EVALUATION OF EVENT DATA RECORDERS IN FULL SYSTEMS CRASH TESTS

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ABSTRACT

The Event Data Recorders (EDRs), now being installed as standard equipment by several automakers, are increasingly being used as an independent measurement of crash severity, which avoids many of the difficulties of traditional crash reconstruction methods. Little has been published however about the accuracy of the data recorded by the current generation of EDRs in a real world collision. Previous studies have been limited to a single automaker and full frontal barrier impacts at a single test speed. This paper presents the results of a methodical evaluation of the accuracy of new-generation (2000-2004) EDRs from General Motors, Ford, and Toyota in laboratory crash tests across a wide spectrum of impact conditions.   The study evaluates the performance of EDRs by comparison with the laboratory-grade accelerometers mounted onboard test vehicles subjected to crash loading over a wide range of impact speeds, collision partners, and crash modes including full frontal barrier, frontal-offset, side impact, and angled frontal-offset impacts. The study concludes that, if the EDR recorded the full crash pulse, the EDR average error in frontal crash pulses was just under six percent when compared with crash test accelerometers. In many cases, however, current EDRs do not record the complete crash pulse resulting in a substantial underestimate of delta-V.

INTRODUCTION

The Event Data Recorders, now being installed as standard equipment by several automakers, are designed to record data elements before and during a collision that may be useful for crash reconstruction. Although manufacturers have assigned many different names to these devices, NHTSA refers to them generically as Event Data Recorders (EDRs). Perhaps the single data element most important to crash investigation is the vehicle's change in velocity or delta-V, a widely accepted measure of crash severity. The traditional method of determining delta-V, based upon correlations with post-crash vehicle deformation measurements, has not always been successful or accurate [Smith and Noga, 1982; O'Neill et al, 1996; Stucki and Fessahaie, 1998; Lenard et al, 1998]. By directly measuring vehicle delta-V, EDRs have the potential to provide an independent measurement of crash severity, which avoids many of the difficulties of crash reconstruction techniques [Gabler et al, 2004].

Little has been published however about the accuracy of the data recorded by the current generation of EDRs in a crash. Previous studies on the accuracy of older-generation EDRs exist, but have been somewhat limited in the range of conditions used. In a study conducted by Transport Canada and General Motors (GM), Comeau et al (2004) examined the accuracy of the delta-V versus time data recorded by GM EDRs in eight separate crash tests involving three vehicle models. EDR delta-V was reported to be $\pm 10\%$ of the delta-V as measured by the crash test instrumentation. The paper stated that this EDR accuracy was within the manufacturer's tolerances on cumulative delta-V. Chidester et al (2001) examined the performance of EDRs from model year 1998 GM passenger vehicles. Accuracy was considered to be acceptable, however occasionally the EDRs would report slightly lower velocity changes than crash test accelerometers. Lawrence et al (2003) evaluated the performance of GM EDRs in 260 staged low-speed collisions and found that the EDRs underestimated delta-V. It was found that errors of greater than 100% were experienced during collisions with a delta-V of 4 km/hr. These errors declined to a maximum of 25% at 10 km/hr.

OBJECTIVE

The primary objective of this study is to establish the accuracy of EDR measurements recorded during full systems crash tests.

APPROACH

Our approach was to evaluate the performance of EDRs in laboratory crash tests across a wide spectrum of impact conditions. The study is based upon crash tests conducted by both the National Highway Traffic Safety Administration (NHTSA) and the Insurance Institute for Highway Safety (IIHS). In a crash test, passenger vehicles are instrumented with high-precision laboratory-grade accelerometers that can be used as a benchmark against which to compare EDR measurements. By validating the EDRs against crash test instrumentation onboard the subject vehicles, this paper will investigate EDR performance across a range of impact speeds, collision partners, and crash modes including full frontal barrier, frontal-offset, side impact, and angled frontal-offset impacts.

As shown in Table 1, data used in this evaluation was collected from thirty-seven separate crash tests. These collisions varied in both severity and type. Twenty-seven of these crash tests were performed by the NHTSA. The remaining ten tests were conducted by the IIHS. Most collisions were frontal impacts of some sort, with approach velocities ranging from 25 to 40mph. Our data set included one side impact. Twenty-five of the NHTSA tests were full frontal rigid-barrier collisions. Eighteen of these collisions were conducted with a vehicle approach speed of 35mph, two at 30mph and five at 25mph. The remaining NHTSA tests include one 25mph 40% offset frontal collision, and one vehicle-to-vehicle collision. The vehicle-to-vehicle collision was conducted using a principal direction of force of 345 degrees and a closing velocity of 68mph. Nine of the IIHS tests were frontal offset tests conducted at an approach velocity of 40mph and an overlap of 40% into a deformable barrier. IIHS conducted the only side-impact test in our data set. Several other EDRs were to be used for the comparisons, but were omitted due to malfunction of the EDR.

ANALYSIS

EDR Data Collection

For all GM vehicles and two of the Ford vehicles, the EDR data were retrieved using the Vetronix Crash Data Retrieval System. This device provides interfacing hardware and software, which permits data retrieval for certain passenger vehicles. Currently, the Vetronix system can retrieve data from most General Motors vehicles manufactured since model year 1996, some pre-1996 GM models, and a limited number of Ford models. For EDRs not readable by the Vetronix system, Ford and Toyota Motor Companies downloaded the EDR data for this study using a different technique.

Thirty of the thirty-seven vehicles tested employed GM EDRs. The GM EDRs in these vehicles have a maximum recording time of 150ms in most cases, with a typical recording duration between 100 and 150ms. Change in velocity is recorded at 10ms intervals. With the exception of the Chevrolet Malibu, the GM EDR records only longitudinal delta-V. The 2004 Chevrolet Malibu, the most advanced GM EDR used in this study, records delta-V in both the longitudinal and lateral directions for up to 300 ms. The remaining vehicles were Fords and Toyotas, which utilize a different type of data recorder. The EDRs used in Ford vehicles record acceleration at 1ms intervals. Of the four Ford EDRs, two are of an older type that record for a duration of approximately 70ms, and two are a newer version that record for approximately 120ms. Toyota EDRs used in this study record velocity for 150ms in 10ms intervals. Both the Ford and Toyota data recorders only record velocity along the longitudinal axis.

Crash Test Instrumentation Selection

The EDRs used in our study measured the acceleration of the occupant compartment during the crash event. Measurements were compared with crash test accelerometers, which were also mounted in the occupant compartment. The accuracy of the crash test accelerometers was evaluated by comparison with other accelerometers in the occupant compartment to ensure that they were internally consistent with one another. Crash test accelerometers mounted in either the crush zone or to the non-rigid occupant compartment components, e.g. the instrument panel, were not used in this study.

Table 1. Data Set Description

Test Number	Vehicle Description	Closing Speed[1] (mph)	Impact Angle (deg)	Overlap	Barrier	EDR Model
3851	2002 Chevrolet Avalanche	35.1	0	0	Rigid	SDMG2001
3952	2002 Buick Rendezvous	35.1	0	0	Rigid	SDMDG2002
4198	2002 Saturn Vue	35.0	0	0	Rigid	SDMD2002
4238	2002 Cadillac Deville	35.3	0	0	Rigid	SDMGF2002
4244	2002 Chevrolet Trailblazer	35.1	0	0	Rigid	SDMGT2002
4437	2003 Chevrolet Suburban	24.8	0	40%	Rigid	SDMGF2002
4445	2003 Chevrolet Cavalier	34.7	0	0	Rigid	SDMG2001
4453	2003 Chevrolet Silverado	24.3	0	0	Rigid	SDMGF2002
4454	2003 Chevrolet Tahoe	24.3	0	0	Rigid	SDMGF2002
4464	2003 Chevrolet Avalanche	35.1	0	0	Rigid	SDMGT2002
4472	2003 Chevrolet Silverado	34.7	0	0	Rigid	SDMGF2002
4487	2003 Saturn Ion	34.8	0	0	Rigid	SDMDW2003
4567	2003 Chevrolet Suburban	35.0	0	0	Rigid	SDMGF2002
4702	2002 Saturn Vue	29.7	0	0	Rigid	SDMD2002
4714	2002 Saturn Vue	29.7	0	0	Rigid	SDMD2002
4775	2004 Pontiac Grand Prix	34.7	0	0	Rigid	SDMDW2003
4846	2004 Toyota Sienna	35.1	0	0	Rigid	89170-08060
4855	2004 Toyota Solara	34.7	0	0	Rigid	89170-06240
4890	2004 Ford F-150	35.0	0	0	Rigid	ARM481+
4899	2004 Cadillac SRX	35.1	0	0	Rigid	SDMGF2002
4918	2004 GMC Envoy XUV	35.0	0	0	Rigid	SDMGT2002
4923	2004 Chevrolet Colorado	35.2	0	0	Rigid	SDMGF2002
4955	2000 Cadillac Seville	70.4	330	50%	Vehicle	SDMG2000
4984	2004 Saturn Ion	24.8	0	0	Rigid	SDMDW2003
4985	2005 Chevrolet Equinox	35.0	0	0	Rigid	SDMDW2003
4987	2005 Ford Taurus	25.0	0	0	Rigid	ARM481+
5071	2004 Toyota Camry	24.6	0	0	Rigid	89170-33300
CEF0107	2001 Chevrolet Silverado	40.0	0	40%	Deformable	SDMG2000
CEF0119	2002 Chevrolet Trailblazer	40.0	0	40%	Deformable	SDMGT2002
CEF0209	2003 Cadillac CTS	40.0	0	40%	Deformable	SDMGF2002
CEF0221	2003 Cadillac CTS	40.0	0	40%	Deformable	SDMGF2002
CEF0326	2004 Cadillac SRX	40.0	0	40%	Deformable	SDMGF2002
CEF0301	2003 Lincoln Towncar	40.0	0	40%	Deformable	3W1A
CEF0313	2003 Lincoln Towncar	40.0	0	40%	Deformable	3W1A
CEF0401	2004 Chevrolet Malibu	40.0	0	40%	Deformable	N/A
CES0403	2004 Chevrolet Malibu	31.0	90	0%	MDB[2]	N/A
CEF0406	2004 Chevrolet Malibu	40.0	0	40%	Deformable	N/A

[1] This is the closing velocity, which is not necessarily the vehicle speed.
[2] Moveable Deformable Barrier

All crash test accelerometer data used was obtained from the NHTSA's public database [NHTSA, 2005], or from the IIHS database [IIHS, 2005].

The EDR crash sensor and the crash test accelerometer were not positioned at the same locations in the car. This may complicate this comparison is some types of crashes. In full frontal barrier crash tests, there should be no difficulty as the EDR accelerometer and a crash test accelerometer located in the occupant compartment should experience the same acceleration. In other types of crash tests such as frontal offset or angled impacts, however, the impact may be characterized by significant vehicle rotation. In these cases, the EDR and crash test accelerometer may experience a different acceleration due to this rotation. One objective of this research study was to quantify this difference.

Time Zero Alignment

EDRs and crash test procedures use different definitions for the beginning of the event. In the NHTSA and IIHS tests, the beginning of the event is defined as the time when the subject vehicle contacts the opposing barrier/vehicle. In an EDR, the beginning of the event is defined to be the time of algorithm-enable or algorithm-wakeup. Algorithm enable occurs when the EDR experiences a deceleration on the order of 1-2 G's. At this point, the EDR, believing that a crash may be occurring, begins to record data. Because the crash is already underway before the EDR begins recording, the EDR will not capture the small change in velocity which occurs before algorithm enable. Hence, the two data sets will not be aligned along either the time axis or the velocity axis, and some time and/or velocity shifting will be necessary for an accurate comparison. Figure 1 shows an example of the time and velocity shift resulting from the difference in time zero definition.

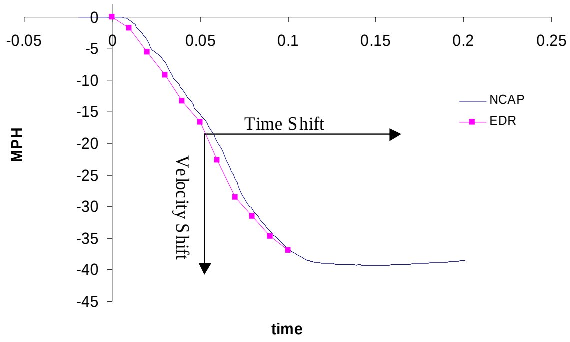

Figure 1. The need for a shifting method.

An algorithm, described below, was developed to find the time of algorithm enable, and apply the appropriate time shift.

Adjustment for Differences in Sampling Rate

To find the time of algorithm enable, the strategy used with GM EDRs was to process the acceleration measured by crash test accelerometer using the same method by which the EDR processed measurements from its internal crash sensor. Comeau et al (2004) report that GM EDRs sample acceleration at 3.2 kHz. These EDRs average the four acceleration samples measured over each 1.25 ms period. The resulting average acceleration values are integrated to obtain the delta-V over a time interval of 10ms. By comparing crash test data processed in this manner with the actual EDR, the time of algorithm enable can be estimated for cases with air bag deployment.

GM EDRs sample acceleration at 3.2 kHz. In contrast, the high precision accelerometers used in NHTSA and IIHS tests are sampled at rates between 10 and 20 kHz. As the sampling rate for the crash test instrumentation is substantially higher than that of the EDR, the crash test data was first sub-sampled to 3.2 kHz using the NHTSA program PlotBrowser. The sub-sampled crash test data were then averaged and integrated identically to the method used by the EDR.

Methods for Finding the Time of Algorithm Enable

Aligning the EDR velocity change plot with the crash test data has one purpose: to correct for the discrepancies that occur at time zero. The lack of agreement regarding time zero results in error throughout the crash pulse. After evaluating several alignment algorithms, it was found that the most effective method of alignment was to apply a time shift to the EDR based on the sequence of incremental delta-Vs between every two consecutive points. Details of the alternative alignment algorithms considered for this study are described by Niehoff (2005).

Essentially, this method checks that the delta-V recorded every 10 ms by the EDR agrees with the delta-V experienced by the crash test accelerometers over the same 10 ms interval. This method first computes the error or difference between the EDR and crash test incremental delta-Vs for each of the 10 ms recording intervals. A 150 ms curve would have 15 such interval error estimates. The EDR curve is then time-shifted to minimize the sum of the squares of these errors. The advantage of this method is that if the EDR suffered an error in one 10 ms recording interval, the effect of this error was restricted to this interval. Errors occurring in the middle of the pulse do not affect the values at the end of the pulse, as they would if the plots were aligned to minimize the cumulative delta-V error.

For consistency with the GM EDR performance analysis, the Ford and Toyota EDRs were also processed in a similar manner. To align the Ford EDR data, the EDR acceleration was integrated over every 10 ms intervals and aligned using the algorithm described above.

RESULTS

This section presents the results of the comparison of EDR measurements against laboratory-grade instrumentation in 37 full systems crash tests. Velocity plots are composed of the unfiltered, integrated crash test data and the EDR velocity curve with the applied time shift.

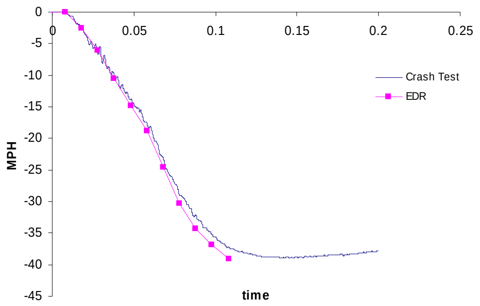

Figure 2. NHTSA Test 3851 – 2002 Chevrolet Avalanche (with EDR time shift of –.002s).

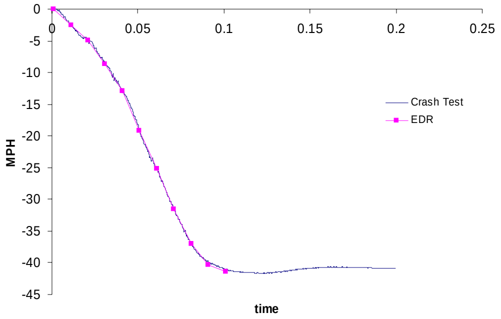

Figure 3. NHTSA test 3952 – 2002 Buick Rendezvous (with EDR time shift of .001s).

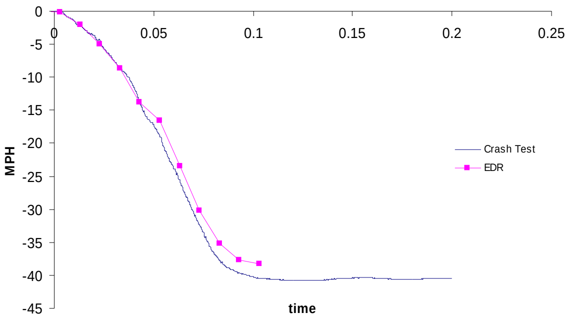

Figure 4. NHTSA test 4198 – 2002 Saturn Vue (with EDR time shift of -.017s).

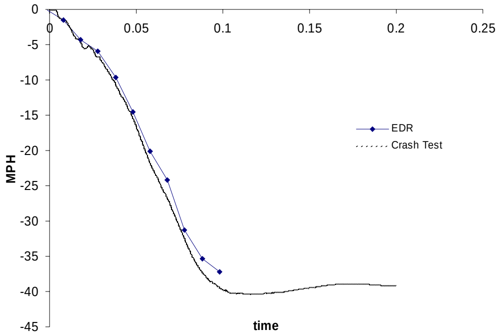

Figure 5. NHTSA test 4238 – 2002 Cadillac Deville (with EDR time shift of -.012s).

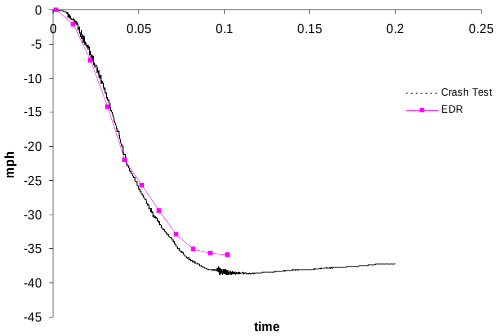

Figure 6. **NHTSA test 4244 – 2002 Chevrolet Trailblazer (with EDR time shift of .002s).**

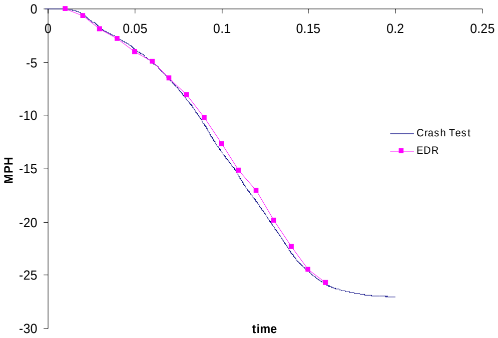

Figure 7. **NHTSA test 4437 – 2003 Chevrolet Suburban (with EDR time shift of .010s).**

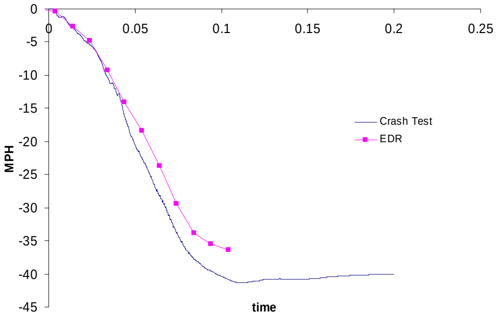

Figure 8. **NHTSA test 4445 – 2003 Chevrolet Cavalier (with EDR time shift of -.006s).**

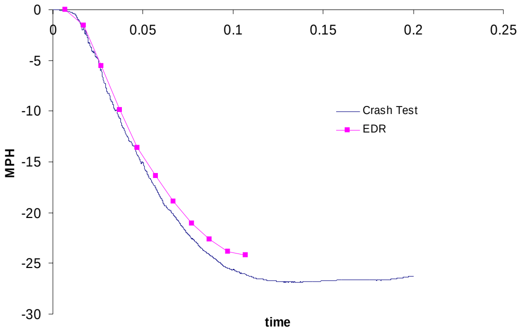

Figure 9. **NHTSA test 4453 – 2003 Chevrolet Silverado (with EDR time shift of .007s).**

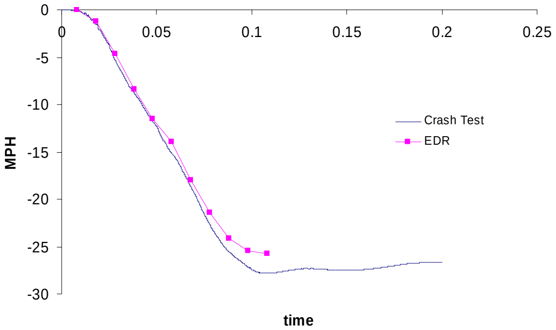

Figure 10. **NHTSA test 4454 – 2003 Chevrolet Tahoe (with EDR time shift of .008s).**

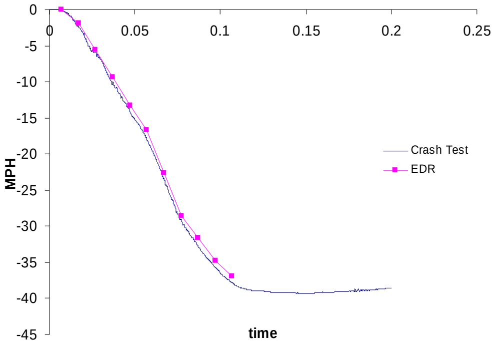

Figure 11. **NHTSA test 4464 – 2003 Chevrolet Avalanche (with EDR time shift of .007s).**

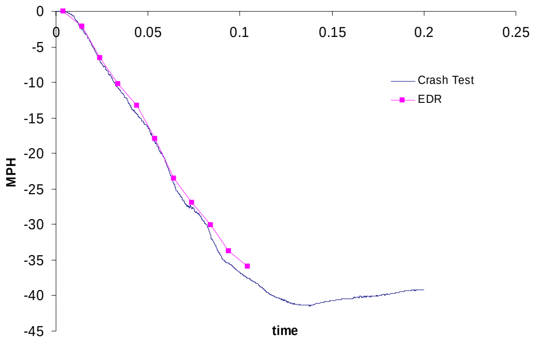

Figure 12. NHTSA test 4472 – 2003 Chevrolet Silverado (with EDR time shift of .004s).

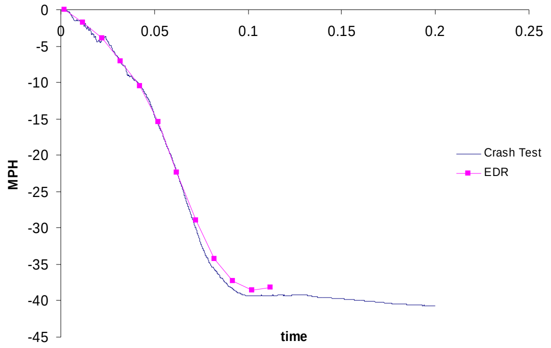

Figure 13. NHTSA test 4487 – 2003 Saturn Ion (with EDR time shift of .002s).

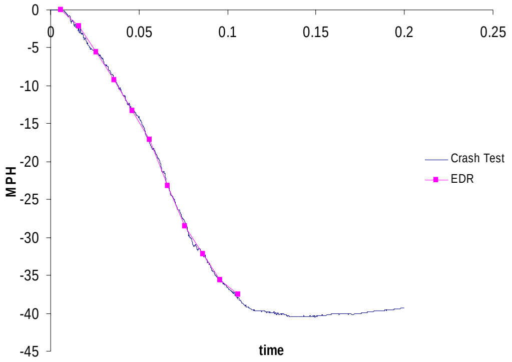

Figure 14. NHTSA test 4567 – 2003 Chevrolet Suburban (with EDR time shift of .006s).

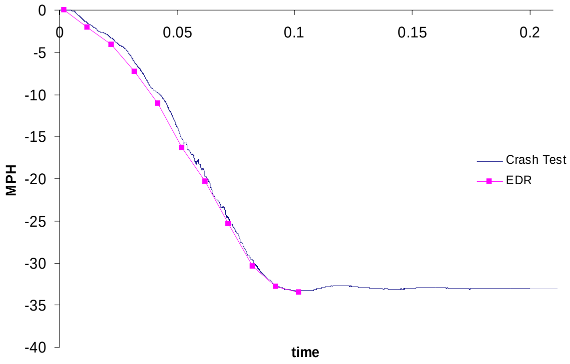

Figure 15. NHTSA test 4702 – 2002 Saturn Vue (with EDR time shift of .002s).

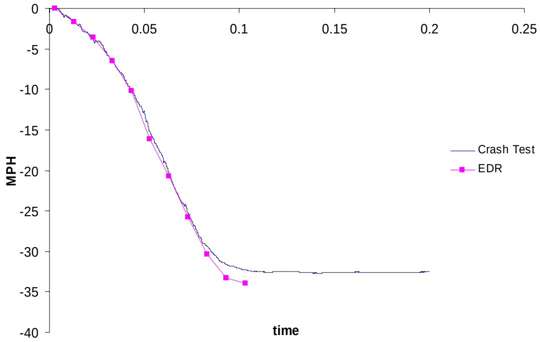

Figure 16. NHTSA test 4714 2002 Saturn Vue (with EDR time shift of .003s).

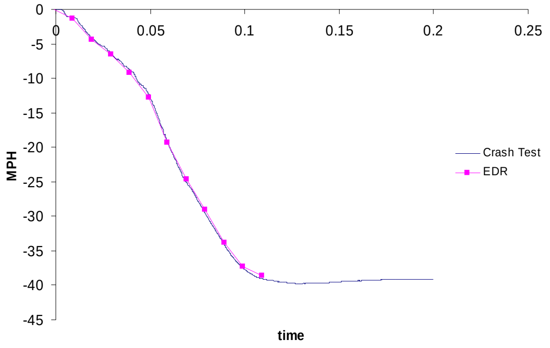

Figure 17. NHTSA test 4775 – 2004 Pontiac Grand Prix (with EDR time shift of -.001s).

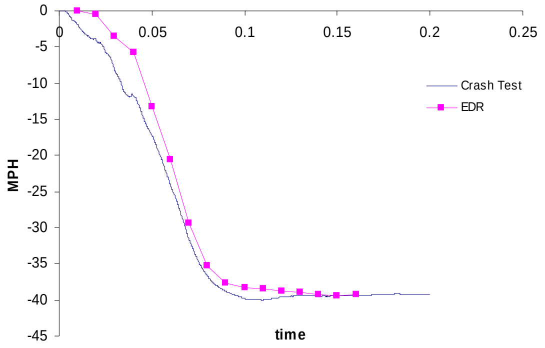

Figure 18. **NHTSA test 4846 2004 Toyota Sienna (with EDR time shift of .010s).**

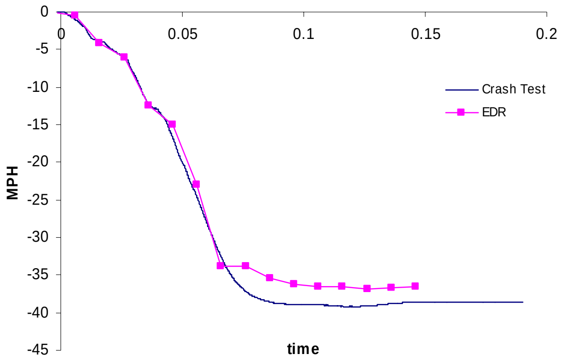

Figure 19. **NHTSA test 4855 2004 Toyota Solara (with EDR time shift of -.004s).**

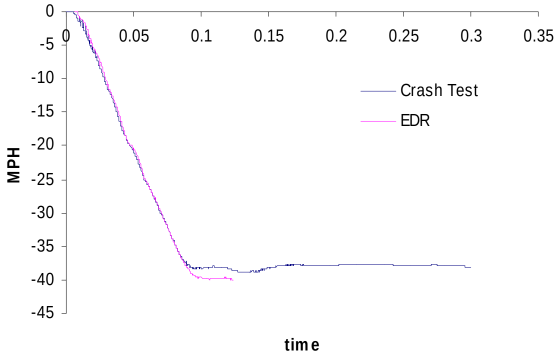

Figure 20. **NHTSA test 4890 – 2004 Ford F150 (with EDR time shift of .009s).**

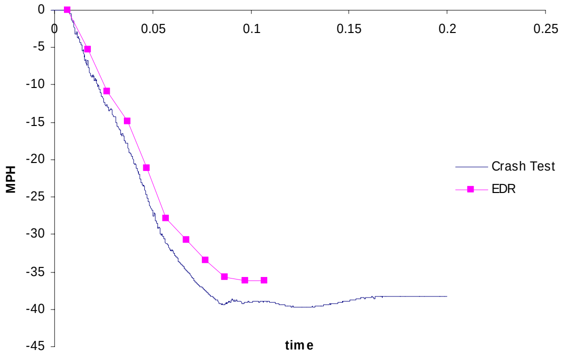

Figure 21. **NHTSA test 4899 – 2004 Cadillac SRX (with EDR time shift of .007s).**

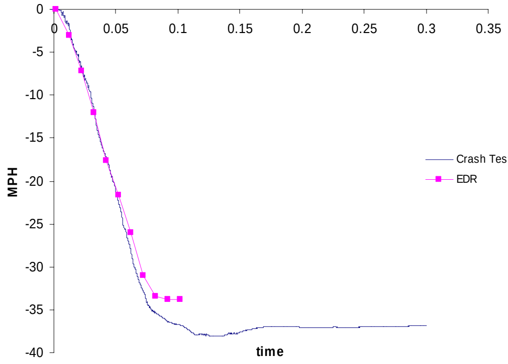

Figure 22. **NHTSA test 4918 – 2004 GMC Envoy XUV (with EDR time shift of .002s).**

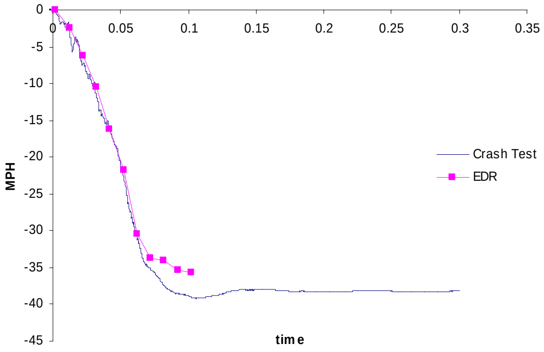

Figure 23. **NHTSA test 4923 – 2004 Chevrolet Colorado (with EDR time shift of .002s).**

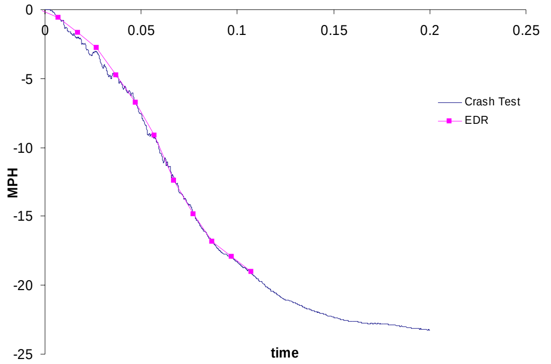

Figure 24. NHTSA test 4955 – 2000 Cadillac Seville (with EDR time shift of -.003s).

