on newest vehicles)*	Must be in a 3-point belt and gross misuse **not** documented Avoid out-of-position cases. (call NHTSA on non-belted cases for consideration)	Any	AIS2+ AIS1 *(with moderate to severe impact)*
PI Special Interest ***	Any	Any	Any	Any	Any
Success Case****	Any	CY-6 yrs*	Appropriate restraint usage (belt and/or air bag)	Any	Any
Fire	All	Any	Any and all, including unrestrained	Any	AIS≥2

* Cases where the vehicle is >6 yrs old may be considered for enrollment if the vehicle contained advanced safety components – NHTSA approval required

** AIS of 2 in 2 or more body regions with medical significance (avoid concussive type injury for inclusion)

* *AIS of 2 in the lower extremity with significant articular injury (pilon/talus/calcaneus/Lisfranc/Choparts)

*** Max. PI SI cases allowed per site per year would be 5 based on a 50 case enrollment (10%)

**** Cases must be extraordinary for consideration – NHTSA approval required

APPENDIX B: CDC EXTENT

Table 18.
U-M CIREN Cases Matched to Frontal Impact Crash Test Types

Crash Test Type	CDC 1-6	≤ Test Extent	> Test Extent	Total
0 degree frontal	12FDEW	51	27	78
	11FDEW	10	4	14
	01FDEW	4	2	6
	11FDAW		5	5
	12FDAW		3	3
	01FDAW		1	1
0 degree frontal Total		65	42	107
left angle or offset	12FYEW	33	19	52
	12FLEW	7	5	12
	11FYEW	2	5	7
	11LYEW	4	2	6
	11LYAW	4	1	5
	11FYAW		1	1
	12FYAW	1		1
left angle or offset Total		51	33	84
right angle or offset	12FZEW	7	9	16
	01FZEW	5		5
	12FREW	1	2	3
	01RZEW	1	1	2
	12FZAW		1	1
	01FREW	1		1
right angle or offset Total		15	13	28
frontal offset pole	12FZEN	5		5
	12FYEN	4		4
	12FLEN	3		3
	12FZAN		1	1
	12FRAN		1	1
	12FREN		1	1
frontal offset pole Total		12	3	15
frontal center pole	12FCEN	10		10
	12FCEW	2		2
frontal center pole Total		12		12
bumper underride	12FDMW	1	2	3
bumper underride Total		1	2	3
Total		156	93	249

Table 19.
U-M CIREN Cases Matched to Side Impact Crash Test Types

Crash Test Type	CDC 1-6	≤ Test Extent	> Test Extent	Total
IIHS side impact	09LPAW	7	5	12
	09LYAW	4	5	9
	03RPAW	3	6	9
	09LPEW	3	2	5
	03RPEW	3	1	4
	09LZAW		4	4
	03RYAW		3	3
	09LYEW	2	1	3
	08LZAW	1		1
	03RYEW	1		1
IIHS side impact Total		24	27	51
side NCAP	10LYAW	7	6	13
	02RPAW	5	3	8
	02RYAW	6	1	7
	02RYEW	2	1	3
	10LPAW	3		3
	10LYEW	3		3
	10LZAW	3		3
	01RPAW	1		1
	02RPEW		1	1
	10LPEW		1	1
side NCAP Total		30	13	43
side pole	09LPAN		2	2
	90LPAW		1	1
	03RPAN		1	1
	09LPEN	1		1
side pole Total		1	4	5
Total		55	44	99

Table 20.
U-M CIREN Cases Matched to Non-Arrested Rollover Crash Tests

Crash Test Type	CDC 1-6	≤ Test Extent	> Test Extent	Total
rollover	00TDDO	5	1	6
	00TYYO	1		1
	00TYZO		1	1
rollover Total		6	2	8
Total		6	2	8