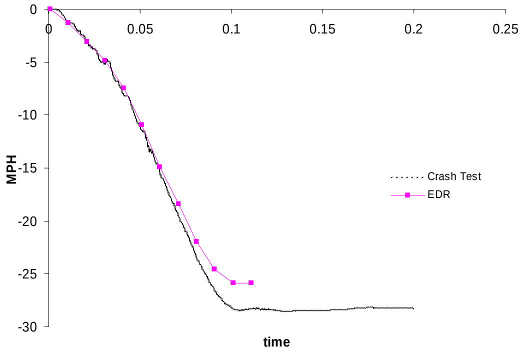

Figure 25. NHTSA test 4984 – 2004 Saturn Ion (with EDR time shift of .001s).

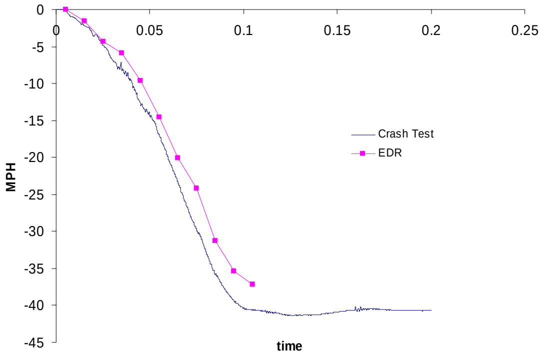

Figure 26. NHTSA test 4985 2005 Chevrolet Equinox (with EDR time shift of -.005s

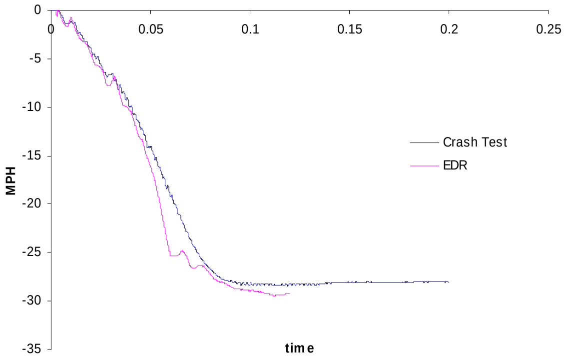

Figure 27. NHTSA test 4987 – 2005 Ford Taurus (with EDR time shift of .006s).

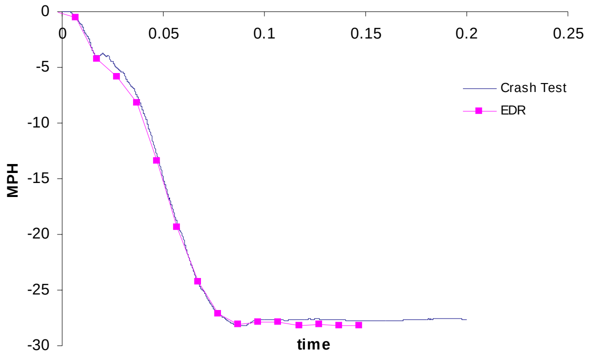

Figure 28. NHTSA test 5071 – 2004 Toyota Camry (with EDR time shift of -.003).

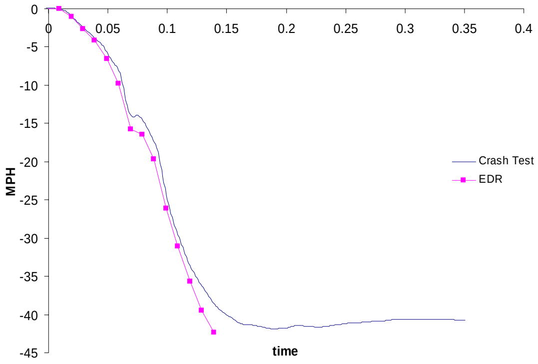

Figure 29. IIHS test CEF0107 – 2001 Chevrolet Silverado (with EDR time shift of -.001s).

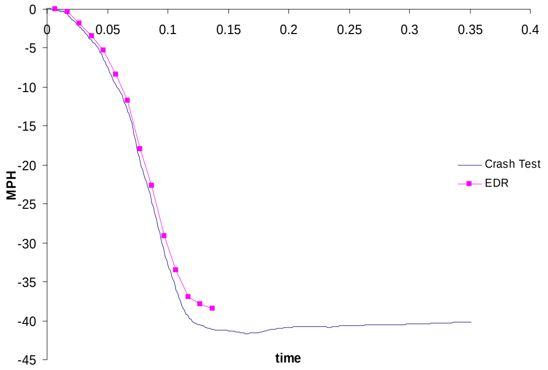

Figure 30. IIHS test CEF0119 2002 – Chevrolet Trailblazer (with EDR time shift of .007s).

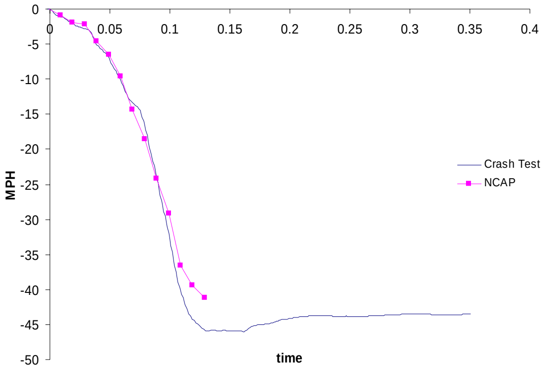

Figure 31. IIHS test CEF0209 – 2003 Cadillac CTS (with EDR time shift of -.001s).

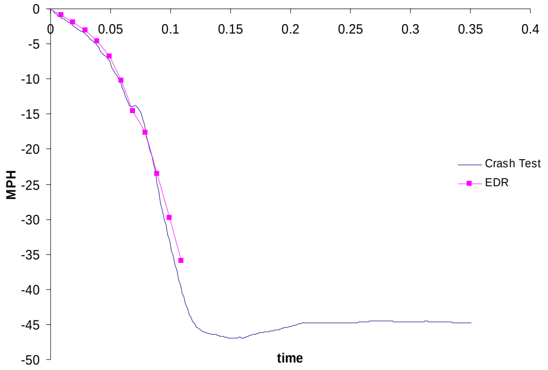

Figure 32. IIHS test CEF0221 – 2003 Cadillac CTS (with EDR time shift of -.001s).

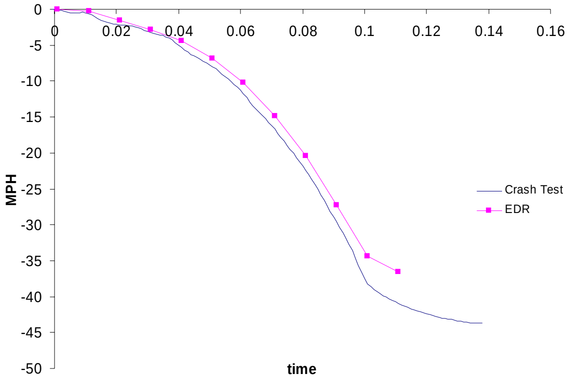

Figure 33. IIHS test CEF0326 – 2004 Cadillac SRX (with EDR time shift of .001s).

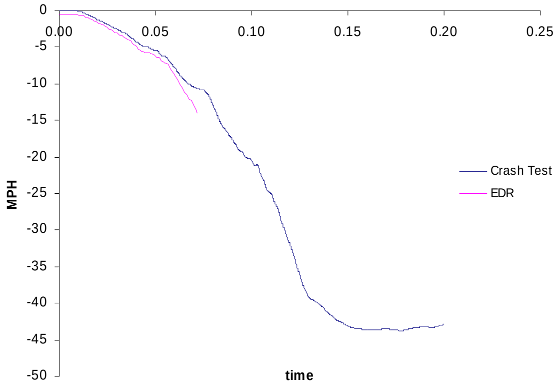

Figure 34. Figure 40. IIHS test CEF0301 – 2003 Lincoln Towncar (with EDR time shift of .013s).

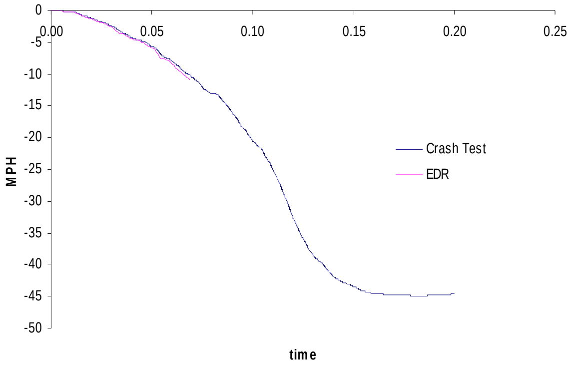

Figure 35. IIHS test CEF0313 – 2003 Lincoln Towncar (with EDR time shift of .010s).

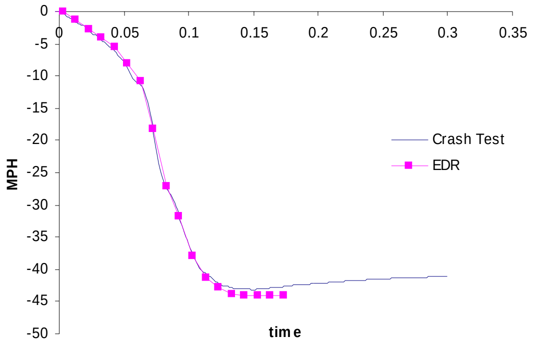

Figure 36. IIHS test CEF0401 – 2004 Chevrolet Malibu, Longitudinal Delta-V (with EDR time shift of -.047s).

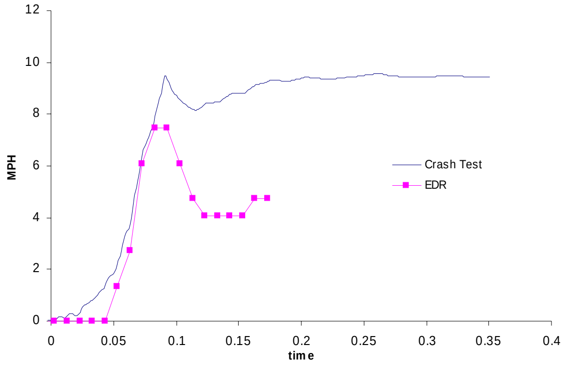

Figure 37. IIHS test CEF0401- 2004 Chevrolet Malibu, Lateral Delta-V (with EDR time shift of -.047s).

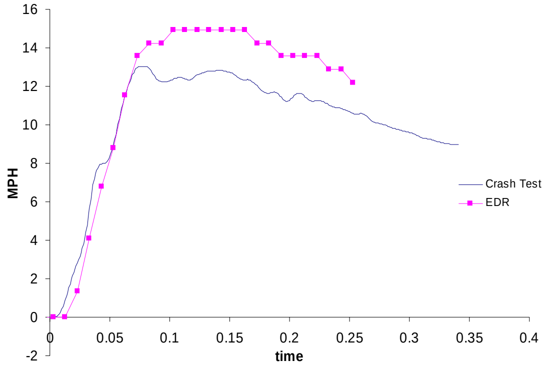

Figure 38. IIHS test CES0403 – 2004 Chevrolet Malibu, Lateral Delta-V (with EDR time shift of -.047s).

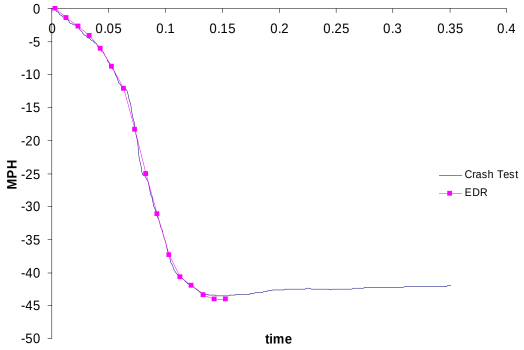

Figure 39. IIHS test CEF0406 – 2004 Chevrolet Malibu, Longitudinal Delta-V (with EDR time shift of -.037s).

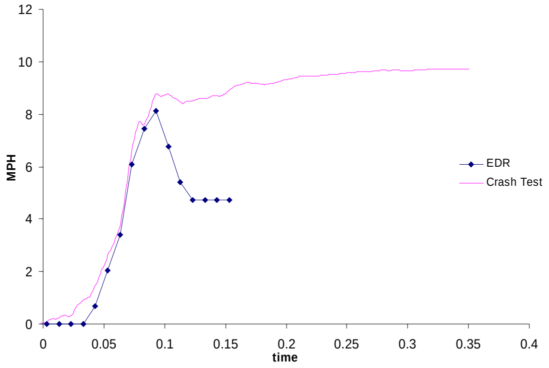

Figure 40. IIHS test CEF0406 – 2004 Chevrolet Malibu, Lateral Delta-V (with EDR time shift of -.037s).

DISCUSSION

Delta-V Data Analyses

All of the delta-v measurements were analyzed to determine if a full crash pulse had been recorded, and also at 100 milliseconds after time zero. First, all units were evaluated, regardless of manufacturer or crash type. Then subsets were examined. Due to there being very few Ford and Toyota units, individual manufacturers were not compared. EDR delta-Vs were compared to the crash test data measurements and percent errors were calculated based on absolute values of the delta-V. Table 2 presents the data for the full crash pulse analyses.

Table 2. Percent Error, Full Crash Pulse Analyses of EDR Delta-V

	All	Frontal	Lateral	Full Frontal	Offset-Frontal
Count	31	28	3	21	7
Avg	7.05	5.82	18.56	5.75	6.04
St dev	5.63	4.23	3.70	4.08	4.98
Min	0.19	0.19	14.40	0.19	1.19
Max	21.47	14.85	21.47	13.41	14.85

For all frontal crashes, the average error was slightly less than 6 percent. When frontal crashes were analyzed by crash offset, the observed error was similar, slightly less than 6 percent for full frontal crashes and slightly more than that value for offset frontal crashes. In some cases, the error was nearly zero. For lateral crash pulses, the observed error approached 19 percent. Two of the tests where lateral measurements were observed were offset frontal crashes with vehicles that have lateral measurement capabilities. In this configuration, the vehicle yaws considerably during the test. The resulting spinning motions will produce different lateral acceleration measurements (and hence different measurements of delta-V) if the sensors are mounted at different locations. Since the EDR and crash test sensors are not mounted together, it is quite possible this factor could have magnified the error percentage.

Table 3 presents similar data for the 100-millisecond delta-V interval analyses. This comparison includes more cases, as well as examines the accuracy of the EDR without penalization for its recording duration. As can be seen from the averages, adding 6 additional EDR comparisons did not change the results significantly.

Table 3. Percent Error, 100-msec Crash Pulse Analyses of EDR Delta-V

	All	Frontal	Lateral
Count	37	34	3
Avg	6.30	5.50	15.43
St dev	4.49	3.43	5.78
Min	0.60	0.60	10.50
Max	21.80	12.60	21.80

Table 4 illustrates the problem of insufficient EDR recording duration. The majority of the EDRs did not record the entire event. In one-third of the GM tests (10 of 30), 10% or more of the crash pulse duration was not recorded. In two of the four Ford tests, the last 100 ms of the crash pulse was not recorded. A data loss of this magnitude would prevent an crash investigator from using an EDR to even estimate the true delta-V of a vehicle. We note that the latest generation of Ford EDRs, downloaded from tests 4890 and 4987, has a greatly increased recording duration sufficient to capture the entire crash pulse in a barrier collision.

As previously discussed, EDRs begin recording a collision after experiencing a deceleration of 1-2 G's. Accordingly, one would believe that a corrective time shift would be positive to compensate for the time lost before algorithm-enable, however this was not always the case. Time shifts varied from negative 17ms to positive 13ms, except for two of the Malibu collisions. In the two Malibu tests, the EDR recorded zero delta-V for the first 40ms. These cases resulted in time shifts of negative 47 and negative 37ms. GM has indicated that these large shifts for the Malibu are the result of an error in the Vetronix software which is being corrected. The problem of negative time shifts was restricted to GM and Toyota EDRs in our dataset. None of the Ford EDRs in our study required a negative time shift.

Negative EDR time shifts can occur for several reasons. First, they may be an artifact of the test. In a crash test, the car is towed down a track and mechanically disconnected from the towing mechanism 8-18 inches from the barrier. The shock of this mechanical disconnect could theoretically prematurely trigger algorithm enable. For our study, we examined pre-crash test data from each crash test, but could find no evidence of a sufficiently high acceleration to prematurely trigger algorithm enable.

Table 4. Summary of the accuracy of EDR performance in crash test

Test Number	Axis	Vehicle Year, Make and Model	EDR Delta-V @100ms (mph)	Crash Test Delta-V @100ms (mph)	Delta-V Error (%)	EDR Time Shift (ms)	Crash Pulse Duration – Estimated (ms)	EDR Recording Time (ms)	Crash Pulse Duration Error (%)
3851	Long	2002 Chevrolet Avalanche	35.9	36.9	-2.8	-3	125	110	12.0
3952	Long	2002 Buick Rendezvous	41.0	41.4	-0.9	1	103	100	2.9
4198	Long	2002 Saturn Vue	40.3	38.3	4.9	-17	102	120	None
4238	Long	2002 Cadillac Deville	39.8	37.2	6.5	-12	102	110	None
4244	Long	2002 Chevrolet Trailblazer	38.1	36.0	5.5	3	96	100	None
4437	Long	2003 Chevrolet Suburban	13.5	12.7	6.2	9	169	150	11.2
4445	Long	2003 Chevrolet Cavalier	40.4	36.4	9.9	-6	105	110	None
4453	Long	2003 Chevrolet Silverado	25.6	23.9	6.6	6	117	100	14.5
4454	Long	2003 Chevrolet Tahoe	27.5	25.4	7.5	8	101	100	1.0
4464	Long	2003 Chevrolet Avalanche	36.6	36.9	-0.7	5	119	100	16.0
4472	Long	2003 Chevrolet Silverado	36.8	36.0	2.3	4	127	100	21.0
4487	Long	2003 Saturn Ion	39.3	38.6	1.9	2	148	110	25.5
4567	Long	2003 Chevrolet Suburban	36.8	37.5	-1.9	5	128	100	21.9
4702	Long	2002 Saturn Vue	33.3	33.5	-0.6	3	94	100	None
4714	Long	2002 Saturn Vue	32.3	33.9	-5.1	2	104	100	3.8
4775	Long	2004 Pontiac Grand Prix	37.8	37.3	1.2	-1	116	110	4.8
4846	Long	2004 Toyota Sienna	38.3	39.8	3.8	10	105	150	None
4855	Long	2004 Toyota Solara	36.3	38.9	6.7	-4	123	150	None
4890	Long	2004 Ford F-150	39.7	38.1	4.2	9	99	114	None
4899	Long	2004 Cadillac SRX	36.27	39.05	7.1	7	95	100	None
4918	Long	2004 GMC Envoy XUV	33.8	36.7	7.8	2	129	100	22.5
4923	Long	2004 Chevrolet Colorado	35.7	38.9	8.2	2	121	100	17.4
4955	Long	2000 Cadillac Seville	18.4	17.9	2.5	-3	157	110	29.9
4984	Long	2004 Saturn Ion	28.3	25.9	8.4	2	101	110	None
4985	Long	2005 Chevrolet Equinox	40.4	35.3	12.6	-4	113	110	2.7
4987	Long	2005 Ford Taurus	28.9	28.2	-2.5	6	95	114	None
5071	Long	2004 Toyota Camry	27.9	27.6	1.1	-3	89	150	None
CEF0107	Long	2001 Chevrolet Silverado	25.0	26.1	-4.4	-1	143	140	2.1
CEF0119	Long	2002 Chevrolet Trailblazer	32.8	29.1	11.1	7	131	130	0.8
CEF0209	Long	2003 Cadillac CTS	32.8	29.1	11.2	-1	127	130	None
CEF0221	Long	2003 Cadillac CTS	33.8	29.8	11.9	-1	134	110	17.9
CEF0326	Long	2004 Cadillac SRX	37.5	34.4	8.3	1	129	110	14.7
CEF0301	Long	2003 Lincoln Towncar	N/A	19.4	N/A	10	154	70	56
CEF0313	Long	2003 Lincoln Towncar	N/A	19.3	N/A	13	151	75	50.3
CEF0401	Long	2004 Chevrolet Malibu	38.0	36.0	-5.6	-47	140	220	None
CEF0401	Lateral	2004 Chevrolet Malibu	7.5	8.7	14	-47	140	220	None
CES0403	Lateral	2004 Chevrolet Malibu	13.6	12.3	-10.5	-47	144	300	None
CEF0406	Long	2004 Chevrolet Malibu	37.3	35.5	-5	-37	145	190	None
CEF0406	Lateral	2004 Chevrolet Malibu	6.8	8.7	21.8	-37	145	190	None

Table 5. Accuracy of Pre-Crash Measurements

Test Number	Vehicle Year, Make and Model	Driver Seat Belt Buckled (y/n)	EDR Reported Buckled (y/n)	Agree-ment?	EDR Pre-Crash Vehicle Speed (mph)	Actual Pre-Crash Vehicle Speed (mph)	% Error
3851	2002 Chevrolet Avalanche	Y	Y	Y	35	35.1	0.3
3952	2002 Buick Rendezvous	Y	Y	Y	35	35.1	0.3
4198	2002 Saturn Vue	Y	Y	Y	35	35	0.0
4238	2002 Cadillac Deville	Y	Y	Y	34	35.3	3.7
4244	2002 Chevrolet Trailblazer	Y	Y	Y	34	35.1	3.1
4437	2003 Chevrolet Suburban	Y	Y	Y	24	24.8	3.2
4445	2003 Chevrolet Cavalier	Y	Y	Y	35	34.7	0.9
4453	2003 Chevrolet Silverado	N	N	Y	24	24.3	1.2
4454	2003 Chevrolet Tahoe	N	N	Y	24	24.3	1.2
4464	2003 Chevrolet Avalanche	Y	Y	Y	34	35.1	3.1
4472	2003 Chevrolet Silverado	Y	Y	Y	35	34.7	0.9
4487	2003 Saturn Ion	Y	Y	Y	35	34.8	0.6
4567	2003 Chevrolet Suburban	Y	Y	Y	35	35	0.0
4702	2002 Saturn Vue	N	N	Y	30	29.7	1.0
4714	2002 Saturn Vue	N	N	Y	29	29.7	2.4
4775	2004 Pontiac Grand Prix	Y	Y	Y	35	34.7	0.9
4846	2004 Toyota Sienna	Y	Y	Y	34.8	35.1	0.9
4855	2004 Toyota Solara	Y	Y	Y	N/A	34.7	N/A
4890	2004 Ford F-150	Y	Y	Y	N/A	35	N/A
4899	2004 Cadillac SRX	Y	Y	Y	35	35.1	0.3
4918	2004 GMC Envoy XUV	Y	Y	Y	35	35	0.0
4923	2004 Chevrolet Colorado	Y	Y	Y	35	35.2	0.6
4955	2000 Cadillac Seville	Y	Y	Y	35	34.7	0.8
4984	2004 Saturn Ion	N	N	Y	25	24.8	0.8
4985	2005 Chevrolet Equinox	Y	Y	Y	35	35	0.0
4987	2005 Ford Taurus	N	N	Y	N/A	25	N/A
5071	2004 Toyota Camry	N	N	Y	N/A	24.6	N/A
CEF0107	2001 Chevrolet Silverado	Y	Y	Y	39	40	2.5
CEF0119	2002 Chevrolet Trailblazer	Y	Y	Y	40	40	0.0
CEF0209	2003 Cadillac CTS	Y	Y	Y	40	40	0.0
CEF0221	2003 Cadillac CTS	Y	Y	Y	40	40	0.0
CEF0326	2004 Cadillac SRX	Y	Y	Y	39	40	2.5
CEF0301	2003 Lincoln Towncar	Y	Y	Y	N/A	40	N/A
CEF0313	2003 Lincoln Towncar	Y	Y	Y	N/A	40	N/A
CEF0401	2004 Chevrolet Malibu	Y	N/A	N/A	N/A	40	N/A
CES0403	2004 Chevrolet Malibu	Y	N/A	N/A	N/A	0	N/A
CEF0406	2004 Chevrolet Malibu	Y	N/A	N/A	N/A	40	N/A

The negative time shifts could also be an artifact of our alignment algorithm. Inspection of the velocity plots however indicates that reasonable alignment has been achieved. As a more analytical check, we performed a sensitivity analysis of variations on time shift, and found that in all cases the alignment algorithm had found the optimal time shift.

Finally, it is possible that the EDR time zero is not always the time of algorithm enable. It is difficult to believe, for example, that the 2004 Chevrolet Malibu EDR, which required a 47 ms negative time shift, could have detected the crash this far in advance of the actual impact without the advantage of exotic technology such as radar crash detection.

Pre-Crash Velocity Measurements

The GM EDRs and some of the Toyota EDR models in our dataset also stored 5 seconds of pre-crash data including a record of vehicle speed, accelerator/engine throttle position, engine revolutions per minute and brake application. None of the Ford EDRs in our dataset contained pre-crash data. In a total of 28 of the tests, the EDR was capable of recording vehicle speed. As can be seen in Table 5, in general the EDRs performed very well regarding pre-crash measurements. For these EDRs, the error in the vehicle speed was less than 1mph in all cases.

Seat Belt Buckle Status

The GM EDRs in our dataset recorded driver seat belt buckle status. The Toyota and Ford EDRs recorded both driver and right front passenger seat belt buckle status. The driver seat belt buckle status as reported in each crash test final report was compared against seatbelt buckle status as recorded by the EDRs. In all cases, the driver seatbelt status was correctly recorded by all EDRs.

CONCLUSIONS

This paper has presented the results of a methodical evaluation of the accuracy of Event Data Recorders in thirty-seven (37) laboratory crash tests across a wide spectrum of impact conditions.

- Results from comparing crash test accelerometers with Event Data Recorders show that if a full pulse is recorded in a frontal crash, the average error is about 6 percent, with some EDRs almost exactly duplicating the crash test instrumentation. If examining the pulse at 100ms, for frontal crashes the average error is also about 6 percent.

- For lateral measurements, the small sample produced large error, but much of the error could be associated with different sensor locations, hence the estimate may be flawed and is not reported in the conclusions.

- In nearly all cases, the delta-V recorded by the Event Data Recorders was less than the true delta-V. One exception is the new Chevrolet EDRs in the Malibu tests. These units consistently recorded a larger delta-V than the crash test instrumentation.

- The majority of the EDRs examined in this study did not record the entire event. In one-third of the GM tests (10 of 30), 10 percent or more of the crash pulse duration was not recorded. In two of the four Ford tests, the last 100 ms of the crash pulse was not recorded. A data loss of this magnitude would prevent an crash investigator from using an EDR to even estimate the true delta-V of a vehicle. Although data recorders generally under-predict delta-V, crash investigators can examine a pulse and determine if it completed recording, which reduces the uncertainty of the measurement. In the future, if EDR manufacturers were to extend the recording duration of their products, significant improvement in accuracy would be seen.

- In all tests, the EDRs correctly measured and recorded driver seat belt buckle status.

- Regarding pre-crash data, of the 28 tests where EDR and test speed were known, the average error was 1.1 percent.

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INJURY RISK ASSESSMENT FROM REAL WORLD INJURY OUTCOMES IN EUROPEAN CRASHES AND THEIR RELATIONSHIP TO EURONCAP TEST SCORES.

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ABSTRACT

Assessment of vehicle occupant injury outcomes from the analysis of real crash data is important not only for measuring the safety performance of particular vehicle models but also for monitoring the design improvements in vehicles over time. This paper describes the development and application of methods to assess driver injury risk and injury severity outcomes from the analysis of large police reported crash databases from two major European countries: France and Great Britain. Analysis of injury risk and severity has utilised a new method of analysis based on the paired comparison approach that corrects for inherent bias in the established methods whilst adjusting the injury risk and severity ratings for the influence of non vehicle factors such as occupant and crash characteristics. Outputs from the initial analysis are example vehicle safety ratings that could be developed and used for consumer information on relative vehicle occupant protection performance throughout Europe. A final focus of the study is to examine the relationship between the injury risk and severity ratings derived from the police crash data sources and the relative vehicle safety performance ratings published by EuroNCAP. Comparison is made both at the overall level and between real crash ratings based on specific crash configurations similar to those used in the EuroNCAP test protocol.

INTRODUCTION

This paper describes the analysis in sub-tasks 2.1 and 2.2 of the second phase of the project *Quality Criteria for the Safety Assessment of Cars based on Real-World Crashes* being carried out by the Safety Rating Advisory Committee (SARAC) for the European Commission who fund the project.

Assessment of vehicle occupant injury outcomes from the analysis of real crash data is important not only for measuring the safety performance of particular vehicle models but also for monitoring the design improvements in vehicles over time. To this end, a number of systems to rate relative vehicle safety from the analysis of injury outcomes recorded in police reported crash data. A review of all these systems can be found in Cameron et al (2001a). A number of these systems regularly produce vehicle safety ratings that are published for consumer information in the countries where the ratings systems were developed. Three ratings systems have been developed by the following European organisations:

- Road and Transport Laboratory, University of Oulu, Finland (Huttula, Pirtala and Ernvall 1997)
- Department of the Environment, Transport and Regions (DETR), U.K. (Transport Statistics Report 1995)
- Folksam Insurance, Sweden (Hägg et al 1992; Kullgren 1999)

Each of these vehicle safety ratings systems has developed different measures of vehicle crashworthiness, each attempting to measure the risk of injury or serious injury to a vehicle driver involved in a two-car collision.

This paper reviews the three identified European crashworthiness measures. It then proposes a new crashworthiness measure which overcomes one of the key deficiencies noted in each of three existing measures considered. Application of the new measure is then demonstrated on police reported crash data from both France and Great Britain. Finally the vehicle safety ratings resulting from the application of the method are compared to the outcomes of EuroNCAP barrier testing to assess the relationship between these two measures of driver injury risk in a crash.

A REVIEW OF THE EXISTING EUROPEAN SAFETY RATING SYSTEMS

The rating criteria for each of the three existing methods considered are measures of the risk of injury or severe injury to drivers of specific car models when involved in a crash. In the first two systems, the criterion stops at the risk of injury. In the Folksam method, the criterion goes beyond injury to measure the risk of severe injury in two steps: (1) the risk of injury in a crash, multiplied by (2) the risk of severe injury, given that the driver is injured. For the moment, only the component which measures the risk of injury in a crash is considered. Each of the three rating systems is based on the injury outcomes of two-car crashes involving specific car models. In each system, only two-car crashes in which at least one driver was injured are analysed. Although the University of Oulu has also developed a rating system based on all two car crashes, including those not involving injury, only the system based on injury crashes is considered here.

In reviewing the vehicle crashworthiness measures, it seems apparent that each of the three considered has been developed to overcome limitations when only crashes involving injury to at least one of the drivers involved in the crash are reported. In each of these systems, measures of driver injury risk have been derived that compensate for the lack of availability of non-injury crash data. Whilst each measure is computationally and conceptually different, each has inadequacies in the way it uses the data to form an estimator of driver injury risk in a crash.

To illustrate these inadequacies, consider a conceptual framework similar to that derived by Folksam in the derivation of their injury risk measure based on the two-car crash matched-pair concept. This framework is also suitable for comparing all other vehicle safety estimators considered under the SARAC project. The Folksam framework is defined as follows.

Consider *N* observed two car crashes involving vehicle model *k*. Let p_{1k} be the average injury probability to the driver of the focus vehicle model, *k*, and p_{2k} be the average injury probability to the drivers of all vehicles colliding with vehicle model *k*. Categorising the *N* observed crashes into a 2x2 table defined by injury or no injury to the focus and other vehicle drivers, the following table of expected crash frequencies arises, assuming p_{1k} and p_{2k} to be independent (Table 1).

Let the observed categorised crash frequencies corresponding to the expected values under the conceptual framework in Table 1 for vehicle model *k* be as shown in Table 2.

For data systems not reporting non-injury crashes, n_{nnk} will be unknown in Table 2.

Table 1.
Expected Number of Two-car Crashes between Vehicle Model (k) and Other Vehicles

Drivers of vehicle model *k*	**Drivers of other vehicles**		
	INJURED	NOT INJURED	
INJURED	$N\ p_{1k}\ p_{2k}$	$N\ p_{1k}\ (1-p_{2k})$	$N\ p_{1k}$
NOT INJURED	$N(1-p_{1k})p_{2k}$	$N(1-p_{1k})(1-p_{2k})$	$N\ (1-p_{1k})$
	$N\ p_{2k}$	$N\ (1-p_{2k})$	N

Table 2.
Observed Number of Two-car Crashes between Vehicle Model (k) and Other Vehicles

Drivers of vehicle model *k*	**Drivers of other vehicles**		
	INJURED	NOT INJURED	
INJURED	n_{iik}	n_{ink}	$n_{iik} + n_{ink}$
NOT INJURED	n_{nik}	n_{nnk}	$n_{nik} + n_{nnk}$
	$n_{iik} + n_{nik}$	$n_{ink} + n_{nnk}$	N

When the total number of two-car crashes where both drivers are uninjured (n_{nnk}) is known, and hence *N* is known, the margins of Table 2 can be used to derive an unbiased estimator of injury risk to the focus car driver. Such an estimator has been used in crashworthiness systems in Australia (Newstead et al, 2002) and Finland (Huttula et al, 1997) and is defined as follows

$$R_{Ck} = \frac{n_{iik} + n_{ink}}{N}$$

Based on the conceptual framework given in Table 1, the expected value of R_{Ck} is given by

$$E(R_{Ck}) = p_{1k}$$

That is, R_{Ck} is an unbiased estimator of the risk of injury to the driver in the focus vehicle model, *k*.

More recently, attention in vehicle safety ratings systems has turned to estimating the relative risk of injury various vehicle models pose to the drivers of other vehicles with which they collide, a concept labelled aggressivity. Using the same conceptual framework defined in Table 1, an aggressivity metric has been developed in Australia based on injury and non-injury two car crashes (Cameron et al, 1998). The aggressivity injury risk measure is defined as follows

$$\mathrm{R}_{\mathrm{Ak}} = \frac{\mathrm{n}_{\mathrm{iik}} + \mathrm{n}_{\mathrm{nik}}}{\mathrm{N}} \text{ with } \mathrm{E}(\mathrm{R}_{\mathrm{Ak}}) = \mathrm{p}_{2\mathrm{k}}$$

Like the crashworthiness injury risk measure, R_{Ak} is an unbiased measure of the risk of injury to drivers of other vehicles colliding with vehicle model *k*. Until the concept of aggressivity was considered, it was often assumed that $\mathrm{p}_{2\mathrm{k}}$ would be the same for all vehicle models. In estimating the aggressivity metric on real crash data, however, Cameron et al (1998) show large differences in the aggressivity of different vehicle models. This is important when considering the European crashworthiness measures based on injury only data.

Consider firstly the Folksam estimator of relative injury risk for their vehicle safety ratings system. The Folksam relative injury risk estimator for vehicle model *k* is defined as follows:

$$R_{Fk} = \frac{n_{iik} + n_{ink}}{n_{iik} + n_{nik}}$$

Descriptively, this measure is the ratio of the number of crashes with injured drivers in vehicle model *k* to the number of crashes with injured drivers in all vehicles colliding with vehicle model *k*. This has been described by Folksam as the risk of injury to drivers of vehicle model k relative to the average injury risk of driver injury across the whole vehicle fleet. Based on the conceptual framework given in Table 1, the expected value of R_{Fk} is given by

$$E(R_{Fk}) = \frac{Np_{1k}}{Np_{2k}} = \frac{p_{1k}}{p_{2k}}$$

If R_{Fk} is to be a relative risk comparable across all vehicle models rated, it must be assumed that p_{2k}, the aggressivity injury risk measure, is equal for each vehicle model rated. Folksam argue that this is the case because each vehicle model collides with a similar population of ‘other’ vehicles. This assumption, however, ignores the possibility that different vehicle models pose different risk of injury to drivers of other vehicles with which they collide, an assumption challenged by the results of Cameron et al (1998). That is, it assumes each vehicle has identical aggressivity which, by definition, is measured by p_{2k} for vehicle model *k*. Consequently, if the Folksam relative injury risk measure is adopted, there can be no corresponding independent measure of vehicle aggressivity derived from the Folksam framework. This point is demonstrated clearly by Broughton (1996).

In practice, the Folksam relative injury risk measure is a function of not only the crashworthiness of the focus vehicle model *k*, p_{1k} , but also its aggressivity, p_{2k}. Further, if there are two vehicles with equal risk of driver injury but differing aggressivity, the vehicle with the higher aggressivity will rate better in the Folksam system.

Consider next the DETR measure of injury risk used in Great Britain defined as follows:

$$R_{Dk} = \frac{n_{iik} + n_{ink}}{n_{iik} + n_{nik} + n_{nik}}$$

Correspondingly, the expected value of R_{Dk} derived from Table 1 is given by

$$E(R_{Dk}) = \frac{p_{1k}}{p_{1k} + p_{2k} - p_{1k}p_{2k}}$$

Conceptually, R_{Dk} measures the risk of injury in the focus vehicle, *k*, given its involvement in a crash where at least one driver is injured. As evident from the expected value of R_{Dk}, the measure, like the Folksam measure, is also a confounded function of the focus vehicle passive safety, p_{1k} , as well as its aggressivity, p_{2k}.

Broughton (1996) considered a partner aggressivity measure similar to the DETR injury risk measure which may also be defined under the conceptual framework being used here as follows:

$$A_{Dk} = \frac{n_{iik} + n_{nik}}{n_{iik} + n_{nik} + n_{ink}}$$

The corresponding expected value is given by

$$E(A_{Dk}) = \frac{p_{2k}}{p_{1k} + p_{2k} - p_{1k}p_{2k}}$$

Whilst A_{Dk} is not the reciprocal of R_{Dk}, as would be the case with a Folksam aggressivity measure derived in the same spirit, A_{Dk} and R_{Dk} are far from independent, as also noted by Broughton (1996).

Turning to the Oulu measure of injury risk derived from injury crash data, defined as follows:

$$R_{Ok} = \frac{n_{iik} + n_{ink}}{2n_{iik} + n_{nik} + n_{ink}}$$

with the corresponding expected value given by

$$E(R_{Ok}) = \frac{p_{1k}}{p_{1k} + p_{2k}}$$

Conceptually, the Oulu injury risk measure is the proportion of all injured drivers in two car crashes involving vehicle model *k* who were drivers of vehicle model *k*. As with the DETR and Folksam measures, crashworthiness and aggressivity of vehicle model *k* are confounded in the Oulu crashworthiness injury risk measure.

AN ALTERNATIVE SAFETY RATING SYSTEM BASED ON INJURY CRASH DATA

To overcome the problem of crashworthiness and aggressivity being confounded in all the existing crashworthiness measures based on the analysis of two-car injury crashes, a new measure is proposed. Again, based on the conceptual framework shown in Table 1, the new measure of driver injury risk in vehicle model *k* is defined as follows:

$$\mathrm{R}_{\mathrm{Nk}} = \frac{\mathrm{n}_{\mathrm{iik}}}{\mathrm{n}_{\mathrm{iik}} + \mathrm{n}_{\mathrm{nik}}}$$

The corresponding expected value given by

$$E(R_{Nk}) = p_{1k}$$

R_{Nk} is an unbiased estimator of p_{1k} and as such is not confounded with the aggressivity parameter for vehicle model k, p_{2k}.

Because the new measure is an estimator of absolute injury probabilities, it can be estimated using logistic regression techniques. This allows simultaneous adjustment of concomitant factors affecting injury risk other than the vehicle model, such as driver age and sex and accident circumstances, in a way identical to that used in both the existing Australian and British crashworthiness rating systems. In practice, to estimate the new injury risk measure via logistic regression, two car crashes involving the focus vehicle where the driver of the other vehicle is injured are identified in the crash data. A dichotomous injury outcome for the driver of the focus vehicle is then defined (injured/not-injured) which becomes the dependent variable in the logistic regression model.

If desired, the new injury risk measure can be combined with an injury severity measure in the same way as the existing Australian and Swedish rating systems (Newstead et al, 2002; Haag et al, 1992) to produce a measure of serious injury risk. For the purposes of this paper, the injury severity measure (S_{Nk}) is defined in the same was as that used in the Australian crashworthiness ratings system of Newstead et al (2002). It is the risk of death or hospitalisation to the driver of the focus vehicle given some level of injury is sustained. It can also be estimated by logistic regression techniques incorporating adjustment for the effects of non-vehicle factors in injury severity outcome. The final crashworthiness measure estimates the risk of death or serious injury to the focus driver given crash involvement and is simply the product of the risk and severity components as follows.

$$\mathrm{CWR}_{\mathrm{Nk}} = \mathrm{R}_{\mathrm{Nk}} \times \mathrm{S}_{\mathrm{Nk}}$$

Figure 1 shows the relationship between injury risk to the focus vehicle driver estimated using the new metric and that estimated using full data from both injury and non injury crashes (R_{Ck} above) using an assembled set of both injury and non-injury crash data from 3 States of the USA (see Cameron et al, 2001a). It shows a high degree of correlation between the two rating measures confirming that the new injury risk rating metric can provide ratings consistent with the unbiased measure derived from injury and non-injury data but using only injury data.

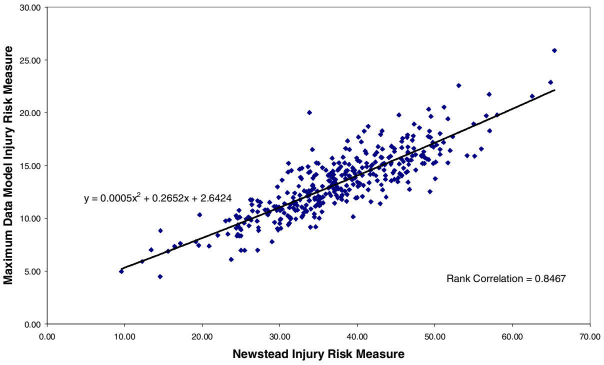

Figure 1: Relationship Between Injury Risk Estimated from Injury and Non-Injury Data and Estimated From Injury Data Only Using the New Metric.

An Associated Aggressivity Measure

It is straight forward to extend the logic by which the new crashworthiness injury risk metric was derived to derive an unbiased measure of aggressivity injury risk from injury only crash data. The corresponding new estimator of aggressivity injury risk in crashes with vehicle make/model *k*, is given by:

$$\mathrm{AR}_{\mathrm{Nk}} = \frac{\mathrm{n}_{\mathrm{iik}}}{\mathrm{n}_{\mathrm{iik}} + \mathrm{n}_{\mathrm{ink}}} \text{ with } \mathrm{E}(\mathrm{AR}_{\mathrm{Nk}}) = \mathrm{p}_{2\mathrm{k}}$$

AR_{Nk} is an unbiased estimator of p_{2k} and as such is not confounded with the crashworthiness parameter for vehicle model k, p_{1k}. Like the crashworthiness risk measure, it can be estimated using logistic regression techniques to adjust for the influence of non-vehicle factors on injury outcome. Like the Australian aggressivity measure based on injury and non-injury crash data (Cameron et al, 1998), the new aggressivity measure can also be extended to measure serious injury risk to the other driver by multiplying the injury risk component by a measure of injury severity.

Figure 2 shows the relationship between aggressivity injury risk to the focus vehicle driver estimated using the new metric and that estimated using full data from both injury and non injury crashes again using the data from 3 States of the USA (see Cameron et al, 2001b). As for the crashworthiness metric, it shows a high degree of correlation between the two aggressivity rating measures confirming that the new metric can provide ratings consistent with the unbiased measure derived from injury and non-injury data but using only injury data.

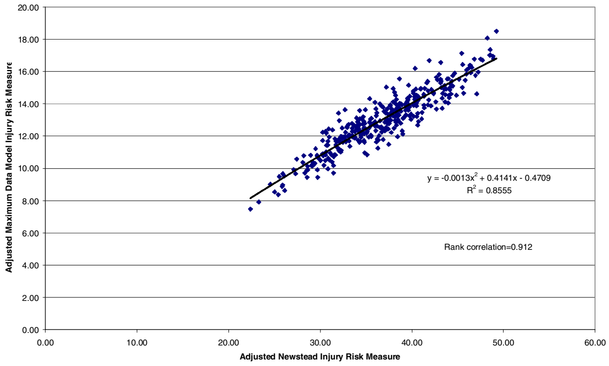

Figure 2. Relationship between aggressivity injury risk estimated from injury and non-injury data and estimated from injury data only using the new metric.

Figure 3 shows the relationship between the new risk measures of crashworthiness and aggressivity for the set of vehicle models rated from the USA data. It demonstrates the desirable property of a high degree of independence between the two measured dimensions of vehicle safety. As noted by Broughton (1996), none of the existing measures of vehicle safety derived from injury only crash data have been able to achieve this level of independence between measures in the two dimensions.

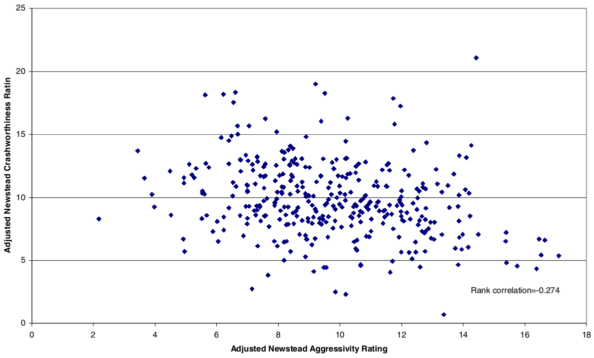

Figure 3. Relationship between the new measures of crashworthiness and aggressivity

APPLICATION OF THE RATING SYSTEM TO POLICE REPORTED CRASH DATA FROM FRANCE AND GREAT BRITAIN

To demonstrate the application of the new crashworthiness measure based on injury only police data, the methods have been applied to estimate crashworthiness ratings for specific vehicles using police reported crash data from two European countries, France and Great Britain. In both countries, only crashes involving injury are reported to police.

Crash Data Sources

Real Crash Data from Great Britain

In Great Britain, all road accidents involving human death or personal injury occurring on the highway ('road' in Scotland) and in which one or more vehicles are involved, are required to be reported to the police within 30 days of occurrence. In addition, all fatal or injury accidents on public roads involving at least one mechanically propelled vehicle should be reported to police unless insurance documents, driver details and ownership and registration information are exchanged between drivers. These data are then recorded in the STATS19 database. Crashes not involving human injury do not appear in the data. Crash data for the period 1993 to 2001 were supplied for use in this study by the UK Department for Transport (DfT).

Driver injury level is coded in the British data using a three level scale. These levels are:

1. Fatal: includes cases where death occurs in less than 30 days as a result of the accident
2. Serious injury: includes fractures, internal injury, severe cuts, crushing, burns, concussion, severe shock requiring hospital treatment, detention in hospital as

an in-patient immediately or at a later date, injuries from the crash resulting in death 30 days or more after the crash

3. Slight injury: including sprains or whiplash not necessarily requiring medical treatment, bruises, slight cuts, slight shock requiring roadside attention.

After selecting passenger vehicles only, complete information for the required variables was available for 1,635,296 crashes. Information on the non-vehicle factors driver age, driver sex, junction, point of impact and speed limit of the crash site was also available in the data. Estimation of injury risk for all crash types using the new method considered 546,984 two-car crashes. Estimation of injury severity for all crash types using the Australian severity measure considered a total of 775,972 injured drivers involved in either single vehicle (159,306) or two-vehicle crashes (616,666). For the purposes of comparison with EuroNCAP results, sub-sets of these data were also used to estimate injury risk and injury severity for front impact and side impact crashes after selecting for the point of impact on the focus vehicle.

Real Crash Data from France

In France, every road accident in which at least one road user received medical treatment is investigated by the police and included in a national database managed by the Ministry of Transportation. An extract this database for the years 1993 to 2001 was supplied by the Laboratory of Accidentology, Biomechanics and Human Behaviour (LAB) in France for use in this study. Only those cases meeting the following criteria were provided:

- No two wheelers involved;
- Only drivers or right front passengers of private cars whose injury severity is known;
- All types of collisions and obstacles.

Driver injury level is coded in the French data using a four level scale. These levels are:

1. Uninjured: no medical treatment
2. Fatal: death within seven days of the crash
3. Serious injury: more than 6 days in hospital
4. Slight injury: less than seven days in hospital

Of the records provided, a total of 610,118 contained complete information for the required variables. Variables on the non-vehicle factors driver age, driver sex, road junction type, point of impact and speed limit of the crash site were also available in the data. Estimation of injury risk using the new method considered 280,603 two-car crashes. Estimation of injury severity using the Australian severity measure considered a total of 379,557 injured drivers involved in either single vehicle (98,249) or two-vehicle crashes (281,308). Sub-sets of these data were used to estimate injury risk and injury severity for front impact and side impact crashes after selecting for the point of impact on the focus vehicle.

Because of fundamental differences in injury level coding of the French and UK data, they could not be combined for analysis and were analysed separately.

Identification of Vehicle Models

Because the secondary focus of this study was to compare the new crashworthiness metric with results from EuroNCAP testing, only EuroNCAP tested vehicle models were chosen from the real crash data for analysis. EuroNCAP tested vehicles were selected for inclusion in the analysis where at least 80 drivers were involved in two-car crashes and at least 20 drivers were injured in single and two-car crashes combined. Of the 138 EuroNCAP vehicle models tested to the middle of 2003, there were 70, 52 and 23 vehicle models with sufficient real crash data from all crash types, front impact crashes and side impact crashes respectively, to be included in the British analysis. The French data was sufficient to estimate 36, 31 and 5 vehicle models in all crash types, front impact crashes and side impact crashes respectively.

Information on the vehicle identification number (VIN) was available in neither the British nor the French database. Therefore, selection of vehicle models from the crash data for comparison with EuroNCAP test result had to be carried out on the basis of the make and model coding descriptions available in the data along with year of manufacture in comparison with the model specifications reported for the EuroNCAP tested vehicles.

Vehicle safety ratings estimated from real crash data

Adjustment for Non-Vehicle Factors

Logistic models of injury risk and injury severity as a function of the non-vehicle factors available in the data were fitted separately for each component using the logistic procedure of the software package SAS. At this stage the vehicle model was not included as a factor in the model. In addition to fitting main effects of the non-vehicle factors, interactions of first and higher order were included. To avoid an overly complex final model or one that might become unstable in the estimation procedure, a stepwise approach was used to fit the model, with the restriction that an interaction could only be considered if the main effect terms of the interaction were significant predictors of injury risk/injury severity. This approach has been used successfully in estimating the Australian crashworthiness ratings (Newstead et al, 2002) and gives a greater chance that the fit of the final model to the data will be acceptable.

Table 3.
Significant factors in the logistic regression models of injury risk and injury severity derived from the British data

Significant Model Factors	Injury Risk	Injury Severity
Main Effects	driver age (age) driver sex (sex) junction type (jun) point of impact (poi) speed limit (sl)	driver age (age) driver sex (sex) junction type (jun) no. of vehicles (nov) point of impact (poi) speed limit (sl)
1st Order Interactions	jun×poi, jun×sl, age×poi, sex×jun, poi×sl, age×sex, sex×poi, age×sl, age×jun	nov×sl, nov×poi, jun×poi, jun×nov, sex×nov, age×sex, sex×sl, poi×sl, jun×sl, age×jun, sex×jun, age×sl, sex×poi, age×poi, age×nov
2nd Order Interactions	jun×poi×sl sex×jun×poi age×sex×poi age×poi×sl age×jun×poi	jun×poi×sl, jun×nov×poi, age×nov×poi, age×jun×poi, jun×nov×sl, sex×jun×sl, sex×jun×nov, age×sex×sl, nov×poi×sl, sex×poi×sl, sex×jun×poi, age×sex×nov
3rd Order Interactions		jun×nov×poi×sl

Tables 3 and 4 detail the main effects and interactions that were judged to be significant predictors of injury risk and injury severity for all crash types through the stepwise logistic modelling approach. As a final step, the model was re-fitted including the significant non-vehicle factors and their interactions along with a variable indicating vehicle model as a main effect in each of the models. In each case, vehicle model was a significant predictor of injury outcome. No interaction between the "vehicle model" and other covariates in the model was included, as this would cause difficulty in interpretation of the vehicle model main effect.

Table 4.
Significant factors in the logistic regression models of injury risk and injury severity derived from the French data

Significant Model Factors	Injury risk	Injury Severity
Main Effects	driver age (age) driver sex (sex) Intersection type (int) urbanisation (urb)	driver age (age) driver sex (sex) number of vehicles involved (nbv) Intersection type (int) urbanisation (urb) year of crash (yea)
First Order Interactions	age × sex sex × int age × urb int × urb age × int	age × sex age × nbv sex × nbv age × int sex × int nbv × int age × urb sex × urb nbv × urb int × urb
Second Order Interactions	age × sex × int age × int × urb	age × nbv × int sex × nbv × urb age × int × urb sex × int × urb age × sex × nbv Age × nbv × urb

An identical approach was adopted to determine the significant predictors of injury risk and injury severity for front impact and side impact crashes. Due to space constraints these results are not presented here.

Estimated Ratings

Crashworthiness ratings for each EuroNCAP tested vehicle included in the analysis were calculated by taking the product of the estimated injury risk and severity components. Tables 5 and 6 show the resulting British and French crashworthiness ratings for all crash types, front impact crashes and side impact crashes. Upper and lower confidence limits for the all crash type crashworthiness rating are also provided and were calculated using the method detailed in the Newstead et al (2002).

Table 5.
Crashworthiness ratings estimated from British crash data

Vehicle Make/Model	Crash-worthiness Rating	Estimated Injury Risk	Estimated Injury Severity	Lower 95% CI CWR	Upper 95% CI CWR	Front Impact CWR	Side Impact CWR
All Model Average	**3.72**	**34.74**	**10.72**			**4.61**	**4.87**
Fiat Punto 94-97	4.28	39.73	10.77	3.59	5.10	4.80	3.93
Ford Fiesta 95-99	4.27	39.25	10.87	3.85	4.73	5.02	5.36
Nissan Micra 93-98	5.76	40.42	14.26	4.94	6.73	6.82	6.97
Renault Clio 91-98	4.97	42.22	11.78	3.42	7.23	5.82	
Rover 100 95-98	5.42	40.18	13.48	4.67	6.28	6.20	7.90
Vauxhall Corsa 93-98	4.05	36.27	11.16	2.70	6.07	6.01	
V'wagen Polo 94-99	4.26	38.98	10.92	3.57	5.07	4.92	5.98
Audi A4 95-00	3.54	31.67	11.18	2.41	5.20	2.83	
BMW 3 Series 91-98	3.10	27.93	11.10	2.64	3.64	3.39	4.04
Citroen Xantia 93-00	3.04	30.08	10.11	2.43	3.80	3.47	3.26
Ford Mondeo 96-00	3.57	33.78	10.57	3.08	4.14	4.01	5.84
Mercedes C180 93-00	1.69	31.29	5.40	0.99	2.90	1.48	
Nissan Primera 96-99	3.64	31.05	11.71	2.71	4.89	4.37	
Peugeot 406 96-99	2.95	27.92	10.57	2.42	3.60	3.65	3.59
Renault Laguna 94-98	3.12	34.35	9.07	2.36	4.12	4.23	
Rover 620 93-99	3.31	32.26	10.27	2.58	4.25	3.27	7.04
Saab 900 93-98	3.02	24.32	12.43	1.64	5.57		
Vauxhall Vectra 95-99	3.92	33.13	11.82	3.42	4.48	4.42	5.47
V'wagen Passat 97-00	4.95	32.40	15.27	3.16	7.75	6.79	
Audi A3 96-02	3.22	33.46	9.62	1.83	5.67	4.43	
Citroen Xsara 97-02	3.82	38.18	10.00	2.42	6.02	4.45	
Daewoo Lanos 97-02	4.06	35.00	11.59	2.68	6.14	4.54	
Fiat Brava 95-02	3.66	35.27	10.38	2.93	4.58	4.62	3.42
Honda Civic 95-00	5.26	37.92	13.87	4.47	6.19	5.79	6.25
Hyundai Accent 94-99	5.20	42.23	12.30	3.48	7.76	4.39	
Peugeot 306 97-01	4.74	38.06	12.47	4.09	5.50	5.24	5.72
Renault Megane 96-99	3.52	34.87	10.09	2.84	4.37	3.97	3.55
Suzuki Baleno 95-01	4.03	35.13	11.46	2.36	6.86	4.41	
Toyota Corolla 97-01	4.22	33.45	12.62	3.04	5.87	3.98	
V'wagen Golf 97-02	3.46	27.65	12.53	1.79	6.69		
Audi A6 97-02	1.92	29.44	6.53	0.84	4.38		
BMW 520i 96-02	3.24	25.25	12.84	2.12	4.95	3.89	
Mercedes E200 95-99	3.36	28.95	11.59	1.87	6.03		
Saab 9-5 97-01	2.05	25.07	8.18	0.74	5.68		
Vauxhall Omega 94-99	2.93	31.94	9.17	2.21	3.88	3.09	2.99
Volvo S70 96-99	4.04	35.63	11.34	1.77	9.21		
Ford Focus 98-02	3.43	33.69	10.17	2.78	4.23	3.86	3.93
Mercedes A140 98-02	5.51	40.42	13.63	3.23	9.39	7.03	
Vauxhall Astra 98-02	4.53	40.21	11.27	3.89	5.28	4.90	6.27
Ford Escort 91-00	4.18	37.79	11.05	3.80	4.59	4.62	5.52
Nissan Almera 95-00	4.01	40.90	9.80	2.66	6.05	5.76	
Nissan Serena 93-00	4.33	32.08	13.49	2.07	9.05		
V'wagen Sharan 95-00	2.69	26.94	10.00	1.25	5.79		
Vauxhall Corsa 98-00	4.02	37.83	10.64	3.30	4.90	4.68	4.76
Honda Accord 98-99	1.01	33.79	2.99	0.25	4.06		
Saab 9-3 98-02	2.22	20.55	10.79	1.00	4.91		

Vehicle Make/Model	Crash-worthiness Rating	Estimated Injury Risk	Estimated Injury Severity	Lower 95% CI CWR	Upper 95% CI CWR	Front Impact CWR	Side Impact CWR
Ford Ka 96-02	4.44	39.12	11.34	3.70	5.32	5.46	4.78
Volvo S40 96-02	2.38	33.69	7.06	1.36	4.15	3.54	
Toyota Avensis 97-00	3.37	36.68	9.18	2.35	4.83	3.25	
Citroen Saxo 96-02	4.80	45.16	10.63	4.17	5.52	5.26	5.97
Daewoo Matiz 98-00	8.69	49.54	17.54	6.05	12.48	9.05	
Fiat Seicento 98-02	5.66	48.13	11.77	3.53	9.10	7.92	
Ford Fiesta 99-02	4.67	41.23	11.32	3.73	5.84	5.74	
Nissan Micra 98-02	6.82	44.22	15.41	4.15	11.19	8.23	
Peugeot 206 98-02	4.15	38.32	10.83	3.14	5.49	4.47	
Renault Clio 98-01	3.08	36.05	8.53	2.22	4.26	3.58	
Rover 25 99-02	4.76	45.19	10.53	3.04	7.44	5.43	
Toyota Yaris 99-02	4.69	42.01	11.16	2.85	7.70	6.20	
V'wagen Polo 00-02	4.08	37.23	10.95	2.54	6.53	4.04	
Nissan Almera 99-02	3.17	35.48	8.93	1.61	6.23		
BMW 3 Series 98-00	3.04	30.11	10.11	2.12	4.36	3.13	
Peugeot 406 99-02	3.46	30.22	11.46	2.41	4.98	4.17	
Rover 75 99-02	1.60	19.96	8.02	0.63	4.08		
Vauxhall Vectra 99-02	4.23	32.41	13.05	3.30	5.43	4.25	4.00
V'wagen Passat 00-02	3.21	33.22	9.66	2.14	4.81	4.06	
Citroen Picasso 00-02	3.93	36.34	10.82	1.62	9.55		
Renault Scenic 99-02	3.25	36.20	8.98	1.77	5.98	3.84	
Mazda MX-5 98-02	5.44	38.70	14.05	3.45	8.58		
Jeep Cherokee 96-02	2.22	22.03	10.09	1.06	4.64		
Vauxhall Corsa 00-02	3.99	39.96	9.99	2.03	7.85		

NB: Blank cells indicate insufficient data was available to obtain an estimate

Table 6.
Crashworthiness ratings estimated from French crash data

Vehicle Make/Model	Crash-worthiness Rating	Estimated Injury Risk	Estimated Injury Severity	Lower 95 CI CWR	Upper 95 CI CWR	Front Impact CWR	Side Impact CWR
All Model Average	**11.45**	**48.88**	**23.42**			**11.76**	**17.35**
Fiat Punto 94-97	13.45	57.06	23.57	11.54	15.67	13.28	15.33
Ford Fiesta 95-99	14.20	56.36	25.20	11.79	17.11	14.88	
Nissan Micra 93-98	16.09	57.51	27.98	8.96	28.88		
Renault Clio 91-98	17.10	59.31	28.84	15.41	18.98	16.59	17.75
Opel Corsa 93-98	15.06	56.52	26.64	12.51	18.11	15.72	
Volkswagen Polo 94-99	15.54	56.29	27.61	12.97	18.63	13.73	
BMW 3 Series 91-98	14.29	46.29	30.87	9.73	20.99	16.00	
Citroen Xantia 93-00	11.52	45.24	25.47	9.87	13.46	10.63	16.52
Ford Mondeo 96-00	4.54	40.57	11.18	2.11	9.75	5.18	
Mercedes C180 93-00	7.89	36.64	21.52	3.15	19.72		
Nissan Primera 96-99	1.97	39.20	5.04	0.30	12.90		
Peugeot 406 96-99	9.28	40.32	23.01	7.39	11.65	9.57	
Renault Laguna 94-98	11.36	45.96	24.71	8.90	14.50	11.61	
Opel Vectra 95-99	8.82	41.89	21.06	5.50	14.15	7.57	
Audi A3 96-02	8.48	45.50	18.63	3.82	18.81	6.08	
Citroen Xsara 97-02	13.60	53.83	25.26	10.19	18.15	15.06	
Fiat Brava 95-02	15.78	52.88	29.85	12.04	20.69	13.58	
Honda Civic 95-00	10.67	42.05	25.38	6.51	17.49	10.90	
Peugeot 306 97-01	12.03	49.16	24.47	10.16	14.25	11.12	16.75
Renault Megane 96-99	15.29	52.00	29.40	12.84	18.20	15.25	
Ford Focus 98-02	10.18	50.51	20.16	5.78	17.93	10.23	
Opel Astra 98-02	9.30	48.89	19.03	5.72	15.13	9.39	
Ford Escort 91-00	14.01	52.08	26.89	11.72	16.73	14.98	
Renault Espace 97-02	5.32	29.83	17.85	2.68	10.59	6.32	
Peugeot 806 95-98	17.02	43.41	39.20	9.60	30.18		
Opel Corsa 98-00	12.67	53.52	23.67	8.76	18.32	14.47	
Ford Ka 96-00	10.30	48.50	21.24	6.40	16.58	12.42	
Citroen Saxo 96-02	17.69	59.90	29.53	15.21	20.56	16.78	16.79
Ford Fiesta 99-02	12.34	62.04	19.89	6.66	22.87	15.20	
Peugeot 206 98-02	13.79	58.01	23.77	10.08	18.86	12.55	
Renault Clio 98-01	10.11	50.34	20.08	7.51	13.61	10.80	
Volkswagen Polo 00-02	14.97	57.42	26.08	8.99	24.93	15.02	
BMW 3 Series 98-00	12.44	39.21	31.72	6.42	24.11		
Peugeot 406 99-02	8.57	40.65	21.09	5.68	12.95	8.65	
V'wagon Passat 97-00	16.22	44.04	36.84	10.38	25.36	12.74	
Renault Scenic 99-02	6.18	43.64	14.17	3.33	11.47	5.81	

NB: Blank cells indicate insufficient data was available to obtain an estimate

COMPARISON OF REAL CRASH RATINGS WITH EURONCAP RATINGS

Having successfully estimated vehicle safety ratings from the French and British police reported crash data using the new crashworthiness metric, of interest was to compare the consistency of these ratings to those derived through the EuroNCAP barrier test program.

In comparing EuroNCAP crash test results with real crash outcomes in Sweden, Lie and Tingvall (2000) computed the average real crash injury rates for vehicles grouped within each overall star rating. It was hypothesised that occupants of EuroNCAP tested vehicles with a particular rating should have a lower average risk of serious injury in real crashes than those with a lesser star rating. If so, the overall barrier crash performance star rating given to each vehicle from EuroNCAP testing would be broadly representative of relative real crash outcomes. Based on the Swedish data analysed, Lie and Tingvall (2000) indeed found that EuroNCAP tested vehicles rated four stars had a lower average risk serious injury risk in real crashes than those rated three stars. The three star vehicles had a correspondingly lower average risk than vehicles rated two stars. The analysis that follows also considers the relationship between real crash safety ratings and overall EuroNCAP star ratings.

An overall EuroNCAP star rating scale of five categories is used to classify vehicle safety performance based on crash test results. The four star categories are derived from the results of both the offset frontal and side impact EuroNCAP test components. In this study the overall EuroNCAP score and corresponding star rating are calculated based only on the driver dummy measurements in the EuroNCAP test to ensure compatibility with the real crash ratings that relate to driver injury outcome only. In contrast, the official scores published by EuroNCAP consider both the driver and front passenger dummy scores in the offset frontal barrier test. Also, the EuroNCAP overall scores used here do not include the pole test result. Analysis conducted using EuroNCAP overall scores including the pole test for those few vehicle models for which it was available produced similar results.

Figures 4 and 5 show overall EuroNCAP scores plotted against crashworthiness estimated from the British and French data respectively. Individual EuroNCAP scores are grouped according to the corresponding star rating and 95 per cent confidence limits are placed on the estimates of the real crash measures.

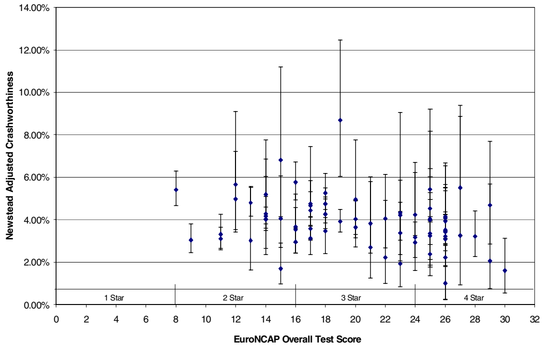

Figure 4. Overall EuroNCAP test score vs. estimated crashworthiness (Great Britain).

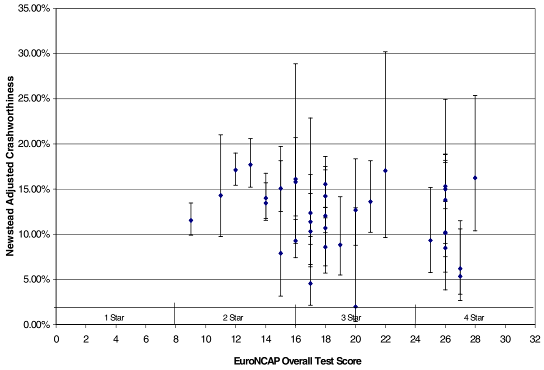

Figure 5. Overall EuroNCAP test score vs. estimated crashworthiness (France).

Figures 4 and 5 show a general trend of improvement in the new crashworthiness measure with increasing EuroNCAP star rating, in line with the findings of Lie and Tingvall (2000). However, within each overall star rating category, there is significant variation in the estimated new crashworthiness measure between vehicles. This variation is partly a product of the estimation error in the crashworthiness measure, particularly for vehicle models with relatively few records in the crash data, as shown by the 95% confidence limits. However, there are significant differences in the real crash measures between vehicle models within the same EuroNCAP star rating, and even between vehicle models with almost the same overall EuroNCAP rating score from which the star ratings are derived. This is demonstrated by the non-overlapping confidence limits on the real crash measures between pairs of vehicles within the same overall star rating category.

These results suggest that there are other vehicle factors, apart from those summarised in the overall EuroNCAP score that are determining real crash outcomes. These other factors are also different from the non-vehicle factors that have already been compensated for in the estimation of the real crash based ratings, such as driver age and sex and speed limit at the crash location.

A comparison of real crash safety ratings and EuroNCAP scores for front and side impact crashes has also been conducted using both the British and French data. In this analysis the driver dummy measurements recorded in the offset frontal and side impact EuroNCAP test components respectively are segregated into four categories to develop a pseudo star rating for comparison with real crash outcomes. Figures 6 and 7 show overall EuroNCAP scores plotted against crashworthiness estimated from the British data for front and side impact crashes respectively. Similar analysis was conducted using the French data producing similar results that are not shown here.

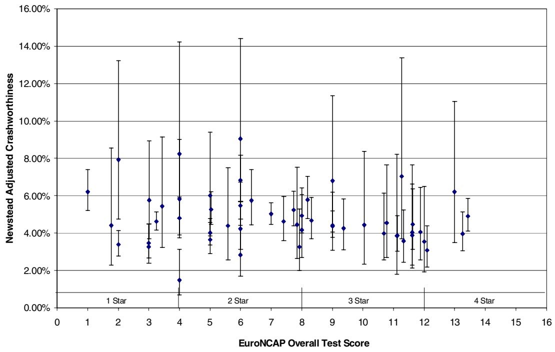

Figure 6. Front impact EuroNCAP test score vs. estimated crashworthiness (front impact crashes: Great Britain).

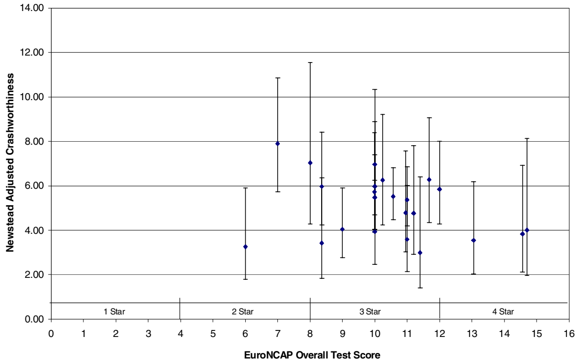

Figure 7. Side impact EuroNCAP test score vs. estimated crashworthiness (side impact crashes: Great Britain).

The comparison of EuroNCAP front and side impact test scores and estimated crashworthiness for front and side impact crashes showed even weaker association between the two measures. Similar to the results found in the analysis of all crash types, analysis by impact type showed significant variation in the estimated crashworthiness of vehicles within each EuroNCAP score range. However, the relatively wide confidence limits on the crashworthiness estimates by impact type make it difficult to draw conclusions from these comparisons.

Logistic regression comparison of real crash ratings and overall EuroNCAP star ratings

The above analysis has studied the general relationships between the real crash based and EuroNCAP based secondary safety ratings using graphical techniques. In order to make more definitive statements about the relationships between the two safety measures a logistic regression analysis framework has been used. Vehicle safety rating measures derived from real crash data have been modelled as a function of the EuroNCAP overall star rating to assess the statistical significance of differences in average serious injury risk in real crashes between EuroNCAP star ratings.

The new crashworthiness measure for each vehicle model *i* (CWR_i) has been modelled as a function of the overall EuroNCAP star rating in a logistic model of the following form.

$$\begin{aligned}&\operatorname{logit}(\mathrm{CWR}_\mathrm{i}) = \\ &\alpha + \beta(\text{EuroNCAP overall star rating}_\mathrm{i})\end{aligned}$$

In the equation, i is the vehicle model index and α and β are parameters of the logistic model. The EuroNCAP star rating is one of 1, 2 ,3 or 4. It may be expected that a higher star rating would be associated with improved crashworthiness in real crashes, or that there will be some monotonic relationship between the barrier test and real crash measure. However, to maintain objectivity, no restriction has been placed on the form of the relationship between the star rating categories and the dependent injury outcome variable.

Previous work has highlighted the relationship between vehicle mass and real crash outcome with vehicles of higher mass generally having better real crash ratings for injury risk, injury severity and crashworthiness. To test this relationship on the current data, a logistic regression, estimating the effect of mass on real crash outcome, has been conducted using the British and French data. Figure 8 demonstrates a strong relationship between the crashworthiness measure and vehicle mass, with vehicles of higher mass generally associated with a lower (better) crashworthiness rating.

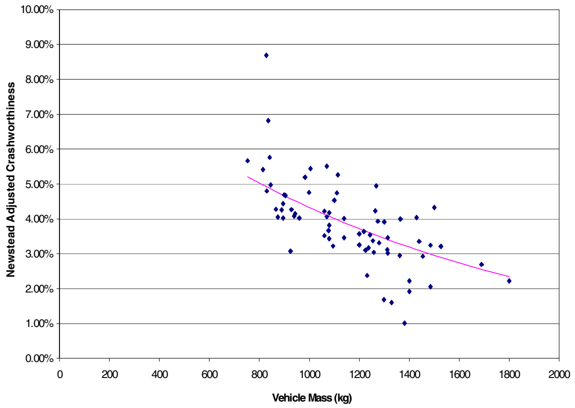

Figure 8. Newstead adjusted crashworthiness for all crash types (Great Britain) vs Vehicle mass.

Analysis of crashworthiness estimates derived front and side impact real crash data produces similar results, as does an analysis of the French data.

In contrast to real crash outcomes, the EuroNCAP score is purported to be independent of vehicle mass. Therefore, in exploring the relationship between the real crash safety measures and EuroNCAP test scores, the apparent contrasting influence of vehicle mass on the two safety measures must be accounted for. To achieve this, vehicle mass is included as an extra predictive term in the logistic regression form given above and operates to remove the effect of mass from the analysis.

The key output from the logistic model is the average crashworthiness across vehicles within each EuroNCAP star rating. Analysis of the point estimates and associated confidence limits of parameters in the logistic regression analysis provides information on the statistical significance of the relationship between each of the real crash safety measures and EuroNCAP star ratings. Non-overlapping confidence limits across EuroNCAP star rating classes indicate that there is a statistically significant relationship between EuroNCAP star ratings and the real crash safety measure. That is, the EuroNCAP star ratings are able to differentiate between levels of real crash outcome. In contrast, overlapping confidence limits across EuroNCAP star rating classes indicate that the EuroNCAP star rating is unable to statistically significantly differentiate between real crash injury outcomes as measured by the new crashworthiness metric.

Tables 7 and 8 present the results of the logistic regression analysis for all crash types based on the British and French data respectively. The tables present the average of the new crashworthiness measure for vehicles within each overall EuroNCAP star class along with 95% confidence limits. To assess which pairs of the star rating classes have significantly different average crashworthiness, the confidence limits on the parameter point estimates generated from the logistic modelling procedure must be compared to see if they overlap.

Table 7.
Mass adjusted Crashworthiness estimates and 95% confidence limits by EuroNCAP star rating categories: all crash types (Great Britain)

	All Crash Types (with mass adjustment)			
	Overall Star Rating			
	1	2	3	4
Estimate	**4.48%**	**3.99%**	**4.14%**	**3.86%**
LCL	4.01%	3.78%	3.93%	3.60%
UCL	4.99%	4.20%	4.36%	4.14%

Table 8.
Mass Adjusted Crashworthiness estimates and 95% confidence limits by EuroNCAP star rating categories: all crash types (France)

	All Crash Types (with mass adjustment)			
	Overall Star Rating			
	1	2	3	4
Estimate		**14.72%**	**13.31%**	**13.00%**
LCL		14.08%	12.66%	12.20%
UCL		15.38%	14.00%	13.83%

Table 7 shows a general trend to improving average crashworthiness with increasing EuroNCAP star rating in the British data, although there is little difference between the average crashworthiness in star categories 2 and 3. Furthermore, because the confidence limits on the average crashworthiness ratings for each star category overall, it is not possible to conclude that the average injury outcomes are statistically significantly different between star rating categories.

Analysis of the French data ratings in Table 8 show a more consistent trend to improving crashworthiness with increasing EuroNCAP star rating from 2 to 4. There were no 1 star rated cars with sufficient French police crash data to assess this category. The French analysis results found that 2 star rated vehicles had an average crashworthiness significantly worse than higher star rated vehicles, indicated by the non-overlapping confidence limits. However, 3 star rated vehicles did not have an estimated crashworthiness rating statistically different to 4 star rated vehicles.

Analysis of the relationship between the EuroNCAP pseudo star ratings developed for front and side impact crashes and the real crash measures for these crash types derived from the British data is presented in Tables 9 and 10. These results do no indicate any statistically significant relationship between the EuroNCAP star ratings and the crashworthiness estimates derived from the British data for either front or side impact crashes. However, the side impact analysis pointed to a trend of improving side impact injury risk in real crashes with increasing EuroNCAP side impact star rating, with 4 star rated vehicles being on average significantly better than 2 star rated vehicles.

Table 9.
Mass adjusted crashworthiness estimates and 95% confidence limits by EuroNCAP star rating categories: front impact crashes (Great Britain)

	All Crash Types (with mass adjustment)			
	Overall Star Rating			
	1	**2**	**3**	**4**
Estimate	**4.58%**	**4.75%**	**4.83%**	**4.70%**
LCL	4.31%	4.48%	4.50%	4.25%
UCL	4.87%	5.03%	5.18%	5.20%

Table 10.
Mass adjusted crashworthiness estimates and 95% confidence limits by EuroNCAP star rating categories: side impact crashes (Great Britain)

	All Crash Types (with mass adjustment)			
	Overall Star Rating			
	1	**2**	**3**	**4**
Estimate		**6.71%**	**5.56%**	**4.04%**
LCL		5.45%	4.75%	3.10%
UCL		8.24%	6.51%	5.24%

DISCUSSION AND CONCLUSIONS

This paper has detailed the development of a new measure of vehicle secondary safety estimated from police reported crash data covering only crashes where an occupant injury has occurred. The new crashworthiness measure estimates the risk if injury to drivers of vehicles given involvement in a crash. It can be multiplied by existing measures of injury severity outcome, typically the risk of death or serious injury given an injury was sustained, to give a resulting measure of serious injury risk to drivers in a crash.

The key feature of the new crashworthiness injury risk measure is that it is not confounded by the aggressivity of the vehicle model of which the secondary safety performance is being assessed. Aggressivity in this context is defined as the risk of injury to the driver of a vehicle colliding with the focus vehicle. Because aggressivity is not confounded with the crashworthiness injury risk measure, a corresponding new independent measure of vehicle aggressivity has also been defined. None of the vehicle secondary safety measures estimated from injury-only crash data currently in use in Europe can claim this property.

Another key advantage of the new measure is that it is an estimator of absolute injury risk in a crash. This allows logistic regression techniques to be used to estimate the measure whilst simultaneously controlling for the effects of non-vehicle factors associated with the occupant and crash that effect injury outcome. Only one of the three currently used European measures has this property, the DETR method. Controlling for non-vehicle factors in the other two methods is achieved through post-hoc normalisation techniques requiring assumptions to be made about the likely asymptotic statistical distribution of the resulting measures to be able to calculate standard errors and confidence limits on the adjusted estimates. No such assumptions need to be made when using logistic regression for the adjustment process.

Successful application of the new measures of secondary safety on police reported crash data from both Great Britain and France has been demonstrated. The resulting ratings by vehicle model only cover those vehicles tested under EuroNCAP to suit the goals of the study. There is no reason why the technique could not be applied to estimate ratings for the full range of vehicle models represented in each data set with sufficient data to produce meaningfully accurate results.

Estimation of the aggressivity measure on the European data sets considered in this study was not demonstrated in this paper. However, prior experience in applying the new measures to sample crash data from the USA confirms the process of estimating aggressivity ratings is also viable producing meaningful estimates that are empirically independent of the corresponding crashworthiness estimates. Given this experience, in tandem, the new measure of crashworthiness and aggressivity presented in this study could together provide a means of ongoing assessment of vehicle secondary safety performance in both dimensions in many European countries where only injury crash data are recorded by police. Currently ratings of vehicle aggressivity are only published in Finland.

On average, there appears to be an association between the new measure of vehicle crashworthiness presented in this paper and EuroNCAP ratings. In both the British and French data, there was a trend towards reduced severe injury risk in police reported crashes with increased EuroNCAP star rating. This relationship was stronger in the French data which uses a somewhat different measure of severe injury outcome to the British data. The French measure might be more compatible with aim of the EuroNCAP protocol in assessing injury outcome. Whilst this general association could also be seen between the side impact EuroNCAP results and police reported side impact crashes, it did not extend to frontal impact comparisons in the data examined.

When examined on an individual vehicle model level the relationship between the new injury outcome measure and EuroNCAP results is not as strong with significant variation in estimates of the new measure for vehicles within the same EuroNCAP star class. This is however not a fatal indictment on either system considering the fundamental differences between the two measures and their clearly different objectives in measuring relative vehicle secondary safety; one prospectively and one retrospectively.

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CADAVER AND DUMMY INVESTIGATION OF INJURY RISK WITH ANTI-SLIDING SYSTEM IN CASE OF STATIC DEPLOYMENT

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ABSTRACT

In frontal impact, thorax and head injuries have strongly decreased with the development of occupant restraining systems including airbags, belt load limiters, and pretensioning systems. Nevertheless, the protection of abdomen and lower limbs has still to be improved, especially in rear seats. Indeed, car stiffness has increased in order to keep enough survival space for severe crashes. Thus, car manufacturers have developed specific restraint devices to improve protection of pelvis and lumbar spine, with prevention of submarining. One of these consists of an anti-sliding system based on an inflatable metallic wrap.

The main goal of the study was to investigate the risk of injury with a prototype of such a device, in case of static deployment, for in-position and out-of-position situations. Because the lack of relevance of the dummies in such conditions is suspected, and because criteria do not currently exist as far as the lumbar spine is concerned, six cadaver tests, including three in out-of-position situation, were carried out and duplicated with small female, and 50th male HIII dummies. Two inflators were used.

Cadavers were instrumented with linear accelerometers and angular velocity sensors for vertebra L2, L3, L5 and sacrum. The seat was equipped with load cells.

For the six cadaver tests, no injury was observed. Intervertebral rotation values are given for the cadavers and lumbar spine forces and moments recorded on dummies are presented. Comparisons regarding lumbar spine kinematics are realized for biofidelity assessment.

INTRODUCTION

In the last decade, the safety of car occupants involved in frontal crashes has been drastically improved thanks to the development of several new restraint technologies. The body areas where the changes were the most noticeable were clearly the head, the thorax and the lower extremities. As a consequence, issues such as submarining became of higher relative importance.

In order to avoid submarining while maintaining the comfort features of the seat, several active “anti-sliding” devices were developed by suppliers. Most of them were based on an inflator-propelled obstacle initially located under the seat cushion. These devices were designed to be ignited as soon as the crash is detected such that an obstacle moves toward the buttocks in order to prevent penetration motion of the pelvis into the seat cushion. As a result, the pelvis is coupled to the seat very early in the crash time history and its rotation is locked such that submarining is prevented.

OBJECTIVES

The first objective of our study was to investigate the potential intrinsic aggressiveness of such a concept on the pelvis and lumbar area for both In-Position (IP) and Out-of-Position (OOP) situations, in case of static deployment. The second objective was to compare the lumbar spine and pelvis kinematics of the dummies and the cadavers in order to assess the relevance of the dummies in these specific situations.

LITERATURE REVIEW

Several studies dealing with the axial compression resistance of either isolated human cadaver vertebrae or vertebral units were available. A few studies on whole cadavers were also available. The tests conditions and results of these studies are presented in the table A1 of the annex.

Isolated vertebrae resistance

The tests were performed in quasistatic. The vertebrae ranged from C1 to L5. In all the studies reported, the vertebrae samples were relatively large, however the results somehow varied from one study to the other.

Coltman [3] tested 75 vertebrae (T1 to L5) in pure compression up to 70% of axial deformation of the vertebrae. The rupture compression force was 5900 N. This value is in good agreement with several other studies. Yoganandan [11] tested 63 vertebrae and reported a rupture compression force equal to 4.6 kN for the lumbar spine (no further information about the exact vertebrae). Myers [8] tested 61 vertebrae (L2 to L4) and reported a rupture compression force equal to 5600 N. In the same conditions, Brinckmann [2], Hutton [6], Kazarian [7] and Yamada [14] reported forces ranging from 4.4 kN to 8.3 kN.

In another study performed on 530 vertebrae (C1 to L5), Gozulov [5] reported, however, a rupture compression force equal to 13 kN. This value was sensibly higher than those reported above.

Vertebral unit resistance

A vertebral unit is defined as two adjacent vertebrae and connective structures (including the disk) in between. Tests were conducted at several compression speeds on several types of vertebral units. In all the tests, the loading was a pure compression. Brinckmann [2], Yoganandan [11] and Myklebust [9] reported the same value for the rupture compression force : 5 kN (5.5 kN for Yoganandan), while Hutton [6] and Willen [13] reported higher values approximately equal to 11 kN.

Whole spine resistance

Myklebust [9] conducted tests on 4 whole cadavers where the spine was loaded in compression through a force applied on T1. The thorax was kept vertical while the neck was flexed such that it was horizontal. A 15 cm x 15 cm plate then pressed the neck in order to apply a vertical force on T1. The compression rate was 10 mm/s. Two plates were placed on each side of the thorax in order to avoid the lateral motion of the thorax. The skin was removed in front of the spine in order to allow a direct seeing of the vertebrae movements during the loading. For a compression force equal to 2.8 kN, crushing fractures were observed. The slope of the fractures ranged from 28° to 50°. For 3 specimens, fractures occurred between T10 and L2 while on the 4th specimen, it occurred on T7.

Synthesis of resistance

From the literature review, it appears that almost all the studies deal with the fracture vertebra mechanism by compression, except a few of them that deal with combined flexion and compression, which seems to be our case.

From these studies, one can find the following tendencies:

- The maximal compression force decrease when going up from the lumbar to the cervical spine (about 1 kN each 3 vertebrae)
- Dynamic loading at 100 mm/s increases the force rupture by 1.5 kN from static loading
- The maximal compression force decrease with age.

Gathering all these data and as a first approximation, the tolerances for pure compression and flexion-compression loading are summarized in the Table 1, which can be used as a reference for risk evaluation on human subjects.

Table 1. Tolerances for lumbar spine.

	Pure compression	Compression-flexion	
	Fz (kN)	Fz (kN)	My (Nm)
20-40 years	8	3	400
40-60 years	6.5	2.5	300
> 60 years	4	1.5	200

Comparison between human subject and dummy lumbar spines

Demetropoulos [4] has performed ten cadaver tests on complete isolated lumbar spine, without muscles. These tests were duplicated with HIII dummy. The results have shown that the HIII lumbar spine is stiffer than the human subject lumbar spine (ratio of 20/1 in flexion and 2/1 in extension). But the HIII lumbar spine represents the overall resistance in flexion including lumbar spine, muscles and abdomen. So, it is difficult to assess the real difference in angular stiffness between human subjects and dummies.

No criterion and no protection limit is currently available for the dummy lumbar spine. A under-evaluation of the risk of injury due to the poor relevance of dummies was feared in IP and OOP situations. As a consequence, tests were carried out on cadavers.

MATERIAL AND METHODS

Loading device

An “anti-sliding” device based on a metallic inflatable cushion was chosen for our study because prototypes were available. This device, prior to ignition, was located under the seat cushion at its forward portion (Figure 1).

Two types of inflators were tested: a standard one and a boosted one.

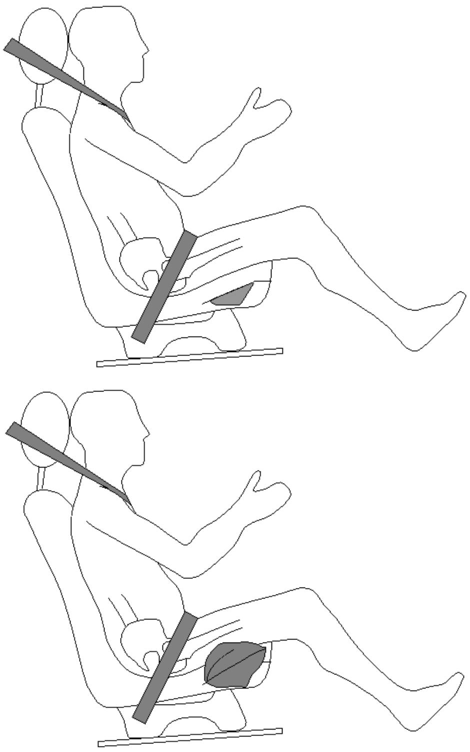

Figure 1. "Anti-sliding" device prior to activation (top view) and when activated.

Specimen

A total of six human cadavers were acquired for this study. There were two females and four males, ranging in age from 47 to 78. Specimens were obtained through the Body Donation Department of the Descartes University in Paris (France). The specimens were not embalmed to prevent undesirable changes in tissue properties. Table 2 shows the anthropometry and age for each cadaver.

Table 2. Specimen anthropometry.

Specimen #	Sex	Height (cm)	Age	Weight (kg)
544	M	169	70	82
545	F	166	64	64
547	M	179	78	70
548	F	163	47	55
546	M	166	67	50
549	M	164	74	58

Dummies

The tests on cadavers were duplicated with the 50th centile male and 5th centile female dummies.

Instrumentation

Seat

The seat was mounted on the test rig through four 3-axis load cells. A 2-axis accelerometer was fixed on the structure of the seat cushion.

Dummies

The HIII dummies were instrumented with head accelerations (x, y, z), upper neck forces and moment (Fx, Fz, My), thorax accelerations (x, y, z), one thorax angular velocity (ωy), lower lumbar spine efforts, moment and accelerations (Fx, Fz, My, Ax, Ay, Az), pelvis accelerations and angular velocity (Ax, Ay, Az, ωy), and femur forces, moments and accelerations (Fx, Fz, My, Mx, Ax, Az). In addition, for the HIII 50th percentile dummy, the upper lumber spine loads and moment were recorded. The SAE J211 recommended practice was used for filtering and sign convention.

Post mortem human subjects (PMHS)

The lumbar spine of the cadavers was instrumented at L2, L3, L5 vertebrae and on the sacrum using cubes equipped with 3-axis accelerometers and 1 MHD aligned along Y axis (Figure 2).

The femurs and tibias were instrumented with one 3-axis accelerometer each.

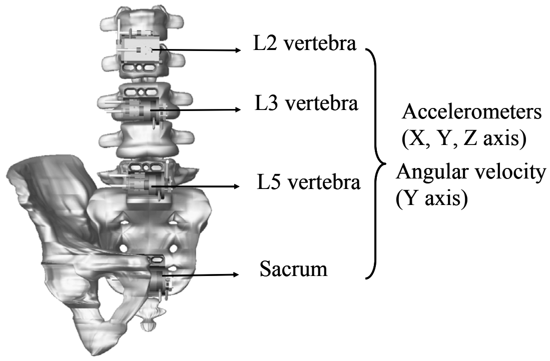

Figure 2. Instrumentation of the lumbar spine and sacrum area on cadavers.

Specimen initial position

Two positions were defined, one for IP and one for OOP situations.

The IP position (Figure 1) was a standard belted driving position (slope of the back seat = 25°, slope of the seat cushion = 5°). A foot rest was installed and adjusted such that the femur angle relative to the horizontal was 18°. A pretensioning system was installed at the buckle anchorage of the seat-belt. The time-to-fire of the anti-sliding device and the pretentioner were the same.

The OOP position corresponded to a passenger seating unbelted with both feet on the dashboard (Figure 3). The seat back slope was 45°. In such a position, the sacrum was exactly in front of the inflatable device (the ischiatic tuberosity was 150 mm backward from the fore edge of the cushion). The femur angle relative to the horizontal was 18°. This situation was assumed to be the worst case (i.e. with the higher pelvis and lumbar injury risk).

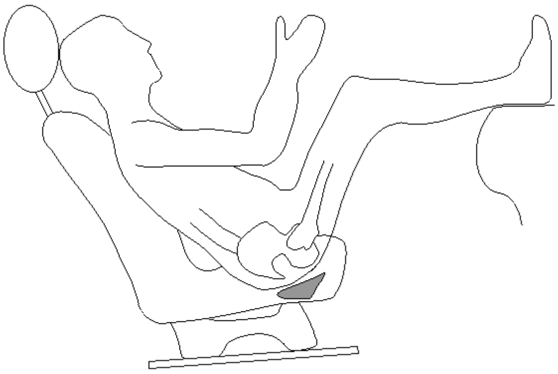

Figure 3: OOP position with the anti-sliding device prior to activation.

The initial position of the specimen was recorded through targets digitized using a Römer 3D arm. Additional attention was paid to the position of the spine cubes relative to the vertebrae landmarks.

Test matrix

The test matrix is presented in Table 3. Note that for all the tests performed in IP, the cadavers or dummies were belted except in test AA6-545 where the cadaver was unbelted.

Table 3. Test matrix

TEST CONDITIONS			HIII DUMMY TESTS		CADAVER TESTS	
Position	Inflator	Belt	Test number	Centile	Test number	PMHS
OOP	Standard	No	AA02	50th	AA07	547
OOP	Standard	No	AA04	5th	AA08	548
OOP	Boosted	No	AA12	50th	AA13	549
IP	Standard	Yes	AA01	50th	AA05	544
IP	Standard	Yes*	AA03	5th	AA06	545
IP	Boosted	Yes	AA11	50th	AA13	549

* Unbelted for cadaver test

RESULTS

Input loads

Figure 4 shows a typical time history of the loads applied on the pelvis with a boosted inflator. The force direction is roughly 55 degrees towards a horizontal axis.

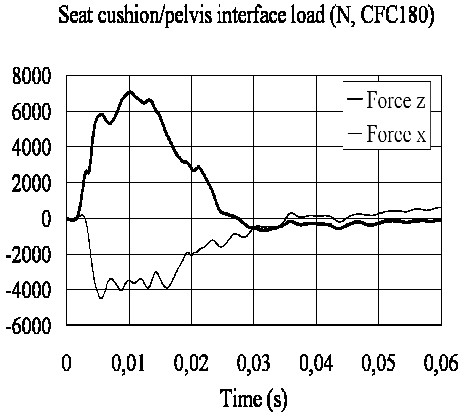

Figure 4. Time histories of seat cushion/pelvis interface forces

Dummy test results

Maximum dummy forces and moments on the lower lumbar spine, chest and pelvis resultant accelerations, thoracic and pelvic rotations are displayed in table 4 on the following page. Mean values, calculated from the three OOP and three IP tests, are also given.

The maximum resultant pelvic acceleration values are very close whatever the situation, with the highest values for the 5th percentile dummy. However, the film analysis shows noticeably different pelvic kinematics according to the situation. In IP, the pelvis moves back, because of the belt tension. In OOP, the pelvic movement according to the z axis is predominant.

On average, the thoracic resultant accelerations are quite half as high than the pelvic resultant accelerations.

The results do not show clearly the effect of inflator, boosted or not, indeed whatever the body part. On the other hand, the situation has an effect on the lumbar spine forces and moments. The compression forces are higher in OOP than in IP. The highest value (2.97 kN) is obtained with the 5th percentile dummy, in OOP situation.

Regarding the lumbar spine moments, flexion in IP is predominant. In OOP, during the first 100 ms, lumbar spine extension is observed, flexion appearing in a second phase. The results show negative pelvic rotations, in all the tests, with a magnitude lower than 6 degrees.

Although the input force seems to be high, the lumbar spine forces and moments are low. In OOP or in IP, inertia effect of pelvis and lower limbs mainly counterbalances the action force of the seat cushion.

Table 4. Main peak values for the dummy tests.

	Out-Of-Position			In-Position			OOP	IP
Test conditions	AA02	AA04	AA12	AA01	AA03	AA11	Mean values	
HIII dummy centile	50th	5th	50th	50th	5th	50th		
Inflator	Standard	Standard	Boosted	Standard	Standard	Boosted		
Pelvis								
Resultant acceleration (g)	21,3	26,1	24,1	22,9	26,9	21,3	23,8	23,7
Rotation (y, degrees)	-7	-8	-7	-5	-8	-6	-7,3	-6,3
Lumbar spine								
Momentum (Nm)	-65	-35	-56	117	80	102	-52	100
Fx (N)	1570	1100	2370	-680	-710	570	1680	-273
Fz (N)	-1970	-2970	-2370	-1240	-1230	-1190	-2437	-1220
Thorax								
Resultant acceleration (g)	10,9	17,6	14,6	7,1	13,7	10,7	14,4	10,5
Rotation (y, degrees)	-6	-5	-5	2	2	3	-5,3	2,3
Pelvis/Thorax								
Rotation (y, degrees)	-6	-5	-5	2	2	3	-5,3	2,3

Cadaver test results

Injury assessment

Autopsies were performed after the tests. No injury was observed on any cadaver.

Test analysis

Table 5 displays the main peak values obtained from the cadaver tests. In the last columns, mean values of the IP and OOP tests are given, with the available data. The intervertebral angular motions are calculated from the angular velocities. The intervertebral angular motion for the L5-L4 and L4-L3 units are estimates (L5-L3 angular motion divided by 2). The results show that the intervertebral angular motion is higher in OOP than in IP, with the most important values localized at the sacrum/L5 unit. The same observation can be done for the resultant accelerations. The differences between IP and OOP seem to be amplified by the 10 kg difference between the two groups.

Regarding the resultant acceleration values, differences between vertebrae and pelvis are not noticeable.

The results do not show a clear effect of the inflator. The highest values are obtained for the test AA09 with a boosted inflator, but also with the lightest cadaver.

In all the situations, the sign of intervertebral angular motions is always positive, indicating a flexion mechanism in IP or in OOP.

Table 5. Main peak values for the cadaver tests

	Out-Of-Position			In-Position			OOP	IP
Test	AA07	AA08	AA09	AA05	AA06	AA13	Mean values	
Subject number	547	548	546	544	545	549		
Subject mass (kg)	70	55	50	82	64	58	58,3	68,0
Inflator	Standard	Standard	Boosted	Standard	Standard	Boosted		
Acceleration (resultant, g)								
Sacrum	29	52	NA	19	NA	31	40	25
L5 vertebra	37	31	70	25	22	33	46	27
L3 vertebra	34	31	66	26	21	25	44	24
L2 vertebra	45	32	68	25	18	19	48	21
Angular motion (degrees)								
Sacrum	22	25	NA	9	20	7	23	12
L5 vertebra	16	16	20	5	7	4	17	6
L3 vertebra	11	13	18	4	2	-4	14	1
L2 vertebra	10	14	17	3	1	-4	14	0
Intervertebral rotation (degrees)								
Sacrum/L5	7	16	NA	4	13	3	12	7
L5/L4 and L4/L3 (estimated)	4	2	2	1	4	2	3	2
L3/L2	4	5	5	2	2	2	5	2
Sacrum/L2	20	24	NA	7	22	9	22	13

NA : not available

DISCUSSION

The first step in the evaluation of a safety system or its unwanted effects, consists in running tests using dummies and compare the criteria recorded on dummies to the tolerances on human being. In our study, although dummies are equipped to measure lumbar forces, their behaviour is questionable for the kind of loading caused by the anti-sliding device. As of today, no limits of tolerance are available for them specifically, and their poor biofidelity in this body area does not allow the direct application of human criteria and tolerances.

However, in spite of the force order of magnitude applied to the pelvis (up to 7 kN), lumbar forces measured on the dummy suggest that the injury risk associated to compression, flexion of both of them remains very low. Nevertheless, to confirm the harmlessness of the device and at the same opportunity to evaluate the dummy response and ability to assess the injury risk, tests were performed on PMHS. No injury was observed in the worst OOP case. It confirmed that the device is safe even with a boosted inflator whatever the specimen anthropometry.

However, the comparison of dummy and PMHS kinematics showed fundamentally different behaviors. The spine of the PMHS was always flexed while the dummy spine was mainly extended during OOP tests. Moreover, the compression of the lumbar spine was predominant for the dummies while the lumbar spine flexion seems to be the main mechanism for PMHS.

This difference of behaviour can be explained by the different initial positioning. The dummy remained straight even in OOP while the PMHS leaned in the seat. In addition to the geometrical differences the lumbar spine stiffnesses are significantly different between the cadaver and the dummy. Both differences highlight the poor ability of the dummy to reproduce realistic loading modes and consequently evaluate the injury risk.

This study did not provide means for lumbar spine characterization, especially since no forces were measured on PMHS. However, useful information are provided for the validation of a mathematical model of the human being, capable to mimic the kinematics of lumbar vertebrae.

CONCLUSIONS

Six dummy tests were performed with prototypes of a new concept of inflatable anti-sliding system. The test conditions included In-Position and Out-Of-Position situations, in order to evaluate the lumbar injury risk in case of static deployment. The forces and moments recorded on the dummy lumbar spine were very low and no risk of injury was suspected.

Nevertheless, six PMHS tests were also performed to complete this statement. The results confirmed that the device was safe. However, they also demonstrate that the dummy had not the same behaviour than the PMHS and by the way, was not able to assess properly the injury risk.

Research has then to be undertaken regarding the lumbar spine, where the protection criteria on dummy will become an issue to evaluate such protection systems.

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APPENDIX

Table A1: Literature review synthesis.

Author	Réf.	Specimen	Loading	Loading rate	Record	Injury
Brinckmann	[1] [2]	134 units of 2 vertebrae (T10 to L5, apophyses included)	Pure compression.	1 kN/s with a preload of 1 kN during 15 mm	F rupture = 5 kN Range from 4.4 to 6.8 kN	Fx of the vertebrae body
Coltman**	[3]	75 isolated vertebrae from T1 to L5	Pure compression up to 70% of the height.	89 mm/s (no preload)	F rupture thorax = 4.5 kN lumbar = 5.9 kN	Crush fx (occurs between 3% and 10% of deformation)
Gozulov	[5]	530 isolated vertebrae from C1 to L5	Pure compression.	Ranged from 0.08 and 1.7 mm/s	F rupture =13 kN	Depends on the deformation
Hutton	[6]	33 units of 2 vertebrae from L1 to S1, apophyses included	Pure compression.	3 kN/s with a preload of 1 kN during 5 mm	F rupture = 5.6 kN for L1, up to 8.3 kN for L5	Fx of the vertebrae body
Kazarian	[7]	61 isolated vertebra	Pure compression.	8900 mm/s 89 mm/s 0.89 mm/s	F rupture thorax = 6.8 kN	Crush fx
Myers	[8]	61 isolated vertebra : 22x L2 22x L3 and 17xL4	Pure compression.	1.5 mm/s (no preload)	F rupture =5.6 kN	Fx of the vertebrae body
Myklebust	[9]	14 whole spines T3 to L5	Pure compression (neck flexed)	Ranged from 10 to 1200 mm/s	F rupture 2.1 kN	Wedge crush fx
		13x T7-T12	Pure compression up to 50% of the height	1 mm/s.	F rupture = 3.3 kN	Fx of the vertebrae body
		9x L1-L5	Pure compression up to 50% of the height	1mm/s.	F rupture 5 kN	Fx of the vertebrae body
		4 whole cadavers	Force applied on T1	10 mm/s	F rupture =1.1 to 2.8kN	Wedge crush fx
Osvalder	[10]	16 units	Flexion - shearing	Static	Fx=0.62 kN My=160N.m	"flexion – distraction" type fx
Yoganandan	[11]	63 isolated vertebrae	Pure compression up to 50% of the height	2.54 mm/s	F rupture thorax = 3.3 kN lumbar= 4.6 kN	Vertebrae crushed
Yoganandan	[12]	38 isolated vertebrae	Pure compression	2.5 mm/s		Vertebrae crushed
		18 whole cadavers	Compression, flexed spine	2.5 mm/s	Fz comp = 2.5 kN associated with My = 170 Nm	Wedge crush fx
Willen	[13]	7 units of 3 vertebrae (T12-L2)	Pure compression.	Free fall of a 10 kg mass from 2 m.	F rupture 11 kN	"burst fracture" type fx

THE SIGNIFICANCE OF "PERMANENT DISABILITIES DATABASE" BASED ON AUTOMOBILE COLLISIONS IN JAPAN

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Paper Number 05-0091

ABSTRACT

In Japan, the number of automobile liability insurance payments in 2002 made to victims with permanent disabilities amounted to 58,380 or 1.56 times higher than a decade ago. Of these, 2,420 or 1.61 times higher than the previous decade were payments for those with severe permanent disabilities. With these statistical data, it is indispensable to consider the occurrence of permanent disabilities, the implementation of automobile safety measures and steps to be taken in the coming years.

The authors analyzed and reviewed the situations of traffic accident injuries resulting to permanent disabilities by examining 429,863 injured cases (persons) and the corresponding automobile liability insurance payments made since 1994 and thereafter. These cases were based from the Ministry of National Land, Infrastructure and Transport's computer data recorded since 1994, and from the compiled database on the national traffic accident of the Institute for Traffic Accident Research and Data Analysis (ITARDA). This indicates that it takes at least 5 to 6 years for the fixation of permanent disabilities symptoms after the occurrence of each automobile accident. The number of victims with severe permanent disabilities (first to third grades) increased by 23 % (annual increase of 45 persons or so) in the 7-year period between 1992 to 1999, while the number of victims with minor permanent disabilities (12th to 14th grades) increased by 76 % in the same period (annual increase of 1,600 persons or so).

It is found that determining the effects of vehicle safety structures (crashworthiness), and occupant protection systems, are indispensable to the reduction of incidence of permanent disabilities, and to the development of such structures and systems.

INTRODUCTION

The number of accidents, injury accidents, and fatal accidents on Traffic in Japan all peaked in 1972, after which they all declined (Figure 1). However, in 1977 the number of accidents in all three accident categories began to increase, especially non-fatal injury accidents. In contrast, the number of fatal accidents has tended to decrease since 1992. The decline in the number of fatalities appears to be largely the result of improvements in automobile safety devices such as seat belts and air bags, better emergency service, and other advancements.

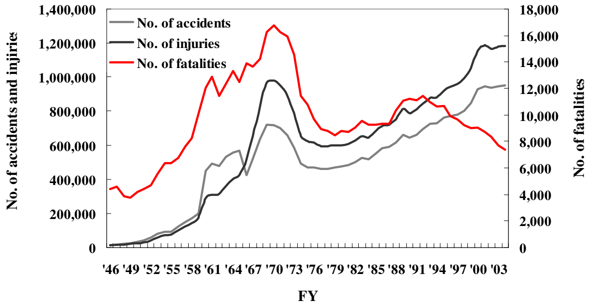

Figure 1 Conditions related to the occurrence of traffic accidents

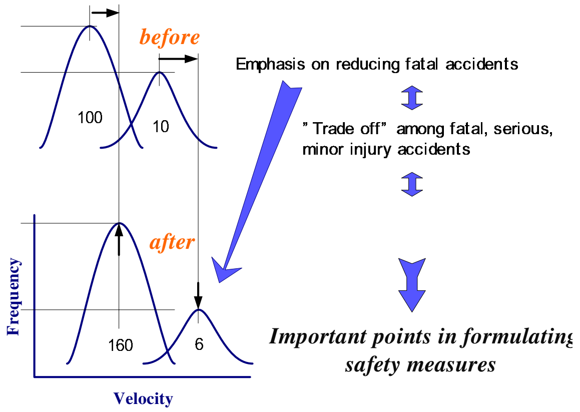

Figure 2 Conceptual diagram of automobile safety countermeasures and associated trade-off

At the same time, improvements in automobile safety countermeasures, emergency services, etc., have meant that what had previously would have been fatal injuries were now serious injuries, and what previously would have been serious injuries were becoming minor injuries (Figure 2). As a result, it appeared that there would be increases in both serious and minor injuries.

Furthermore, if the occupant protection devices, car crashworthiness, etc., are not adequate to reduce the energy force on the human body, the increase in serious injuries could be assumed to be reflected in the increase in accident victims suffering lasting effects from their injuries.

Efforts are now being made to further improve automobile safety technology. To better guarantee the effectiveness of these improvements, we must have a thorough understanding of trends in the occurrence of injuries to the human body and work to introduce more effective automobile safety technology.

In the present study, an effort was made to match permanent disability data based on liability insurance claims from the Road Transport Bureau, the Ministry of Land, Infrastructure and Transport (MLIT), with integrated traffic accident data of the Institute for Traffic Accident Research and Data Analysis (ITARDA). Trial and error analyses were also made on the state of permanent disabilities caused by automobile collisions, and the necessity and practicality of constructing a "permanent disability database" were investigated.

DATA SOURCE

Occurrence of permanent disabilities resulting from traffic accidents

The number of people becoming seriously injured in traffic accidents has stabilized (Figure 3). However, in contrast to the decline in fatalities, the number of people receiving lasting injuries has tended to increase.

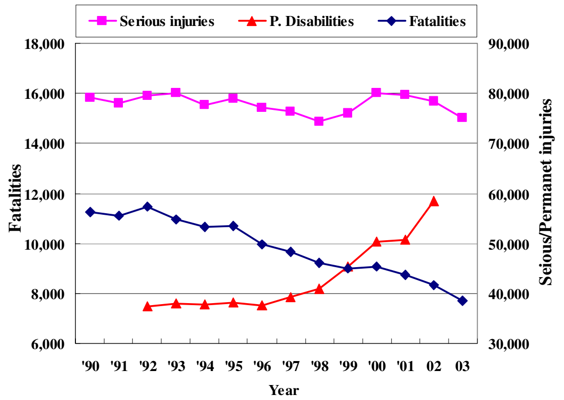

Figure 3 Annual trends in number of people with permanent disabilities vis-a-vis number of fatalities and serious injuries

Incidentally, 58,380 of the claims paid by liability insurance companies were for permanent disabilities in FY 2002, including payments made on 2,420 claims of serious permanent disabilities. Compared with the data from 1992, that is, 11 years ago, these figures represent increases of 54% and 61%, respectively. Given this background, it will be necessary in future traffic safety measures to incorporate the perspective of reducing injuries, including permanent disabilities.

Trends in occurrence of accidents and symptoms of permanent disabilities by year

Insurance payment for permanent disabilities is not necessarily made in the year the accident occurs, and is often made one or a few years after the accident. In many cases, therefore, payment to an injured person is made more than once, and sometimes over a few years. This study is intended to analyze the occurrence of permanent disabilities in traffic accidents for individual victims. So we must make an effort to match the "integrated traffic accident data" which is constructed in the year of an accident with "permanent disability data based on liability insurance claims" constructed after permanent disabilities are certified by the appearance of symptoms sometime after an accident.

Table 1 shows the relationship between the year an accident occurred and the year when symptoms of permanent disability became apparent. As for the accidents which occurred in 2001 and 2002 it can be estimated that a large amount of data has not been added to the database since permanent disabilities have not yet been confirmed. Incidentally, for accidents which occurred in 1992 or 1993, it took 5 or 6 years for about 98% of the permanent disabilities to be confirmed.

Table 1 Year-by-year trends in the fixation of permanent disability symptoms caused by different accidents

（Unit：Number of people involved in traffic accidents (upper column) and % (lower column）)

		Year of fixation of permanent disability symptoms												
	Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
Year of occurance of an accident	1992	3,229 13.5%	11,982 50.2%	5,725 24.0%	1,708 7.2%	617 2.6%	304 1.3%	137 0.6%	78 0.3%	40 0.2%	28 0.1%	15 0.1%	2 0.0%	23,865 100.0%
	1993		5,960 21.5%	13,372 48.2%	5,615 20.2%	1,686 6.1%	579 2.1%	282 1.0%	114 0.4%	69 0.2%	39 0.1%	13 0.0%	2 0.0%	27,731 100.0%
	1994			5,973 22.1%	13,044 48.3%	5,303 19.6%	1,649 6.1%	579 2.1%	250 0.9%	125 0.5%	67 0.2%	21 0.1%	5 0.0%	27,016 100.0%
	1995				6,318 22.0%	13,715 47.7%	5,872 20.4%	1,815 6.3%	627 2.2%	256 0.9%	87 0.3%	47 0.2%	7 0.0%	28,744 100.0%
	1996					6,227 21.8%	14,109 49.5%	5,667 19.9%	1,685 5.9%	555 1.9%	210 0.7%	60 0.2%	10 0.0%	28,523 100.0%
	1997						6,683 21.8%	15,486 50.6%	6,113 20.0%	1,648 5.4%	526 1.7%	152 0.5%	20 0.1%	30,628 100.0%
	1998							7,451 22.5%	17,775 53.7%	6,028 18.2%	1,451 4.4%	349 1.1%	45 0.1%	33,099 100.0%
	1999								8,723 23.7%	20,325 55.2%	6,307 17.1%	1,333 3.6%	119 0.3%	36,807 100.0%
	2000									9,299 25.5%	20,967 57.6%	5,696 15.6%	453 1.2%	36,415 100.0%
	2001										9,420 29.0%	20,646 63.7%	2,369 7.3%	32,435 100.0%
	2002											7,271 46.5%	8,369 53.5%	15,640 100.0%
	Total	3,229 1.0%	17,942 5.6%	25,070 7.8%	26,685 8.3%	27,548 8.6%	29,196 9.1%	31,417 9.8%	35,365 11.0%	38,345 11.9%	39,102 12.2%	35,603 11.1%	11,401 3.6%	320,903 100.0%

Note 1) The year of symptom fixation is adjusted by the difference between the age at which the accident occurred and the age at which the claim was made for permanent disability.

2) The period of 5 years after the occurrence of an accident goes to 1999, and is shown by hatching.

According to this result, it can be pointed out that it takes about 5-6 years for the symptoms to become fixed. In order to make a more precise analysis of these injuries, we need at least 5 or 6 years after their occurrence for the study. This means that it is important to make a prompt and accurate diagnosis at the time of the accident, as well as to accurately predict the occurrence of permanent disabilities. In other words, it is necessary to develop a scale for permanent disabilities at the time of injury diagnosis.

RESULTS AND DISCUSSION

Trends in the number of people sustaining permanent disabilities

Figure 4 shows annual trends in the number of occurrences of permanent injuries from 1992 to 2002. As we can see, there is an increasing trend. It should be noted that there is still a large amount of data missing for 2001 and 2002, making it difficult to confirm permanent disabilities.

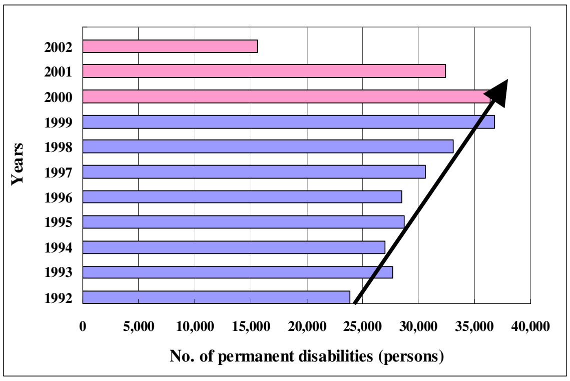

Figure 4 Annual trends in the number of persons with permanent disabilities

State of occurrence of major and minor permanent disabilities

As for the number of victims of permanent disabilities from 1992 to 2002, we have classified their ratings into four classes (Grades 1-3: severe permanent disabilities, Grades 4-8, Grades 9-11, and Grades 12-14). At the same time, we have picked out the victims of high- (Grades 1-3) and low-severity (Grade 12-14) permanent disabilities from the four classes, and the Figure 5 B), A) shows the trend by year. Please refer to the appendix for an overview of the rating of permanent disabilities in the liability insurance system. Figure 4 shows that while the number of people with permanent disabilities has been on an upward trend over the past few years, minor injuries have had a higher tendency than severe injuries.

From its base of 100% in 1992, the number of people with severe permanent disabilities was 123% in 1999, indicating that during that time about 45 people sustained high-severity permanent disabilities each year as a result of traffic accidents. In contrast, the number of low-severity permanent disabilities grew from a base of 100% in 1992 to 176% in 1999, indicating that during that time about 1,600 people sustained low-severity permanent disabilities each year as a result of traffic accidents.

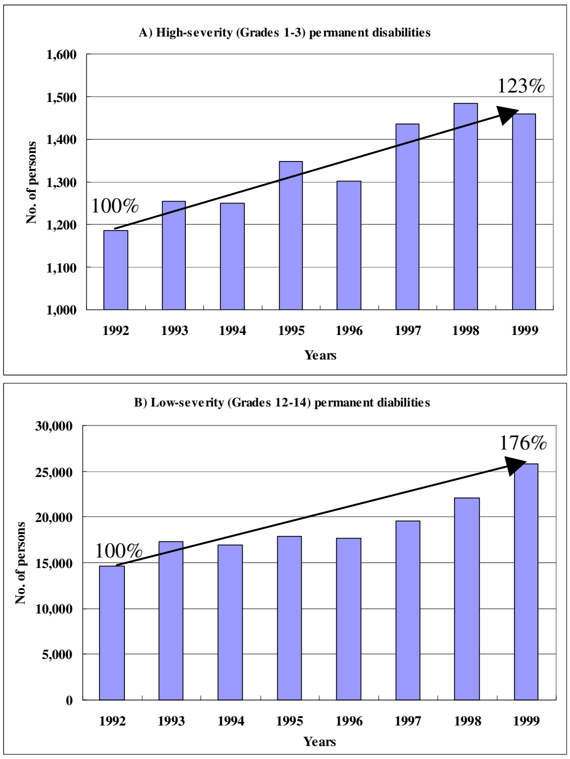

Figure 5 Trends in high-severity (A: Grades 1-3) and low-severity (B: Grades 12-14) permanent disabilities

Annual trend in rating and series (symptoms) of permanent disabilities

The number of severe permanent disabilities (Grades 1-3) has shown an increasing trend. However, since the increase in minor permanent disabilities (Grades 12-14) is more significant, the component of severe permanent disabilities has been in a decreasing trend annually. Permanent disabilities of composite or equivalent symptom have been decreasing, and the occurrence of multiple permanent disabilities has been decreasing. This suggests that the types of personal injuries at the time of traffic accidents have been changing, which may imply that the improvements on in-car equipment and car body design structure have had an effective influence.

The permanent disabilities series (symptoms) is classified into (1) nervous system, (2) composite or equivalent symptom, and (3) symptoms other than (1) and (2). Their yearly trends are shown together with the number of traffic accident victims in Figure 6.

The numbers of permanent disabilities related to symptoms of the nervous system have shown an increasing trend. In 1992, for example, there were 7,220 occurrences of such injuries (component of 29.3%), but by 1999 that figure had nearly doubled to 17,899 occurrences, and the component also grew, to 37.3%.

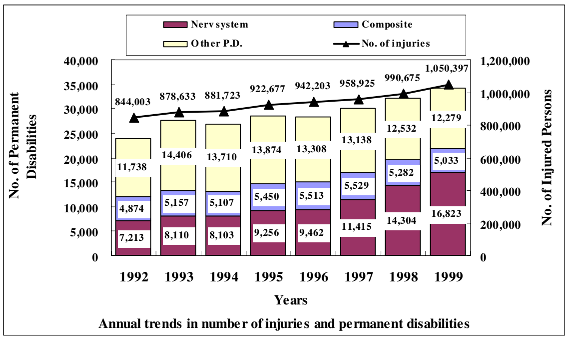

Figure 6 Annual trends in number of permanent disabilities by symptom

Occurrence of permanent disabilities by type of accident

The trends in the number of people sustaining permanent disabilities are compared with the number of fatal and injury accidents by type of accident, and also by year. Figure 7a shows the number of fatal and injury accidents where permanent disabilities occurred in 1992. Figure 7b shows the number of fatal and injury accidents where permanent disabilities occurred in 1999.

In the fatal and injury accidents in 1992 and 1999, while the number of fatal cases decreased in every accident type, the number of minor injuries caused by rear-ends collisions increased remarkably. On the other hand, looking at the types of accidents that have caused permanent disabilities, we can see that in 1999, there was a notable increase in permanent disabilities caused by minor rear-end collisions as compared with 1992, as well minor injuries caused by minor front-end collisions. While the number of permanent disabilities resulting from overall severe injuries is decreasing in trend, the number of permanent disabilities resulting from severe and minor injuries in car-to-car or other types of accidents is notably increasing.

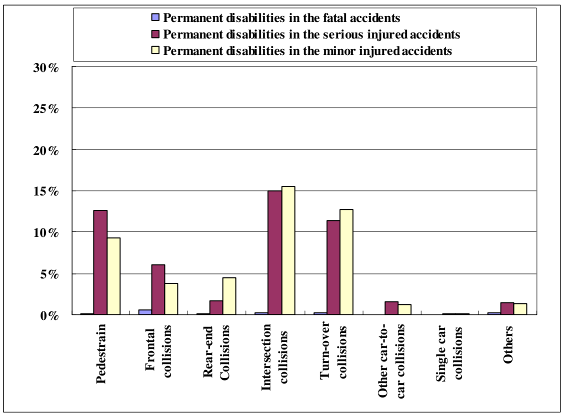

Figure 7a Frequency rate of permanent disabilities classified by types of accidents in 1992

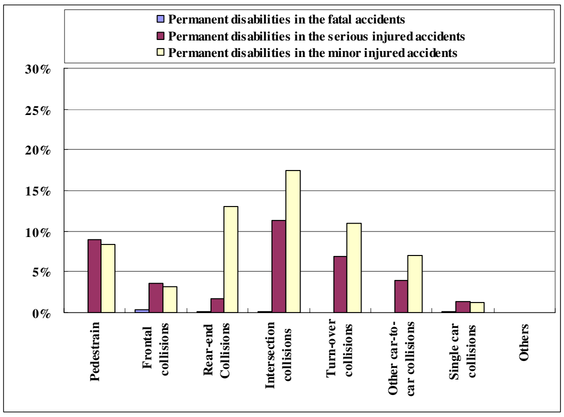

Figure 7b Frequency rate of permanent disabilities classified by types of accidents in 1999

Occurrence of permanent disabilities by type of group

The trends in the occurrence of permanent disabilities are classified by group, and also by region of primary injury. Then the yearly changes are compared. Figure 8a shows the number of occurrences of permanent disability by group and by region of primary injury in 1992. Figure 8b shows the number of occurrences of permanent disability by group and by region of primary injury in 1999.

The group seeing the biggest change in yearly figures for occurrence of permanent disabilities were occupants of four-wheeled vehicles, whose injuries were primarily in the neck region. In 1992, there were 1,500 persons in four-wheeled vehicles receiving permanent neck injuries, but by 1999 this figure had nearly tripled, to 7,000 persons (Figs. 8a and 8b). Following the neck injuries, the most common permanent disabilities for this type of vehicle were in the legs, then the head, but these latter two types of injuries have not increased as much as neck injuries. Groups that have had little change in neck injury occurrence are motorcyclists, bicyclists, and pedestrians; in all of these groups, the most common type of permanent disability is in the legs (in the order of motorcyclists, bicyclists, pedestrians), followed by head injuries (pedestrians, bicyclists, motorcyclists).

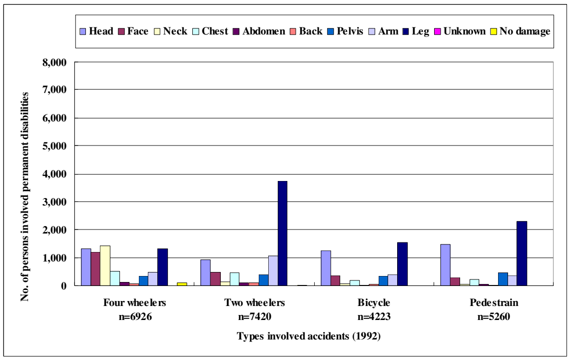

Figure 8a Number of occurrences of permanent disabilities and region of disability among different groups, 1992

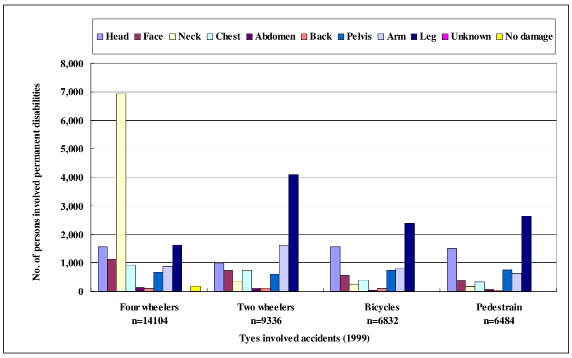

Figure 8b Number of occurrences of permanent disability and region of disability among different groups, 1999

Occurrence of fatalities, permanent disabilities, and injuries by gender

Generally speaking, women tend to sustain permanent disabilities more often than men, with the frequency of occurrence being about 2-5% higher, especially in the young and middle age groups (Figs, 9a, 9b). However, in the 55 and older age group, men and women tend to have a similar rate of permanent disability occurrence. For this trend, it should be noted that these data are from 1999, and there were fewer women than men of this age group who had driver's licenses, so these figures may just be a reflection of fewer chances to drive for women.

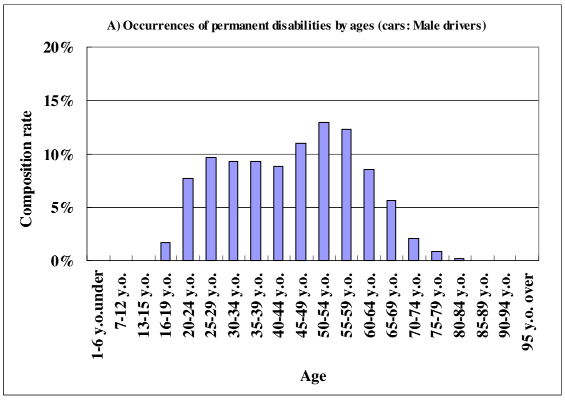

Figure 9a Occurrence of permanent disabilities in men by age group (drivers in passenger cars)

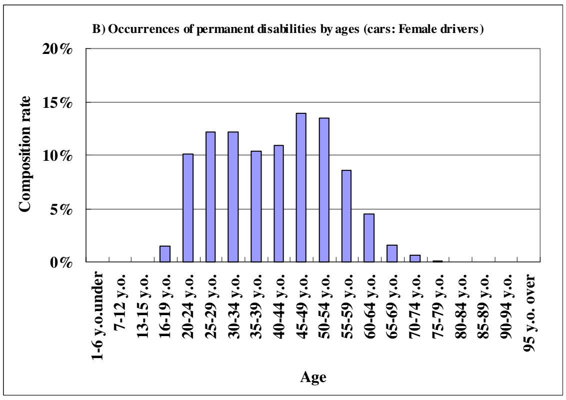

Figure 9b Occurrence of permanent disabilities in women by age group (drivers in passenger cars)

Relation between vehicle structure and permanent disabilities

It has been noted that in accidents involving four-wheeled vehicles, a relatively large number of injuries occur in the legs. Here are some figures from 1995 to 1999 regarding the 2,792 drivers who sustained permanent disabilities (First guilty party: 314 persons; Second guilty party: 2,478 persons)

In accidents involving collisions between SUVs and vans in which seat belts were in use and/or airbags inflated, there is a growing number of deaths, serious injuries, minor injuries, and permanent disabilities sustained by persons in vans. In collisions involving SUVs and regular passenger cars there are many fatalities and serious injuries, but not so many minor injuries and permanent disabilities as compared with vans. Thus, the rate of occurrence of permanent disabilities varies by type of vehicle.

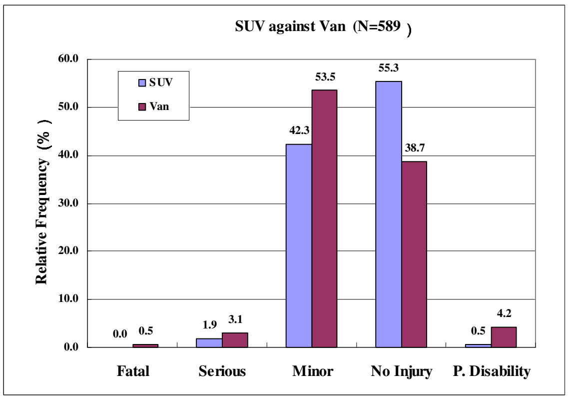

Figure 10a Differences in degrees of seriousness of injuries sustained in collision with different types of vehicle (SUV against van)

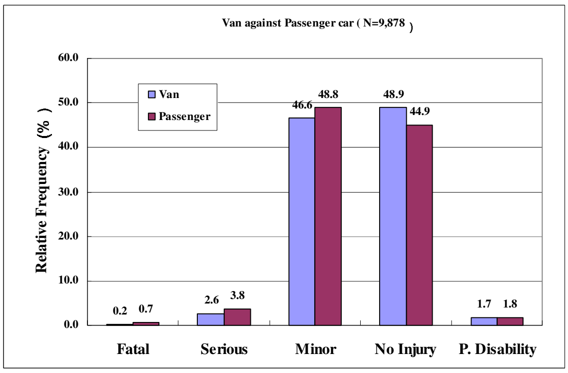

Figure 10b Differences in degrees of seriousness of injuries sustained in collision with different types of vehicle (van against ordinary passenger car)

Relation between equipment designed to protect drivers and passengers and permanent disabilities

The number of fatalities of a passenger car driver wearing a seat belt with an airbag inflated is 374 (1.16%), that of severe injuries is 2,785 (8.66%), and that of minor injuries is 29,007 (90.18%).

Among them, the number of people with permanent disabilities is 892 (2.77%). In contrast, the number of fatalities of a passenger car driver not wearing a seat belt with an airbag inflated is 662 (11.95%), that of severe injuries is 995 (17.96%), and that of minor injuries is 3,882 (70.08%). Among them, the number of people with permanent disabilities is 146 (2.64%) (Table 2). On the other hand, the number of fatalities of minivan drivers wearing seat belts with an airbag inflated is 61 (1.04%), that of severe injuries is 600 (10.18%), and that of minor injuries is 5,232 (88.78%). The number of people with permanent disabilities is 183 (3.11%). In contrast, the number of fatalities of minivan drivers not wearing seat belts with an airbag inflated is 97 (10.05%), that of severe injuries is 192 (19.90%), and that of minor injuries is 676 (70.05%). The number of people with permanent disabilities is 26 (2.69%) (Table 2).

Figure 11a shows a similar trend in the occurrence of fatality, severe injury, non-severe injury, and permanent disability both for passenger car and minivan drivers. In particularly, wearing a seatbelt is 10 times as effective as not wearing it in preventing fatal accidents.

While the non-fatal rate is high when a seat belt was used and an airbag inflated, it appears that the component of permanent disabilities is also high. On the other hand, even if an airbag inflated, the fatality rate did not drop when a seat belt was not used, and the component of fatality stayed high, which may seem to result in a relatively low proportion of permanent disabilities. When an airbag didn’t inflate, the non-fatal rate became high due to wearing a seat belt (Figure 11b). However, the component of permanent disabilities is not as high as when an air bag inflated. On the other hand, when a seat belt is not in use, a driver is more likely to suffer permanent disability. This may be because when a driver’s body is not secured, it can collide with various parts of the inner wall of a vehicle (Table 3).

Accordingly, usage of a driver restraint system such as wearing a seat belt or inflation of an airbag can produce an effect to reduce fatality, but at the same time, it can increase the occurrence of permanent disabilities. However, this trend should be examined further from the aspects of the area receiving permanent disabilities, the type of the disability, etc. after the influences of driver’s gender, difference of collision speed, and others are adjusted.

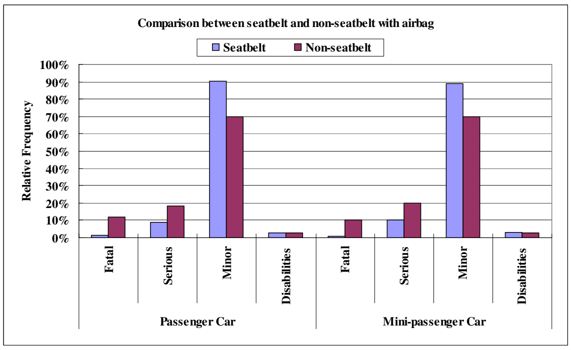

Figure 11a Comparison of the effect of wearing a seat belt and not wearing it when an airbag inflated (frontal collision)

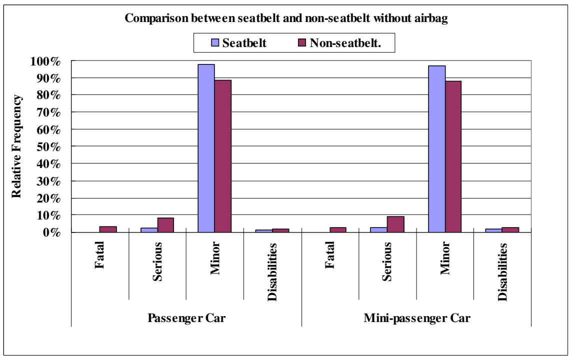

Figure 11b Comparison of the effect of wearing a seat belt and not wearing it when an airbag did not inflate (frontal collision)

Table 2 The number and component of drivers wearing a seat belt and those not wearing one by degree of seriousness of injuries sustained in a frontal collision when an airbag inflated

	Airbag diployment									
	Passenger Car				Total	Passenger Car				Total
	Fatal	Serious	Minor	Disabilities		Fatal	Serious	Minor	Disabilities	
Seatbelt	374 (1.16%)	2,785 (8.66%)	29,007 90.18%)	892 [2.88%]	32,166	61 (1.04%)	600 (10.18%)	5232 (88.78%)	183 [3.11%)	5,893
Non-seatbelt	662 (11.95%)	995 (17.96%)	3,882 (70.08%)	146 [2.64%]	5,539	97 (10.05%)	192 (19.90%)	676 (70.05%)	26 [2.69%]	965

Table 3 The number and component of drivers wearing a seat belt and those not wearing it by degree of seriousness of injuries sustained in frontal collision when an airbag didn’t inflate

	No airbag									
	Passenger Car				Total	Passenger Car				Total
	Fatal	Serious	Minor	Disabilities		Fatal	Serious	Minor	Disabilities	
Seatbelt	1,671 (0.17%)	21,754 (2.18%)	975,691 (97.66%)	15,889 [1.50%]	999,116	505 (0.21%)	6,887 (2.80%)	238,307 (96.99%)	4,334 [1.76%]	245,699
Non-seatbelt	2,919 (3.33%)	7,099 (8.09%)	77,761 (88.59%)	1,754 [2.00]	87,779	716 (2.78%)	2,360 (9.17%)	22655 (88.05%)	655 [2.55%]	25,731

CONCLUSIONS

In an effort to use permanent disability data to analyze, from a new perspective, the relationship between automobile accidents and personal injuries, matching was made between integrated traffic accident data and liability insurance permanent disability data. Also an attempt was made to construct a permanent disability database. Furthermore, to get a clear understanding of personal injuries, particularly of the occurrence of permanent disabilities, we examined the effects of the crashworthiness and vehicle interior & exterior equipment designed for occupant protection and vulnerable users.

The following results were obtained:

1) A total of 275,434 of 370,287 accidents (persons) could be matched between the integrated traffic accident data and the permanent disability data, for a matching rate of 74.4%.
2) It takes about 5-6 years to confirm the severity of about 98% of the permanent disabilities in automobile traffic accidents.
3) The number of people with permanent disabilities tends to increase year by year. This trend is more pronounced in the low-severity group (Grades 12-14) than in the high-severity group (Grades 1-3). In the years between 1992 and 1998, the number of people with high-severity permanent disabilities increased by 23% (equivalent to about 45 new high disabled persons each year). In contrast, the number of low-severity disabilities increased by 75% during the same time period (equivalent to about 1,600 new low disabled persons each year).
4) There has been a remarkable increase in low-severity permanent disabilities caused by rear-end and side collisions. There has also been a remarkable increase in both high- and low-severity permanent disabilities caused by other types of vehicle-to-vehicle collisions)."
5) The group showing the greatest change over the years is the four-wheeled vehicles, where the most common type of injury is in the neck. From 1992 to 1999, the number of permanent disabilities sustained in four-wheeled vehicle accidents more than tripled, going from about 1,500 persons (incidents) to about 7,000 persons (accidents).
6) Women tended to be more susceptible to permanent disabilities than men. For example, disabling injuries to young and middle-aged women drivers (20-55 years of age) were 2-5% higher than to men in the same age group.
7) The degree of bodily injury varied by types of vehicle. Serious injuries were highest for vans, followed by regular passenger cars and SUVs. Van accidents also tended to show a high rate of permanent disabilities.
8) While the non-fatal rate is high when a seat belt was used and an airbag inflated, it appears that the component of permanent disabilities is also high.

Using the results from the present study, we would like to do a more detailed analysis of the occurrence of permanent disabilities in an effort to obtain more concise results about the effectiveness of automobile safety features and to come up with relevant and related topics and issues.

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2) Kaneda K., ITARDA – Traffic Accident Database and Current Activities, IPC-8, 1995

3) Automobile Liability Security Law & Related Cabinet and Ministerial Ordinances Including Policy Conditions for Compulsory Automobile Liability Insurance, Translated and Published by NLIRO (Non-life Insurance Rating Organization of Japan), 2002

Rating of permanent disabilities

Overview of the rating of permanent disabilities in the liability insurance system.

Grading of Permanent Disabilities

Grade	Permanent disability
1st grade	(1) Loss of sight of both eyes
	(2) Loss of functions of both mastication and speech
	(3) Loss of both upper limbs upwards of the elbow joint
	(4) Total loss of the functions of both upper limbs
	(5) Loss of both lower limbs upwards of the knee joint
	(6) Total loss of the functions of both lower limbs
2nd grade	(1) Loss of sight of one eye and partial loss of vision in the other eye to 0.02 or
	(2) Partial loss of vision in both eyes to 0.02 or less
	(3) Loss of both upper limbs upwards of the wrist joint
	(4) Loss of both lower limbs upwards of the ankle joint
3rd grade	(1) Loss of sight of one eye and partial loss of vision in the other eye to 0.06 or
	(2) Loss of functions of either mastication and speech
	(3) Severe disabilities in the functions of the nervous system or in mentality, causing inability to engage in work for the remainder of their lives
	(4) Severe disabilities in the functions of the thorax and abdominal organs, causing inability to engage in work for the remainder of their lives
	(5) Loss of all of thumbs and fingers on both hands
4th grade	(1) Partial loss of vision in both eyes to 0.06 or less
	(2) Severe disabilities in the functions of both mastication and speech
	(3) Total loss of hearing in both ears
	(4) Loss of one lower limbs upwards of the elbow joint
	(5) Loss of one lower limbs upwards of the knee joint
	(6) Loss of the use of all of thumbs and fingers on both hands
	(7) Loss of both legs upwards of the Lisfranc's joints
5th grade	(1) Loss of sight of one eye and partial loss of vision in the other eye to 0.1 or
	(2) Severe disabilities in the functions of the nervous system or in mentality, causing inability to engage in anything but very light work
	(3) Severe disabilities in the functions of the thorax and abdominal organs, causing inability to engage in anything but very light work
	(4) Loss of one upper limbs upwards of the wrist joint
	(5) Loss of one lower limbs upwards of the ankle joint
	(6) Total loss of the use of one upper limb
	(7) Total loss of the use of one lower limb
	(8) Loss of all toes on both feet
6th grade	(1) Partial loss of vision in both eyes to 0.1 or less
	(2) Severe disabilities in the functions of either mastication and speech
	(3) Partial loss of hearing in both ears such a degree that they are unable to hear a loud voice unless it is close to the ear
	(4) Total loss of hearing in one ear and partial loss of hearing in the other ear to such a degree of inability to hear a speaking voice at a distance of 40
	(5) Severe deformity or motor impediment in the spinal column
	(6) Loss of the use of two of three major joints in one upper limb
	(7) Loss of the use of two of three major joints in one lower limb
	(8) Loss of thumb and all fingers on one hand or loss of four digits including the thumb and index finger of one hand
7th grade	(1) Loss of sight of one eye and partial loss of vision in the other eye to 0.6 or
	(2) Partial loss of hearing in both ears to such a degree of inability to hear a normal speaking voice at a distance 40 centimeters or more
	(3) Total loss of hearing in one ear and partial loss of hearing in the other ear to such a degree of inability to hear a normal speaking voice at a distance of 1
	(4) Disabilities in the functions of nervous system or in mentality, causing inability to engage in anything but light work
	(5) Disabilities in the functions of the thorax and abdominal organs, causing inability to engage in anything but light work
	(6) Loss of thumb and index finger on one hand, or loss of three or more digits including either the thumb or index finger on one hand
	(7) Loss of the use of thumb and four fingers on one hand, or loss of the use four digits including the thumb ad index finger on one hand
	(8) Loss of one leg upwards of the Lisfranc's joints
	(9) Pseudoarthrosis with a severe motor impediment in one upper limb
	(10) Pseudoarthrosis with a severe motor impediment in one lower limb
	(11) Loss of the use of all toes on both feet
	(12) Severe deformity in female's appearance
	(13) Loss of both testicles
8th grade	(1) Loss of sight of one eye or partial loss of vision in the other eye to 0.02 or
	(2) Motor impediment of the spinal column
	(3) Loss of thumb and one finger on one hand
	(4) Loss of the use of the thumb and index finger on one hand, or loss of use of thumb and two or more fingers including the index finger on one hand
	(5) Shortening of one lower limb by five centimeter or more
	(6) Loss of the use of one of three major joints in one upper limb
	(7) Loss of the use of one of three major joints in one lower limb
	(8) Pseudoarthrosis in one upper limb
	(9) Pseudoarthrosis in one lower limb
	(10) Loss of all toes on one foot
	(11) Loss of a spleen or one kidney on one side
9th grade	(1) Partial loss of vision in both eyes to 0.6 or less
	(2) Partial loss of vision in one eye to 0.6 or less
	(3) Hemianopsia, contraction of the visual field or distortion of the visual field in both eyes
	(4) Severe loss in both eyelids
	(5) Loss of nose with severe disabilities in the functions thereof
	(6) Disabilities in the functions of both mastication and speech
	(7) Those who have a partial loss of hearing in both ears to such a degree of inability to hear a normal speaking voice at a distance of one meter or more
	(8) Partial loss of hearing in one ear to such a degree of inability to hear a loud voice unless it is close to the ear, and partial loss of hearing in the other ear to such a degree of inability to hear a normal speaking voice at a distance one
	(9) Total loss of the hearing in one ear
	(10) Disabilities in the functions of nervous system or in mentality, causing inability to engage in anything but limited work to considerable extent
	(11) Severe disabilities in the functions of the thorax and abdominal organs, causing inability to engage in anything but limited work to considerable extent
	(12) Loss of thumb on one hand, loss of the index finger and one other finger on one hand, or loss of three digits except the thumb and index finger on one
	(13) Loss of the use of thumb and one finger on one hand
	(14) Loss of two or more toes on one foot including big toe
	(15) Loss of the use of all toes on one foot
	(16) Severe disabilities in the genital organs
10th grade	(1) Partial loss of vision in both eyes to 0.1 or less
	(2) Disabilities in the functions of either mastication and speech
	(3) Dental prostheses on fourteen teeth or more
	(4) Partial loss of hearing in both ears to such a degree as to make it difficulty to hear a normal speaking voice at a distance one meter or more
	(5) Partial loss of hearing in one ear to such a degree of inability to hear a loud voice unless it is close to the ear
	(6) Loss of the index finger on one hand, or loss of two digits except the thumb and index finger on one hand
	(7) Loss of the use of the thumb on one hand, loss of the use of the index finger and one finger on one hand, or loss of the use of three digits except the thumb and index finger on one hand
	(8) Shortening of one lower limb by three centimeters or more
	(9) Loss of the big toe on one foot, or loss of four toes except the big toe on
	(10) Severe disabilities in the functions of one of three major joints of one
	(11) Severe disabilities in the functions of one of three major joints of one
11th grade	(1) Severe disabilities in focusing or motor impediments in both eyeballs
	(2) Severe motor impediment in both eyelids
	(3) Severe residual loss in one eyelids
	(4) Dental prostheses on ten teeth or more
	(5) Partial loss of hearing in both ears to such a degree of inability to hear a low voice at a distance one meter or more
	(6) Partial loss of hearing in one ear to such a degree of inability to hear a normal speaking voice at a distance of forty centimeters or more
	(7) Deformity of the spinal column
	(8) Loss of either a middle finger or ring finger on one hand
	(9) Loss of the use of the index finger on one hand, or loss of the use of two digits except the thumb and index finger on one hand
	(10) Loss of the use of two or more toes on one foot including big toe
	(11) Disabilities in any thorax or abdominal organs
12th grade	(1) Severe disabilities in focusing of focusing or motor impediments in one
	(2) Severe motor impediment in one eyelid
	(3) Dental prostheses on seven teeth or more
	(4) Loss of major part of auricle in one ear
	(5) Severe deformity of clavicle, sternum, ribs, scapula or pelvis
	(6) Disabilities in the functions of one of three major joints of one upper limb
	(7) Disabilities in the functions of one of three major joints of one lower limb
	(8) Deformity of a long pipe bone
	(9) Loss of the use of either a middle finger or ring finger on one hand
	(10) Loss of the second toe on one hand, loss of two toes including the second toe on one foot, or loss of all of third to fifth toes on one foot
	(11) Loss of the use of big toe or four other toes except the big toe on one foot
	(12) Obstinate nervous symptoms in affected parts
	(13) Severe deformity in male's appearance
	(14) Deformity in female's appearance
13th grade	(1) Partial loss of vision in one eye to 0.6 or less
	(2) Hemianopsia, contraction of the visual field, or distortion of the visual field in one eye
	(3) Partial loss of eyelids or residual baldness of eyelashes in both eyes
	(4) Dental prostheses on five teeth or more
	(5) Loss of the little finger on one hand
	(6) Loss of part of the bones of thumb on one hand
	(7) Loss of part of the bones of index finger on one hand
	(8) Inability to bend and stretch the last joint of index finger on one hand
	(9) Shortening of one lower limb by one centimeters or more
	(10) Loss of one or two of the third to fifth toes on one foot
	(11) Loss of the use of the second toe on one foot, loss of the use of two toes including the second toe on one foot, or loss of the use of all of third to fifth
14th grade	(1) Loss in a part of one eyelid, or residual baldness of eyelashes in one eye
	(2) Dental prostheses on three teeth or more
	(3) Partial loss of hearing in one ears such a degree of inability to hear a low voice at a distance of one meter or more
	(4) Palm-size ugly scar(s) on the exposed part of one upper limb
	(5) Palm-size ugly scar(s) on the exposed part of one lower limb
	(6) Loss of the use of the little finger on one hand
	(7) Loss of part of the bones of digit(s) other than the thumb and index finger on one hand
	(8) Inability to bend and stretch the last joint of digit(s) other than thumb and index finger on one hand
	(9) Loss of the use of one or two of the third to fifth toes on one foot
	(10) Nervous symptoms in affected parts
	(11) Deformity in male's appearance

Crash Injuries and Long-Term Consequences: The CIREN Experience

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ABSTRACT

The Crash Injury Research and Engineering Network (CIREN) is a multi-disciplinary collaboration of trauma physicians, engineers, epidemiologists, crash investigators and other social scientists researching the “cause and effect” of serious and/or disabling injuries sustained as a result of an automotive collision. CIREN is a network of 10 level 1-trauma centers spanning the United States and investigating approximately 400 crashes per year that result in serious and/or disabling injuries.

The CIREN utilizes several unique processes and tools to research automotive crashes. One such tool utilized is the Medical Outcomes Study 36 – Item Short Form Survey (SF-36). The SF-36 has become one of the most widely used scoring tools for measuring outcomes after multiple trauma events. The purpose of this study is to evaluate the SF-36 scores for CIREN occupants, one year after their crash. Over three hundred CIREN occupants have been followed and responded to the SF-36 on the one-year timeline. These scores were analyzed in conjunction with crash dynamics and occupant factors in an attempt to determine which crash scenarios and injuries result in long-term physical and or mental consequences.

This paper reviews the SF-36 scores for 346 CIREN occupants who were interviewed 12 months after their crash. We attempt to isolate injuries or injury types that show significant long-term consequences and possibly serious injuries that show little long-term issues. Associated factors are analyzed such as crash type, vehicle parameters, age and others.

INTRODUCTION

The concept of outcomes is an immense one, on one end of the spectrum it may be a tangible count like lost wages or hospital costs and on the other end it might be represented by a much more difficult problem to capture as seen in a crash occupant’s undiagnosed depression, brought about by a mild concussion.

In the United States the economic impact of automotive crashes is estimated at $231 billion per year, this is the equivalent of $820 for every living person in the country [1].

With the ever-increasing safety technology available to occupants of vehicles (air bags, safety belts, etc.) more individuals are surviving crashes that were once nearly always fatal. One of the main inclusion criteria for the Crash Injury Research and Engineering Network (CIREN) is the case occupant’s vehicle be no more than 8 model years old from the current model year available. Crashes resulting in serious and/or disabling injuries are another one of the main inclusion criteria for the CIREN program. This concentration allows CIREN to collect in-depth crash and injury data on the most costly crashes occurring on our roadways. Crashes resulting in serious injuries account for approximately 12% of all crashes nationwide, however this 12% constitutes approximately 77% of the economic impact related to automotive crashes [2].

In many crash cases the significant portion of the costs are not incurred during the initial hospitalization phase, but in the days, months and years after the crash and initial hospitalization. These costs are born in additional hospital admissions, surgical procedures, lost wages, out of pocket medical expenditures, and long-term mental and/or physical impairment just to name a few.

Recent history studies have shown significant long-term consequences associated with certain types of injuries [3,4]. Serious brain injuries resulting in anatomical lesions have long been known to have extremely long-term costs and consequences. The SF-36 outcome tool (detailed below) has been shown to be less than ideal when testing for outcomes related to head trauma, especially in the areas of cognitive function. MacKenzie et al. indicated the SF-36 required additional cognitive testing supplements to develop a more accurate outcome indicator for individuals who sustain multiple trauma involving head injury [7].

Most recently Read, et al. (2004) examined 65 occupants from CIREN crashes utilizing SF-36 and other outcome tools such as testing for post-traumatic stress disorder (PTSD) as well as personal interviews and questionnaires. Read, et al. showed 22% of the population that suffered an ankle/foot fracture who were employed prior to their crash stated they were unable to return to work at 1 year due to their injury, compared to 3% of the occupants that did not suffer an ankle/foot injury [5].

The majority of outcome studies related to blunt trauma are pursued retrospectively from state or system based trauma data registries. The CIREN program prospectively follows the case occupant for the 12 months following the occupant's crash collecting the SF-36 scores at baseline (while in the hospital) and again at 6 and 12 months post crash. Therefore, a detailed examination of the available SF-36 data and related crash and injury parameters was developed for this study.

BACKGROUND ON THE SF-36

The Short Form 36 (SF-36) was derived from the work of the Rand Corporation of Santa Monica during the 1970's. Rand's Health Insurance Experiment compared the impact of alternative health insurance systems on health status and utilization. The outcome measures developed for the study have been widely used. They were subsequently refined and used in Rand's Medical Outcomes Study (MOS), which focused more narrowly on care for chronic medical and psychiatric conditions [8].

The SF-36 was designed for use in clinical practice and research, health policy evaluations, and general population surveys. The form is used in identifying and tracking limitations in physical or social activities because of health problems relating to the traumatic event. It is a generic measurement and does not target specific ages, sex, or disease. The SF-36 measures eight health concepts (see Table 1).

Although the SF-36 can be self administered, CIREN uses trained interviewers to administer the questionnaire at the time of the traumatic event to develop a baseline to determine the physical and emotional health status of a person at that time compared to how they were prior to the event. The same questions are asked at 6-months and 12-months post event. These data are invaluable in determining overall medical outcomes.

Table 1.
SF-36 Health Status Concepts

Health Concept		Description
PF	Physical Functioning	The PF score indicates the amount health limits physical activities such as walking, lifting, bending, stair climbing and exercise.
RP	Role Physical	The RP score indicates the level that physical health interferes with work or other daily activities
BP	Bodily Pain	The BP score indicates the intensity of pain and its effect on normal work in and out of the home.
GH	General Health Perceptions	The GH score evaluates health, current and future outlook as well as resistance to illness.
V	Vitality	The V score indicates the extent of energy level.
SF	Social Functioning	The SF score indicates a level to which physical or emotional problems interfere with daily social activities.
RE	Role Emotional	The RE score indicates a level that emotional problems interfere with work or other daily activities.
MH	Mental Health	The MH score identifies general mental health including depression, anxiety and behavior.

* Physical Functioning, Role Physical, Bodily Pain and General Health scores are combined to obtain the Physical Component Summary.

** Vitality, Social Functioning, Role-Emotional and Mental Health are combined to obtain the Mental Component Summary

Scales that load highest on the physical component are most responsive to treatments that change physical morbidity, whereas scales loading highest on the mental component respond most to drugs and therapies that target mental health [9

METHODS

The CIREN database was queried for years 1997-2004 to extract all cases where a complete baseline and 12-month SF-36 data were available. In conjunction with the available SF-36 data, crash reconstruction data, injury coding and complete clinical data were required to be complete and available in the database. Several crash and injury variables were extracted for every case. Including, but not limited to, demographics, restraint status, principal direction of force (PDOF), crush and intrusion measurements, Delta V, Injury Severity Score (ISS), Maximum Abbreviated Injury Scale (MAIS), and injury codes for analysis.

The SF-36 scores are derived from the answers given by case occupants on 36 standardized questions. The questions inquire about issues ranging from the their opinion of general health now and a year ago, ability to climb stairs, lift groceries, physical limitations at work or daily activities to feelings of depression, pain issues and energy levels. The results are used in calculating scores for eight categories, four physical related and four mental related. The final composite scores are based on a 100-point scale. The lower the score in any given SF-36 category indicates a decreased ability in that category for the occupant.

The medical data in CIREN is prospectively captured at each of the 10 CIREN trauma centers while the occupant is in the hospital. All injuries captured in CIREN are coded using the Abbreviated Injury Scale (AIS) and the International Classification of Disease 9th Edition (ICD-9). Radiology images and clinical photographs are utilized to record and detail each applicable injury. Every injury recorded is reviewed by the clinical CIREN team to validate and detail the injury coding. In addition to these coding methodologies all upper and lower extremity fractures and joint dislocations are coded using the Orthopaedic Trauma Association (OTA) coding system. The OTA system requires review of appropriate radiology images and clinical reports to achieve correct coding of injuries.

The crash data in CIREN is captured by inspection of the crash scene and the vehicle(s) involved in the crash. The crash investigations are conducted using the National Automotive Sampling System (NASS) protocol and standards [6]. This protocol is then enhanced with additional procedures utilized in CIREN. The known anthropometric measurements (height, weight, seated height, etc…) of the occupant are available to the crash investigator. Also, injury and fracture pattern data is available to the crash investigator prior to field investigation. These procedures add greater reliability to the placement and position of the occupant in the vehicle and aid in the determination of occupant kinematics and possible contact points.

The multidisciplinary CIREN teams at each site consist of at least a crash investigator, trauma physician, engineer and data coordinator. They review each injury in the case to determine a probable mechanism of injury causation. Every injury mechanism is coded with a level of confidence (certain, probable, or possible) in conjunction with the evidence and data available.

In conjunction with the injury and crash variables queried from the CIREN database a thorough case study was conducted via the CIREN graphical users interface in an attempt to establish for each case the AIS body region most significantly injured for each case. Data points beyond MAIS, ISS and AIS were reviewed to aid in determining the significance of an injury to a specific body region beyond that of “threat to life” measure provided by AIS. Case review data included AIS/ICD-9/OTA codes, radiology images and reports, surgical codes and reports, comorbidity, complications, Glasgow Coma Scale (GCS) scores, ventilation requirements, disposition status and discharge summaries. All injuries were reviewed to determine one key injury and/or injured body region for each case. In cases where this objective could not clearly be determined the case was categorized as multiple injury. In many cases it was quite evident by the amount of surgeries, complications and clinical indicators that one particular injury or injured body region was the most significant in the case. In many cases this did not often correlate with the MAIS scores in each case. Injuries that often had a higher threat to life score via MAIS were treated non-operatively while lower scoring injuries resulted in multiple surgical interventions and a higher incidence of complications.

RESULTS

There were a total of 346 CIREN occupants that had completed case data including baseline and 12 month SF-36 scores at the time of analysis. The general description of the study population is displayed in

Table 2. Fifty three percent were female and the mean age was 40 years (range, 15-86). Pre-morbid conditions were documented in 43% of the population. The top 3 premorbid conditions were hypertension, asthma and diabetes.

Table 2.
Demographic Data

Number of occupants	346
Gender - Female	182 (53%)
Mean age - years	40
Pre-morbid condition	147 (43%)

Crash data and injury parameters are detailed in Table 3. The role of the CIREN occupant in the population was typically as the driver (82%). The dominant crash type for this population was frontal (70%). Restraint use illustrated safety belt compliance at a level of 78%, and belted with an air bag deployment was 60%. The mean delta V for this population (when calculable N=231) was 41 kph (25.6 mph) and the mean maximum crush measurement was 70 cms (27.6 in.).

Injury severity was significant for this population as would be expected with the CIREN inclusion criteria. The mean Injury Severity Score (ISS) was 15 (range, 4-50) and the mean Maximum AIS (MAIS) was 3 indicating an injury severity level of serious.

Table 3.
Crash Data

Role	
Driver	285 (82%)
Crash Type	
Frontal	241 (70%)
Nearside	67 (20%)
Farside	25 (7%)
Rear	5 (1%)
Roll	6 (2%)
Restraint Status	
Belted w/ deployed air bag	208 (60%)
Deployed air bag only	65 (19%)
Belted only	61 (18%)
Unrestrained	10 (3%)
Unknown	2 (<1%)
Mean Delta V (N=231)	41 kph (25.6 mph)
Mean maximum crush	70 cms (27.6 in)
Mean ISS	15
MAIS Distribution	
2	85 (24%)
3	203 (59%)
4	41 (12%)
5	17 (5%)

The mean change in SF-36 scores for the entire population is displayed in Figure 1. All four physical and all four mental categories show a decrease from the occupant's original baseline.

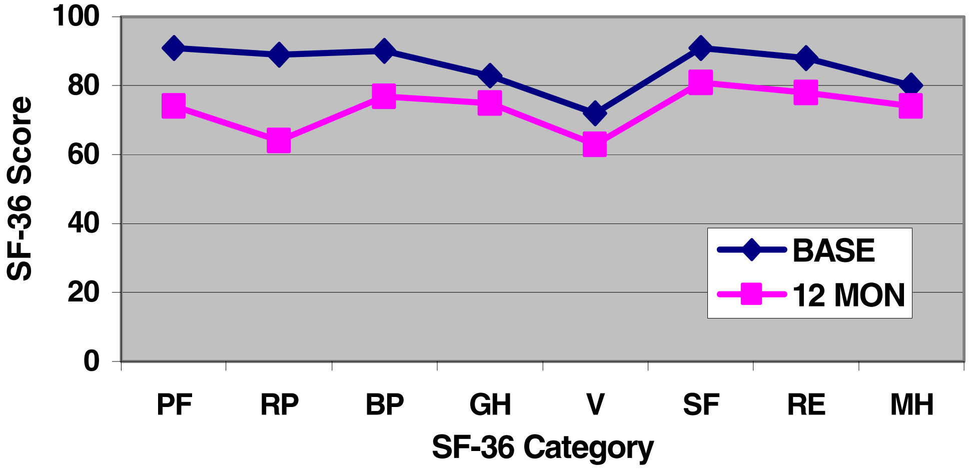

Figure 1. Mean Change in SF-36 Scores From Baseline to 12 Months (N=346)

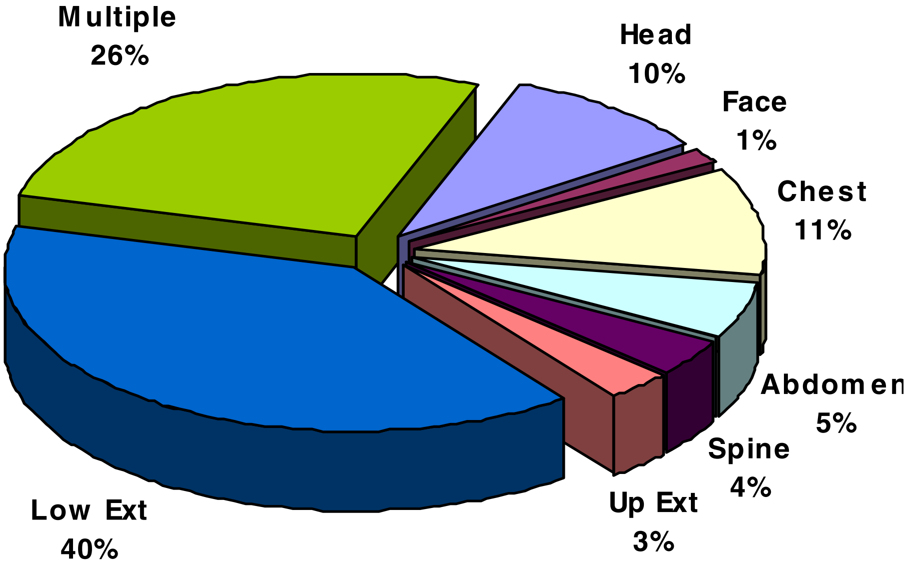

Figure 2. Distribution of BRIC's (N=346)

The distribution of the study population Body Region Injury Categories (BRIC) is displayed in Figure 2. It was determined through the individual case review that nearly 40% of the population sustained only a significant lower extremity injury. In 26% of the cases reviewed significant injuries were sustained in two or more body regions. Cases resulting in two or more BRIC's were grouped together in the "Multiple" category.

Due to the relatively low N values for BRIC's face (N=5), abdomen (N=19), spine (N=13), and up ext (N=10) additional exploration was not pursued. Although substantially decreased scores were observed in upper extremity and spine cases, the minimal case counts for these BRIC's and high standard deviations resulted in eliminating these categories from continued review.

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The mean differences in SF-36 scores for the established BRIC's with N values over 30 are detailed in Table 4. General Health and Role Emotional were statistically significant for occupants sustaining only significant injury to the head (P-value<.01). Occupants who sustained only significant chest injury indicated statistical significance in the mental health category. Lower extremity and multiple category occupants were significant in all categories

Table 4. Mean SF-36 Changes From Baseline To 12 Months By BRIC

Body Region	Occupants (N)	PF	RP	BP	GH	V	SF	RE	MH
Head	34	-8.1	-7.6	-0.3	-6.8*	-6.5	-7.4	-19.8*	-3.1
Chest	37	-3.2	-7.4	-7.6	-4.0	-3.6	-6.3	-6.3	-6.5*
Low Ext	137	-22.9*	-33.6*	-17.4*	-7.8*	-8.7*	-12.9*	-10.1*	-3.9*
Multiple	91	-20.6*	-35.0*	-18.1*	-8.5*	-9.6*	-13.9*	-11.0*	-4.5*

* - indicates statistical significance at <.01 level using SAS Proc Univariate

The head injury group indicated significant decreases in their perceptions of their overall general health 12 months after their crash. The same group indicated significant limitations in their usual role activities because of emotional problems or issues. The chest injury group indicated a significant decrease in the population's mental health score resulting in possible psychosocial distress, anxiety and or depression. The lower extremity and multiple group scores indicate a wide spectrum of problematic issues affecting these individuals 12 months after their crash. The correlation between the lower extremity group and the group sustaining significant injury to two or more BRIC's is quite close as seen in Figure 3. The correlation is further justified by the BRIC distribution for the multiple group in Table 5.

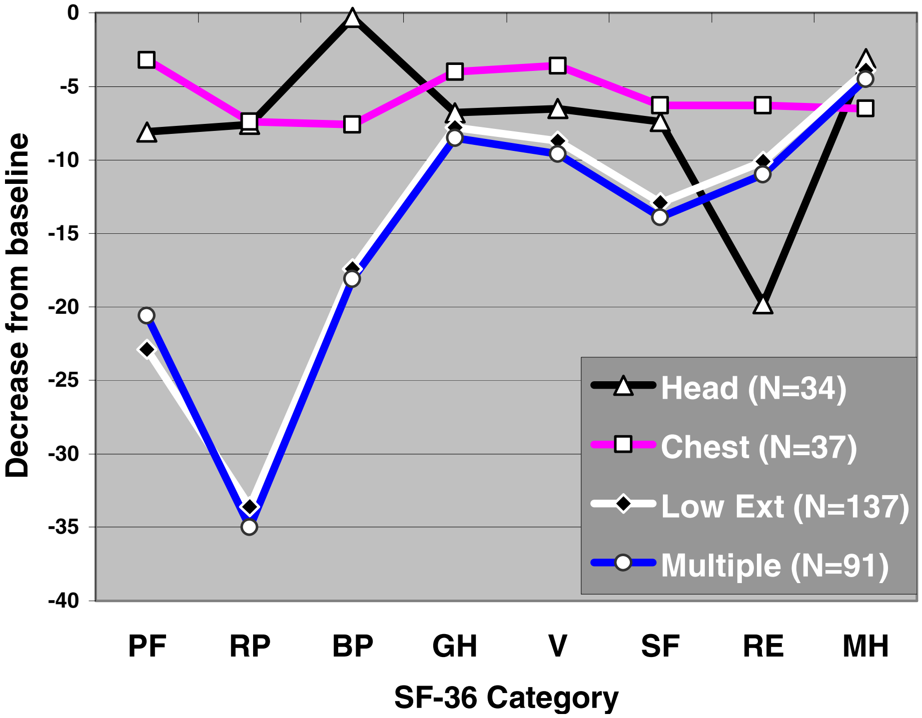

Figure 3. Mean SF-36 Changes From Baseline to 12 Months By BRIC

The multiple injury group (N=91) contained significant injury combinations involving all eight original body regions. The distribution of the involved body regions for the multiple group is demonstrated in Table 5. With the lower extremities having the highest amount of involvement within the multiple group, it is another indicator that the injuries sustained to this body region continue to be a major factor-affecting outcome even when other significant injuries are involved.

Table 5.
Distribution of BRIC's in Multiple Group

BRIC	Number of Occupants	Percent of Multiple Group
Head	22	24
Face	6	7
Neck	2	2
Chest	47	52
Abdomen	18	20
Spine	9	10
Upper Extremity	32	35
Lower Extremity	63	69

With the injury coding detail available in CIREN, an additional distribution breakdown within the three isolated BRIC's could be achieved. The head group was diagnosed with anatomical injuries 56% of the time, while 44% of the injuries were concussive in nature. The chest group was diagnosed with significant bony injury (ribs) 54% of the time. Internal organ injury (lungs, etc…) accounted for 43% of the significant chest cases and 3% were vascular type injury (aorta). The lower extremity group was 97% bony injury and 3% muscle/tendon/ligament type injury.

Table 6.
Demographic and Crash Data by Category

BRIC	HEAD	CHEST	LOW EXT	MULTIPLE
Number of occupants	34	37	137	91
Gender - Female	18 (53%)	18 (49%)	71 (52%)	55 (60%)
Mean age - years	34	51	38	42
Pre-morbid condition	15 (44%)	17 (46%)	55 (40%)	34 (37%)
Role Driver	29 (85%)	32 (87%)	122 (89%)	69 (75%)
Crash type Frontal	15 (44%)	21 (57%)	112 (82%)	66 (73%)
Nearside	9 (27%)	14 (38%)	17 (13%)	18 (20%)
Farside	7 (21%)	2 (5%)	6 (4%)	3 (3%)
Rear	3 (9%)	0	0	1 (1%)
Roll	0	0	1 (1%)	3 (3%)
Restraint status Belted w/ deployed air bag	17 (50%)	18 (49%)	89 (65%)	56 (61%)
Deployed air bag only	4 (12%)	8 (22%)	33 (24%)	15 (17%)
Belted only	10 (29%)	8 (22%)	13 (10%)	16 (18%)
Unrestrained	3 (9%)	3 (8%)	1 (<1%)	3 (3%)
Unknown	0	0	1 (<1%)	1 (1%)
Mean DeltaV - kph (mph)	31 (19.3)	34 (21.1)	43 (26.7)	44 (27.3)
Mean maximum crush - cms (in)	55 (21.7)	59 (23.2)	75 (29.5)	82 (32.3)
Mean ISS	15	17	11	22
Mean MAIS	3.1	3.2	2.7	3.4

Demographic and crash details were explored for each of the BRIC's with N values greater than 30 (see Table 6). All four groups were similar in demographic and crash configuration with a few notable differences. The mean age for the groups had a range of 4-18 years between the groups. The lower extremity and multiple groups, which had the worse SF-36 scores, were involved in a high percentage of frontal crashes. These groups also had the highest percentages of air bag and safety belt use, 65% and 61% respectively. The highest mean delta V as expected was in the multiple group, however it only surpassed the lower extremity group by 1 kph. The mean ISS and MAIS again as expected were highest in the multiple group. However, it should be noted that the lower extremity group with outcomes as poor as the multiple group indicated less threatening injuries by it's low mean ISS and MAIS scores.

The OTA codes allow the lower extremity population to be detailed to an even finer level for evaluation of injury and outcome. Utilizing the OTA codes available in CIREN the lower extremity group was farther divided into two new categories. One subgroup included all significant lower extremity injuries involving an articular surface. The second subgroup contained the remaining significant lower extremity injuries not involving an articular surface. Articular surfaces are found where two or more bones come together to form a joint such as the knee or elbow. For the 137 cases sustaining only significant lower extremity injury, 67%(92) sustained articular injury and 33%(45) sustained non-articular injury. Review of the mean changes in the SF-36 scores for these two groups indicate a negative impact in outcomes when articular surfaces are involved (see Figure 4).

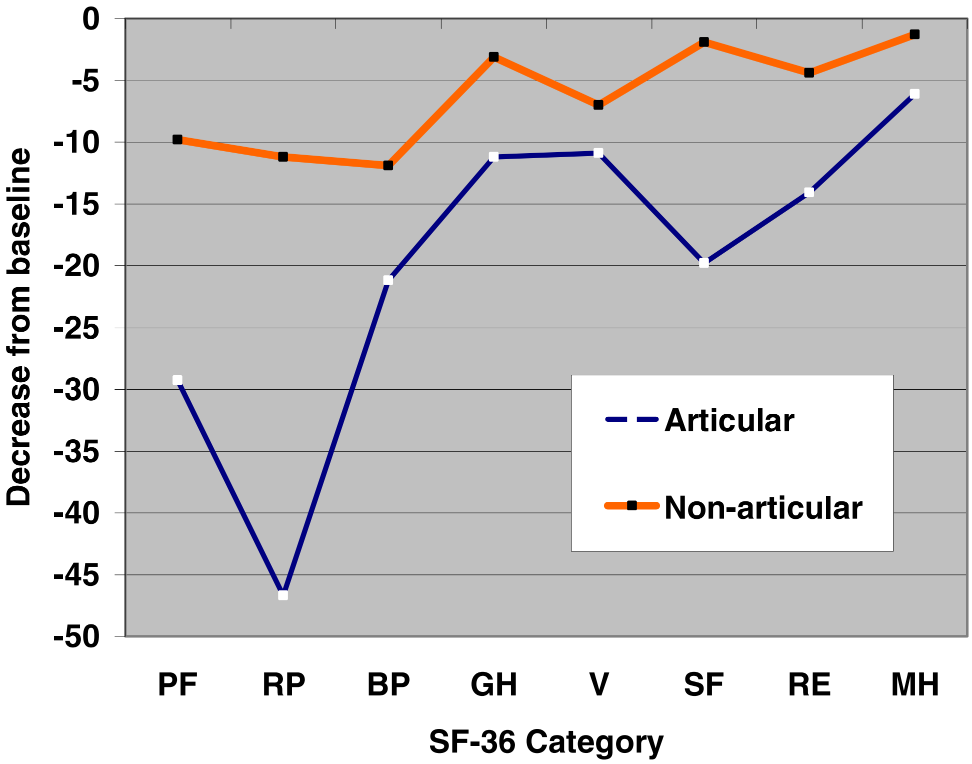

Figure 4. Changes In SF-36 From Baseline To 12 Months By Articular And Non-Articular Surfaces

CONCLUSIONS

Outcomes after motor vehicle crashes result in a wide spectrum of costs, consequences and other issues. On one end of the spectrum it might be as simple as an insurance settlement and vehicle repairs. On the other end is the ultimate poor outcome, death. In between those two points are possibilities beyond imagination. The intention of this study was to look at one of the unique parts of the CIREN program, the SF-36 outcome data. The basic concept was to review the data for individuals 12 months after their crash and to examine their outcomes. In particular to examine if any unique injury could be associated with poorer outcomes 1 year after the crash event.

After a case-by-case review of the 346 cases, significant BRICs were established. With these categories established the outcome data showed significant decreases in SF-36 scores related to head, chest, lower extremity and multiple injury categories.

Although the SF-36 has been shown not to be the best tool for measuring outcome after head trauma [7], our isolated head injury group did show statistically significant decreased scores in General Health and Role Emotional, which could lead to such psychosocial factors as depression and other quality of life issues. Nearly half of the head injury group suffered non-anatomical injuries (concussion), although this type of injury is often referred to as a mild brain injury, the outcome data indicate relevant long-term issues. Many of the more severe brain injury in CIREN do not receive SF-36 scores due to the occupant's inability to answer the questions during the follow-up phase.

The chest group had statistically significant decreased scores in Mental Health, which again could impact the occupant's quality of life. These small emotional and behavioral changes often take a long time to diagnose and treat, if they are properly diagnosed at all. The impact on family and dependents over time can be substantial.

By far the most dramatically impacted groups were the lower extremity and multiple groups. Both of these groups were statistically significant in decreased SF-36 scores in all categories. The SF-36 scores clearly show the lower extremity group suffers long-term consequences and decreased function at a level comparable to the multiple group. The mental category scores are statistically as significant as the physical category scores giving some indication that the effects of these lower extremity injuries have a global effect on the occupant's quality of life.

The multiple group cases are from the most severe crashes, resulting in significant injury in at least two body regions, in some cases as high as four. The crashes for this group had the highest delta V and maximum crush average. The ISS and MAIS average scores were higher for the group as well. Sixty-nine percent of the multiple group cases involved significant lower extremity injury, indicating that even with other body regions sustaining significant injury the lower extremity injury continues to impact the long-term scenario.

The dramatic decreases in Physical Function and Role Physical for both groups indicate the possibility of considerable impact on the occupant's ability to be mobile. Deficits in these two categories greatly impact the basics of locomotion and daily living. Low scores in these categories can indicate issues ranging from job performance / retention to the some of the more basic activities of daily living, such as the ability to stand and walk.

This study also utilized the unique OTA coding in CIREN to farther evaluate the injury details of the lower extremity group. This comparison clearly demonstrates that certain lower extremity injuries have much more significant impacts on the SF-36 scores, especially Physical Function and Role Physical. The ability to capture injury detail to this level really allows the outcomes to be correctly associated with precise lower extremity injury. Other more common coding systems such as AIS and ICD-9 do not attain this level of detail for musculoskeletal trauma and therefore could not achieve this distinction in the lower extremity group.

As more occupants survive crashes secondary to increased presence of air bags, safety belt use and other safety enhancements we may see more disabled occupants. Head and thoracic injuries have been reduced with the evolution of restraint technology, yet lower extremity injuries are the most frequently injured body region. To properly evaluate outcomes, data must be represented appropriately for the task. With the high frequency of lower extremity injuries occurring and many of them involving articular surfaces, this is an issue that warrants further consideration.

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IDENTIFICATION OF REAL WORLD INJURY PATTERNS IN AID OF DUMMY DEVELOPMENT

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ABSTRACT

Current testing mandated by regulations relies on well-designed dummies. These dummies must be able to detect highly injurious situations as identified in real world crashes. The current study seeks to rank the severity of specific types of injuries – denoted by body region and skeletal/non-skeletal – in terms of threat to life and costs.

The data approach attempted to explore the questions: What types of injuries should The National Highway Traffic Safety Administration (NHTSA) strive to prevent; what measurements are required of a crash dummy to ascertain whether such injuries are sustainable in a crash test; and how many lives are likely to be saved under a given performance requirement to prevent such injuries? A comprehensive data set has been formed to address these issues including crash, vehicle, occupant, and injury parameters. The data set allows for identification of the most severe injuries based upon a variety of identifiers. Identification of the crash type, vehicle type, and Delta V, etc. was made for each case. It can be disseminated amongst researchers in a spreadsheet or database software file.

This current work provides an update of the data analysis component of the dummy development effort within NHTSA. Further, it will serve to introduce a new data set specifically tailored to the needs of the dummy developers, as well as researchers in the field.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA), of the United States Department of Transportation, has taken a lead in biomechanical research. For this reason, the development of dummies to test for injury conditions occurring in real world crashes has been of paramount importance. Dummy development has been reliant upon the feedback provided by the epidemiological databases, such as those compiled at NHTSA.

OBJECTIVES

The Crashworthiness Data System (CDS), a dataset compiled under the aegis of The National Automotive Sampling System (NASS), is a nationally representative sample of police-reported tow away crashes occurring on public roadways compiled since 1988, in its current form. This data was used to form a data set of crashes and their associated vehicle occupant injuries. Its high level of detail allowed for a description of the occupant injuries. These injuries could then be associated with the work of Zaloshnja (2004) to obtain a cost estimate.

The goal of this paper is, not only to aid in the NHTSA initiative to enhance dummy development but also to provide a tool for researcher to use in the form of a real world injury data set by crash mode. The final form of this data set would contemplate a ranking of injuries from the standpoint of mortality. It also could serve to provide live and cost saving estimates to calculate the benefit and cost associated with the introduction of a new countermeasure.

Advanced Dummy Development

A new generation of air bags and further occupant safety advances required improvements in dummy development and a broader range of crash test dummies to accurately measure various crash forces imparted to a range of occupant sizes in different crash situations. As occupant protection requirements for men, women and children of varying sizes, are expanded, appropriately sized and instrumented dummies will be needed to provide estimates of the severity and extent of injury.

Advanced dummies require considerable research and development prior to incorporation into Part 572 of the Code of Federal Regulations or any safety standard. Most NHTSA work on particular crash dummies focuses on a particular type of crash – e.g., frontal, side, rollover, and rear.

The aim of the advanced dummies is to provide a measurement instrument that can discriminate between effective and ineffective safety systems. Its ability to do so depends largely on the fidelity of the measuring instrument – the dummy – and the faithfulness of the performance yardstick – the injury criteria. In the THOR dummy, a more biofidelic instrument is sought to assure that vehicle safety systems are tailored to humans.

It should be noted that a critical preliminary subtask for several dummy rulemaking projects is a determination of the performance and injury criteria for the dummies.

Data Driven Research

NHTSA is responsible for reducing deaths, injuries, and economic losses resulting from motor vehicle crashes. This is accomplished in part by setting and enforcing safety performance standards for motor vehicles. The performance of a vehicle in mitigating injuries is assessed through the Federal Motor Vehicle Safety Standard (FMVSS) 200 series, which make use of a dummy exposed to collision forces. In searching for appropriate dummy metrics, NHTSA takes a data driven approach to assure that its use in a federal regulation will lead to a reduction in injuries. Within NHTSA's biomechanics division, real-world data are used to answer three basic questions that guide the search for injury metrics:

1. What types of injuries should NHTSA strive to prevent?
2. What measurements are required of a crash dummy to ascertain whether such injuries are sustainable in a crash test?
3. How many lives may be saved under a given performance requirement to prevent such injuries?

Generally, there must be enough existing data to show that a proposed countermeasure (such as implementing an additional or new head injury metric) will reduce the risk of injuries. To aid such assessments, NHTSA maintains epidemiological data on the nature, causes, and injury outcomes of crashes. While CDS outcomes are fatal/nonfatal, cost-per-injury figures have been applied, as described in subsequent sections to evaluate cost-based outcomes.

This document will provide an outline of the work to be completed during the course of the data analysis in support of NHTSA. Further, it will propose the questions that will be answered at the close of the data analysis and provide insight into the methods used to answer these questions. The work is in the data identification stage and reporting findings available to date.

DATA SOURCE

The creation of the current data set was predicated upon the use of several tools. The NASS CDS was consulted to select relevant crashes, as described below. Further, selection parameters were applied to increase vehicle fleet homogeneity in the data set. Finally, the injury coding information was merged with mortality rates and crash costs based upon the injury severity coding of the NASS CDS.

The National Automotive Sampling System - Crashworthiness Data System

The Crashworthiness Data System (CDS) is an epidemiological database maintained by NHTSA. CDS is a nationally representative probability sample of police-reported automobile crashes in the United States. CDS cases are limited to crashes that involve at least one passenger vehicle that was towed from the crash scene due to damage resulting from the crash. Each case is assigned a weighting factor that represents an estimate of the number of like-mannered cases that occurred during the sample year.

Abbreviated Injury Scale and CDS Injuries

All injuries to motorists involved in CDS cases are recorded in the database. Injuries are denoted with a seven-digit code in accordance with the Abbreviated Injury Scale (AIS). Maximum severity is denoted as MAIS.

NASS CDS injury codes were concatenated to form seven-digit AIS 90 codes (NHTSA, 2000). These seven digit codes formed the basis for sorting. An initial sort was performed based upon an abbreviated five-digit code and yielded over 300 different injury codes. A secondary sort was performed collapsing the 5-digit codes into 17 body region categories, per Table 1. The subsequent charts were based upon the 17 categories.

The most general practice has been to use the maximum injury sustained by each occupant in the population to calculate the total societal cost, HARM. Zaloshnja (2004) provided an update to these concepts and allowed for their application to individual injuries, as described using the NASS CDS AIS 90 injury coding.

Attributable cost, a further refinement based upon the work of Martin (Martin, 2005) allowed for a costing of the injury based upon the introduction of a countermeasure that alleviated the most serious injury for an occupant. Pursuant to this costing method, it was also possible to more accurately assess injury costs per case without summing all of the injury costs. This was important because a series of injuries would build on to the overall severity and the subsequent injuries may not be as costly because some part of the less severe injury costs might have been subsumed within the most serious injuries.

Table1.
Identification Code Mapping, as used in the Analysis

ID	Body Region Identification	ID	Abbreviated Body Region Identification
1	Skull	1	Skull
2	Brain/Intercranial	2	Brain/Intercranial
3	Ear	3	Ear
4	Eye and adnexa	3	Eye and adnexa
5	Nose/mouth/face/scalp/neck	4	Nose/mouth/face/scalp/neck
8	Neck-internal organs/blood vessels	3	Neck-internal organs/blood vessels
9	Neck-spinal cord	5	Neck-spinal cord
10	Shoulder/clavicle/scapula/upper arm	6	Shoulder/clavicle/scapula/upper arm
11	Elbow	6	Elbow
11.1	Upper extremities, superficial	6	Upper extremities, superficial
12	Forearm	6	Forearm
13	Wrist/hand/finger/thumb	6	Wrist/hand/finger/thumb
16	Upper extremities, multiple/unspecified	6	Upper extremities, multiple/unspecified
17	Chest/breast/abdomen	7	Chest/breast/abdomen
18	Ribs/sternum	8	Ribs/sternum
19	Back (including vertebrae)	9	Back (including vertebrae)
21	Trunk - Superficial	10	Trunk - Superficial
22	Trunk, multiple/unspecified	10	Trunk, multiple/unspecified
20	Trunk-spinal cord	11	Trunk-spinal cord
23	Thoracic organs/blood vessels	7	Thoracic organs/blood vessels
24	Liver	12	Liver
25	Spleen	12	Spleen
26	Kidney	12	Kidney
27	Gastrointestinal	12	Gastrointestinal
28	Genitourinary	12	Genitourinary
28.1	Trunk, other organs/blood vessel	10	Trunk, other organs/blood vessel
30	Pelvis bone and external	13	Pelvis bone and external
31	Lower extremities, superficial	15	Lower extremities, superficial
32	Hip/thigh	13	Hip/thigh
33	Knee	14	Knee
34	Lower leg	15	Lower leg
35	Ankle/foot/toes	15	Ankle/foot/toes
38	Lower extremities, multiple/unspecified	15	Lower extremities, multiple/unspecified
40	Burns, unspecific body part	16	Burns, unspecific body part
41	Whole body-minor external,	17	Whole body-minor external
41.1	Burns, unspecific sev	16	Burns, unspecific body part

Source: Zaloshnja, 2004

Application of Crash Cost to Crash Occupant Injuries

The HARM method of categorizing and ranking the crash injuries was used (Malliaris, 1982). This is a method for applying a societal cost, or HARM. HARM was calculated by assigning a dollar cost to injuries by maximum injury severity (MAIS).

CDS Case-By-Case Characterization: Mortality and Cost

Mortality rates and injury costs are assigned to each case in the data set. Lives saved are computed using the methods described in Martin (2003a,b). Costs are assigned in accordance with Zaloushnja (2004). The rationale for using MAIS>1 as a threshold is that mortality rates associated with all AIS 1 injuries are known to be extremely low; this is not necessarily the case for all AIS 2 injuries.

Attributable fatalities are the number of lives lost due to a particular injury. The method for computation is shown in Appendix A.

Computing the costs attributable to a particular injury follows a similar methodology, per Appendix B.

Interactive Application of Mortality Rates

The factors set forth by Zaloshnja were instrumental in the publications of Martin (2003) for refining the mortality rates attributable to each injury classified using the AIS 90 injury coding. An iterative algorithm was developed to increase the precision of these estimates. This gave rise to a concept termed "survival rate." (Martin, 2003) This was not only used to compute overall survivability but to select which two injuries were chosen to represent the injured victim. This will be used in the development of the data analysis.

METHODOLOGY

By incorporating epidemiological and biomechanical parameters, the data set may be assessed in terms of crash mode injury frequency and associated costs for the crash mode. The baseline comparison considered all of the previously described adult occupants. This data set was further disaggregated by crash mode: planar frontal, planar rear, planar near side, planar far side, and other. Other included any crash mode not specifically stated and could contain planar or non-planar crashes.

Baseline Data Set Composition

The data set governing this project, consisting of 3,456 unweighted records representing approximately 402,800 occupants involved in tow away crashes, was selected based upon the following parameters:

- Vehicles of model year 1998 or later
- MAIS injury greater than or equal to MAIS 2 (all AIS 1 injuries were disregarded).
- Injuries of unknown severity (AIS=7) were included in the dataset.

The data set also included traditional descriptive variables, such as model year, vehicle type, crash type, delta-v, occupant age, body region injured, and AIS level of injury. Additional variables relating to mortality and cost attributable to injuries were included, per Table 2.

Within the CDS injury severity coding, about 10% of all injury codes have a "Not Further Specified" (NFS) designation. NFS is used when detailed medical information is lacking. NFS injuries are always given an AIS score that is equal to or lower than the same general injury that is described more fully. Thus, counts based on MAIS are biased toward more severe injuries.

Initially the occupant body region injuries were ranked on four bases:

- Total injuries to occupants (counting all injuries to every occupant)
- Maximum injury to an occupant MAIS (ties were broken using mortality rate)
- Mortality variables (greatest contributor to potential or actual fatality)
- Cost variables (highest to lowest cost injuries, per Zaloshnja, 2004)

Currently, work has focused on disaggregating the various crash modes. The frontal results were reached based on the above parameters and excluding unbelted occupants. This subset of data consisted of 763 records estimating approximately 138,000 occupants. Among these cases, 57 cases involving fatality were reported representing 2,800 occupants.

Injury Tree

A schematic was created to indicate the areas of focus in dummy creation and their representation within the context of all crashes involving adult occupants with moderate through fatal injuries. Figure 1 was prepared as a five-tiered summarization of the data analysis efforts. The next tier disaggregated the occupants into front-seated adults, rear seated adults, children seated in safety seats secured to a rear seating position, and other. The front seated adults, rear seated adults, and children seated in safety seats secured to a rear seating position were further disaggregated by restraint usage. The belted members of each group were then categorized by crash mode: planar front, planar side, and planar or non-planar other impact. For the front seated and rear seated adults, only, the side crash was further segmented by near and far side impacts. Among the children involved in side impacts, none were seated on the near or far side of the crash.

The highlighted subgroups were also shown by percentage contribution to total fatality, MAIS 3 through 6 injuries, and percentage of aggregate costs

APPLICATIONS

The dummy development initiative is ongoing and the data analysis results are reported periodically. These findings will form the basis of subsequent publications focusing on the topics to be investigated using the NASS CDS. Potential areas of study have been identified as: near side impacts, frontal impacts, children in child restraints, face/neck/scalp injuries, characterization of brain injuries.

Injury Distributions for Specific Cases

Several specific studies have been chosen to examine the distribution of injuries compared to the baseline distribution. A comparison will consist of examining the distributions using the five metrics described above based on specific CDS investigations. Moreover, the influence of an aging population will be highlighted for all proposed investigations.

I. For Near Side Impacts – Front and Rear Seat Belted Adults, NHTSA's FMVSS No. 214 side impact upgrade proposal considers head, thorax, and pelvis protection, and side impact Anthropomorphic Test Devices (ATD's, including EuroSID2, SID2s, WorldSID) have instrumentation to measure responses in these three body areas. Two specific study areas relevant to this data set are discussed below. These are abdominal organ and thoracic injuries. Currently, accurate abdominal organ instrumentation is absent from current dummies.

Further, there is little basic biomechanical knowledge of injury thresholds associated with abdominal injuries largely due to the difficulty in observing such injuries in laboratory experiments. This interrogation will be aimed at examining the requirements of abdominal injury in an ATD.

Table 2.
Baseline Injured Body Regions by Case Costs, Total Incidence, Maximum Injury Severity Count, Attributable Costs, and Attributable Fatalities

Region Number	Body Part	Case Costs $M	Weighted Total Incidence	MAIS	Attributable Costs ($M)	Weighted Attributable Fatals
1	Skull	7,384	17,958	5,052	2794	4,964
2	Brain/intracranial	96,646	157,779	102,434	5663	68,612
3	Ear, eye, internal neck organs	556	1,289	453	5	529
4	Nose, mouth, face, scalp, neck	3,263	52,749	21,684	2739	2,935
5	Cervical spinal cord	9,240	3,281	2,514	509	5,116
6	Upper Extremity	10,150	137,682	72,729	182	7,631
7	Thorax	12,956	53,461	25,056	5843	7,199
8	Ribs/sternum	5,307	70,718	42,335	5128	5,199
9	Back (including vertebrae)	8,018	55,608	28,474	10	3,352
10	Trunk (other abdomen, thorax)	2,427	7,054	3,356	774	1,722
11	Trunk - Spinal Cord	1,099	718	278	26	444
12	Abdominal Organs	2,881	42,328	6,660	609	1,634
13	Hip, Thigh, Pelvis	13,224	55,224	18,515	644	7,875
14	Knee	2,194	52,711	46,890	12	1,977
15	Lower Leg	15,604	173,048	84,329	121	12,366
16	Burns, unspecific body part	4,758	2,534	2,144	1220	3,326
17	Whole body-minor external	0	0	0	0	0

Source: Source: NASS CDS, 1997 – 2003, and Zaloshnja, 2004

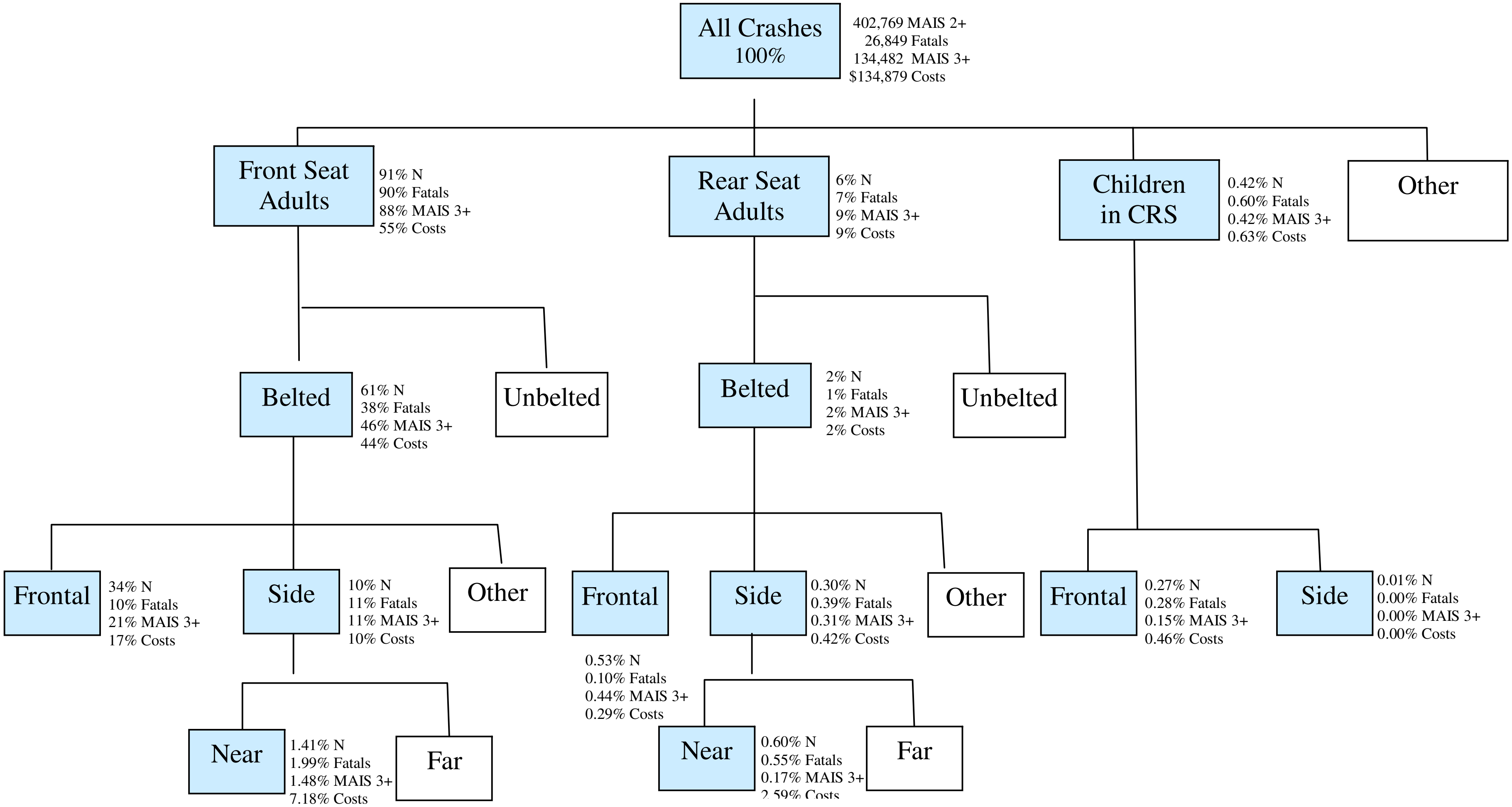

Figure 1a.

INJURY ANALYSIS TREE, Weighted Values

Note: Some zero percents are due to rounding (Near Side Impacts, Children in CRS, and Rear Seat Side) and were taken to decimal places. No Near Side or Far Side Impacts were registered for Children in CRS.

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

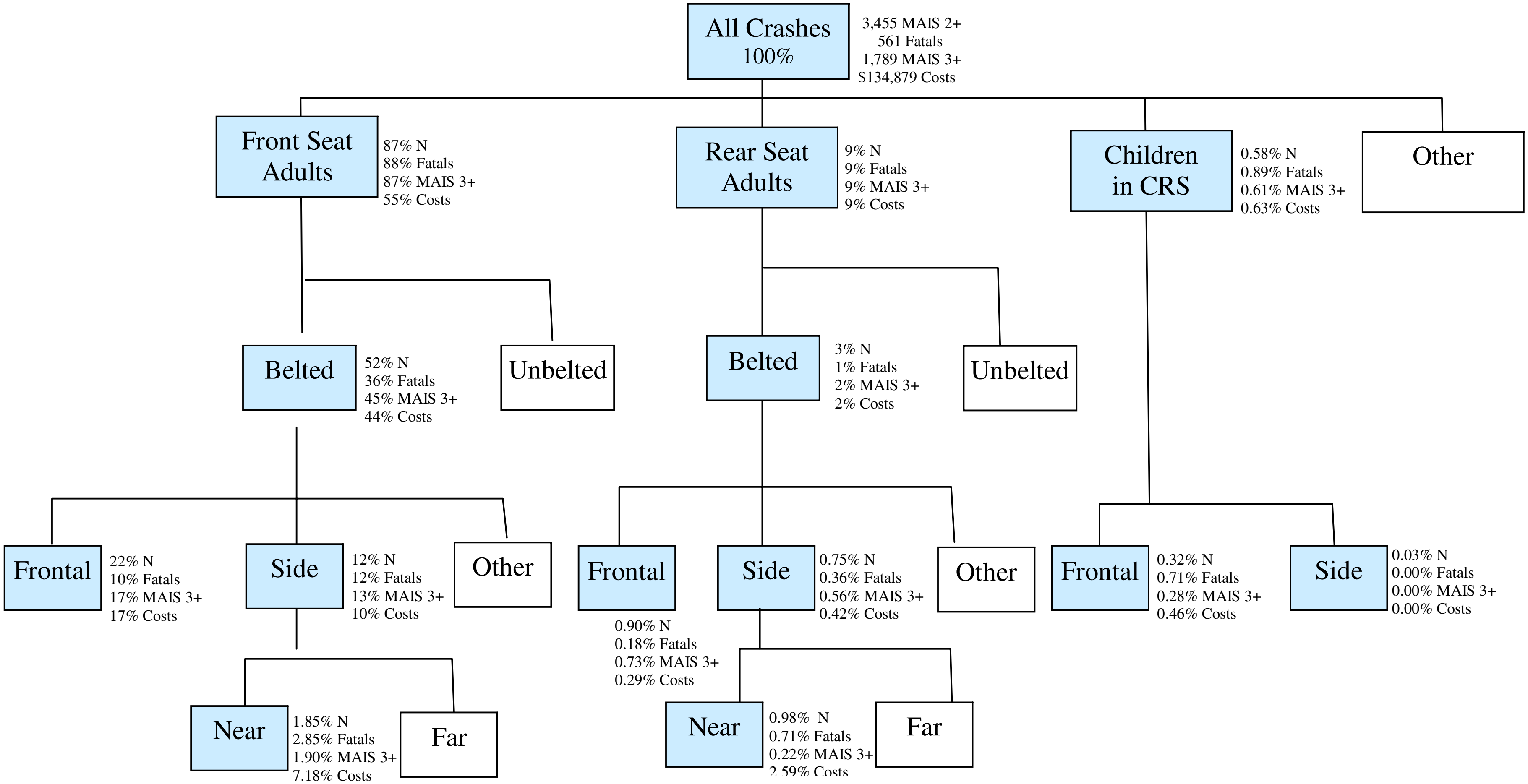

Figure 1b.

INJURY ANALYSIS TREE, Raw Values

Note: Some zero percents are due to rounding (Near Side Impacts, Rear Seat Side, and Frontal and Side Crashes with Children in CRS) and were taken to decimal places. No Near Side or Far Side Impacts were registered for Children in CRS.

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

ATDs use rib deflection sensors to assess potential for thoracic injury. Moreover, the criteria for thorax injury potential are largely based on the number of broken ribs observed in post-mortem human subjects (PMHS) tests. This interrogation will look for thoracic organ injuries with and without significant rib fractures to gain insights into whether rib deflection measurements adequately gauge thoracic trauma.

II. For Frontal Impacts – Front Seat Belted Adults, the Agency is also monitoring and investigating occult injuries from frontal crashes. Knee-thigh-hip (KTH) complex injuries to belted occupants are one of the injury patterns being investigated.

A specific study might include an interrogation aimed at examining the makeup of knee versus thigh versus hip and pelvis injuries in order to gain insights into the need for acetabulum measurements in an ATD and the need for a more biofidelic KTH assembly.

III. For Children in Child Restraint Systems, NHTSA has addressed the TREAD Act by incorporating new requirements into FMVSS No. 213, including improved child test dummies. Moreover, Anton's Law requires the development of an anthropomorphic test device simulating a 10-year-old child and an evaluation of integrated child restraint systems.

A specific study using the newly formed data set, might include the examination of general injury distributions for children in Child Restraint Systems (CRS) in frontal and side crashes in an effort to examine the body regions most apt to be injured.

IV. For Face/Neck/Scalp Injuries, preliminary analysis of the CDS Injury Distribution Dataset has shown a prevalence of face/neck/scalp injuries. These injuries can be studied in more detail under each of the crash modes described above to gain a better insight into their specific attributes and the circumstances under which they occur.

V. For Characterization of Brain Injuries, Table 1 shows that brain injuries have the highest total attributable costs. A general interrogation of the dataset reveals that brain injuries in real-world car crashes may be placed into three broad categories: those manifested by rotation only (such as diffuse axonal injuries), those manifested by translation only (such as skull fractures), and those manifested by either rotation or translation. The proposed metric relies on CDS reporting of general injury patterns and their related costs, Zaloshnja (2004), that will stimulates the ATD designer to focus on a body region of significance. This focus will allow the designer to start developing theories on mechanisms of injury within a particular body region.

In FMVSS standards, the risk of head injury is judged by the HIC metric, which is a function of the resultant linear acceleration at the center of gravity of a dummy headform. The HIC metric has roots as a correlate to skull fractures in drop tests performed on cadavers. Over the years, researchers at NHTSA and other institutions have contemplated the use of some other metric – such as angular acceleration – to be used along with or in lieu of HIC to assess head injury probability in a crash test.

A specific study might result pursuant to categorizing each code into one of the three categories, NASS-CDS data may be interrogated to gain insights into the various types of head injuries. Such results may help clarify the applicability of HIC and the need for a rotation-based anthropomorphic dummy metric to gauge head injury potential in crash tests.

The five topic areas are proposed applications of the baseline data set. No commitment has been made to undertake any of these studies nor have all other possible applications been discarded from consideration. For illustrative purposes, near side abdominal injuries were chosen as the applied example.

Applied Example

Restrained adult occupants, age 12 years and older seated near side of the left or right side impact, sustaining abdominal organ injury, have been chosen for a closer look. As part of the international harmonization, the Agency has studied this body region (March, 1999), however, the data was not analyzed using these techniques. Injuries to the liver, spleen, kidney, as well as insult to the gastrointestinal and genitourinary regions have been included to describe the aggregated abdominal region.

When considering abdominal injuries as a subset of all MAIS 2 through 6 injuries, approximately two percent of all attributable costs and three percent of the attributable fatalities may be assigned to this rubric. Of the nearly 31,000 front-seated, restrained, near side crash occupants (weighted from 307 sampled occupants,) 9 percent of all near side occupants sustained abdominal injuries, 2 percent of which were the maximum injury for the case. The abdominal injuries ranked tenth among the 17 injury groupings, with regard to total incidence. Among the estimates provided by CDS, only front seat occupants were involved in this crash scenario. For this reason, the 307 near side crashes describe the experience of front seat occupants. The near side crash occupants traveling in the rear seating positions only added 13 more occupants sustaining injuries other than abdominal.

When considering all abdominal injuries, regardless of whether it was the most severe injury to the occupant, the data set consisted of 66 occupants, estimating nearly 24,000 occupants, with injuries to the abdominal region. If this group was further reduced to include those cases in which the abdominal injury was the most severe, this group decreased to 11 cases, representing 548 weighted occupants. For purposes of analysis, any instance of abdominal injury was accepted regardless of the mortality ranking within the case. Abdominal injuries found among front-seated, nearside crash occupants, were found to have an attributable cost of approximately $138 million, per Figure 2. When considering the cases where at least one abdominal injury was present, the attributable costs of all injuries present, in concert with the abdominal injury, exceeded $1.5 billion. This cost included the presence of up to 15 maximum injuries, of which at least one was abdominal. These represented nearly 7,000, occupants, on average 1,000 per year, tow away crash occupants, traveling in vehicles of model 1998 or later, involved in nearside crashes since 1997. It should be noted, however, that the incidence of abdominal organ injuries did not indicate their overall severity for the occupant, per Figure 5. Brain and rib/sternum injuries continued to represent the highest incidence of maximum severity injuries. Cumulative case costs, where the occupant sustained at least one abdominal injury, approached $5 billion, of which abdominal injuries contributed 12 percent of these costs. This contrasted with the attributable costs, which assumed the elimination of the most severe injury, as in the case of a countermeasure introduction. When focusing the study to near side abdominal injuries in Table 3, as one of the top 15 mortality injuries, the brain continued to lead costs, however, the lower leg disappeared from considerations, as compared to all MAIS 2+ injuries in Table 2. The injury ranking, based upon attributable costs changed completely upon including occupants with abdominal injury sustained in a near side crash, as seen in Tables 2 and 3. Countermeasure introduction might account for this.

Currently, the working file consists of all crashes conforming to the parameters described earlier in paper. This data set has been disaggregated into the various crash modes for future study. The file will also be dependent upon the increasing accuracy of the mortality rates used to calculate survivability.

Table 3.
Body Regions with Cumulative Injury Costs for Occupants with Near Side Abdominal Injury

ID	Body Part	Cost, $M
1	Skull	118
2	Brain/intracranial	2,763
3	Ear, eye, internal neck organs	0
4	Nose, mouth, face, scalp, neck	0
5	Cervical spinal cord	278
6	Upper Extremity	119
7	Thorax	280
8	Ribs/sternum	0
9	Back (including vertebrae)	72
10	Trunk (other abdomen, thorax)	71
11	Trunk Spinal Cord	153
12	Abdominal Organs	568
13	Hip, Thigh, Pelvis	192
14	Knee	0
15	Lower Leg	0
16	Burns, unspecific body part	0
17	Whole body-minor external	0

Source: NASS CDS, 1997 – 2003, and Zaloshnja, 2004

Baseline Comparison

From the complete database, costs were most frequently associated with brain and intracranial injuries. These approach a composite cost of $68 billion. The lower leg injuries, the second most costly, accounted for nearly $12 billion, per Figure 3. Thoracic injuries over took the brain, with regard to fatality. Approximately 5,800 thoracic injuries were reported, as compared to approximately 5,600 brain injuries attributable to fatally injured occupants. The ribs and sternum, although less costly in monetary terms, were found to account for nearly 5,100 fatalities.

The frontal crash outcome was deemed the first priority, owing to its prevalence amongst all crashes, pursuant to disaggregation of the crash modes. The disaggregation was warranted since dummy development has been dictated by crash mode. This has been especially true in the instrumentation of the frontal versus side impact crash dummy. Further, only moderate through maximum injuries, AIS 2 through 6, for restrained occupants were considered in these findings.

It was found that lower limb injures occurred most frequently. When studying the highest severity

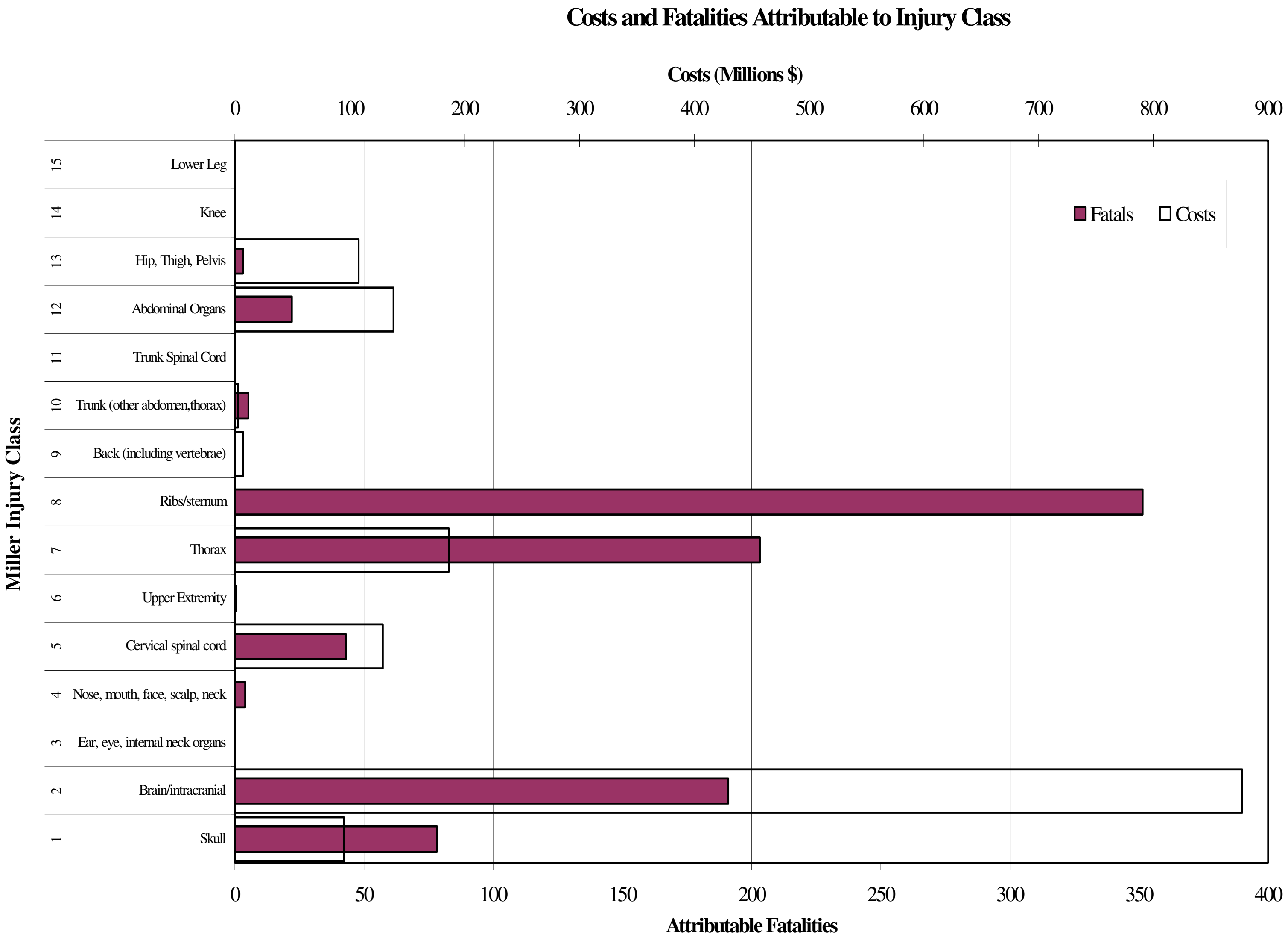

Figure 2.

Cumulative Costs and Weighted Fatalities Attributable to Injured Body Regions for Belted Front Seat Passenger Vehicle Occupant with at least one MAIS 2+ Abdominal Injuries Pursuant to a Tow Away Near Side Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

injury per occupant, lower limb injuries continued with prevalence. When considering case costs, however, brain injuries were the most costly, followed by lower leg injuries. Costs per case were attributed to a single injury (the one having the highest associated cost per case according to Zaloshnja, 2003.) When considering costs attributable to each injury, lower leg injuries were the most costly, followed by brain injuries. These were referred to as attributable cost. Injuries to the ribs and thorax, in general, were associated with the most fatalities. These attributable fatals were described as the number of fatalities attributable to each injury.

DISCUSSION

The preceding sections provided a framework for the dummy development predicated on data analysis. Many priorities exist in the development of biofidelic dummies to replicate real world injury outcomes induced in laboratory vehicle crash testing. Within this context, a better understanding might be gained in the search for injury metrics.

It should be noted, that although brain injuries are of maximum frequency, the other injury categories should not be ignored. This argument was based upon frequency, as well as maximum injury severity. Most injured occupants sustained more than one injury. Further, these injury costs were not meant to be summed to obtain a case cost. Each injury may increase severity, however, the injury costs were devised on a per injury basis. The development of attributable and overall case costs was required to accurately assess the cost of injuries to an occupant. This composite approach allowed for a ranking of priorities with regard to frequency, as well as societal cost of injuries.

The baseline example provided a data set from which to examine injury mitigation opportunities. Among these cases, the illustrative example was found to rank fifth among total near side incidence, when considering only cases in which at least one abdominal injury occurred. Among the injuries of maximum severity for near side crashes, abdominal injuries ranked tenth out of seventeen injury types.

The selection of the abdominal injuries sustained by near side crash occupants was meant as an illustrative example of the data base contents and use. It is the intention to examine the remaining topics and report these in subsequent publications.

A framework of data analysis has shaped dummy development by focusing on the real world crash data. The use of such data allowed for identification of injury mechanisms present in the different crash modes. To this point, NHTSA has used three issues to guide this study. These have been: the type of injuries to prevent, dummy measurements needed to ascertain the presence of these injuries, and calculation of lives to be saved under a given countermeasure regime.

What types of injuries should NHTSA strive to prevent? This issue has been very much a question of policy tempered by the needs of the safety community at large. Within the confines of this project, however, the data base queries have been meant to ascertain injury frequencies. From these frequently occurring injuries, a ranking by means of a universally accepted metric had to be made. The mortality rates have been shown, in previous publications (Martin, 2003) to have merit and provide the basis for calculation of survivability. This disaggregation of the two most severe injuries allowed for accurate occupant injury costs to be calculated. Upon completion of the data analysis initiative, a ranking of the top ten injuries of concern will be available.

What measurements are required of a crash dummy to ascertain whether such injuries are sustainable in a crash test? Based upon the findings of the data analysis, experts in biomechanics will be able to draw conclusions regarding injury prevalence, costing, and countermeasure development. These can be examined within the framework of benefit cost models. Further, the current capabilities of the dummies must be outlined and matched to the emerging needs found from the real world analysis. These findings will be published for use by dummy manufacturers, regulators, and test designers.

Upon providing a listing of the top ten injuries by crash mode, crash mechanisms may be isolated. From this point, the crash kinematics may be recreated. It would then be incumbent upon manufacturers to refine instrumentation to collect data relevant to the injuries in question.

How many lives are likely to be saved under a given performance requirement to prevent such injuries? Based upon the refinements to the mortality iterations, the survivability rate (Martin, 2003) also allows for countermeasure valuation within the framework of injury severity and costing. This topic will continue to be developed during the preparation of this data analysis initiative. This method is not currently used in NHTSA rulemaking.

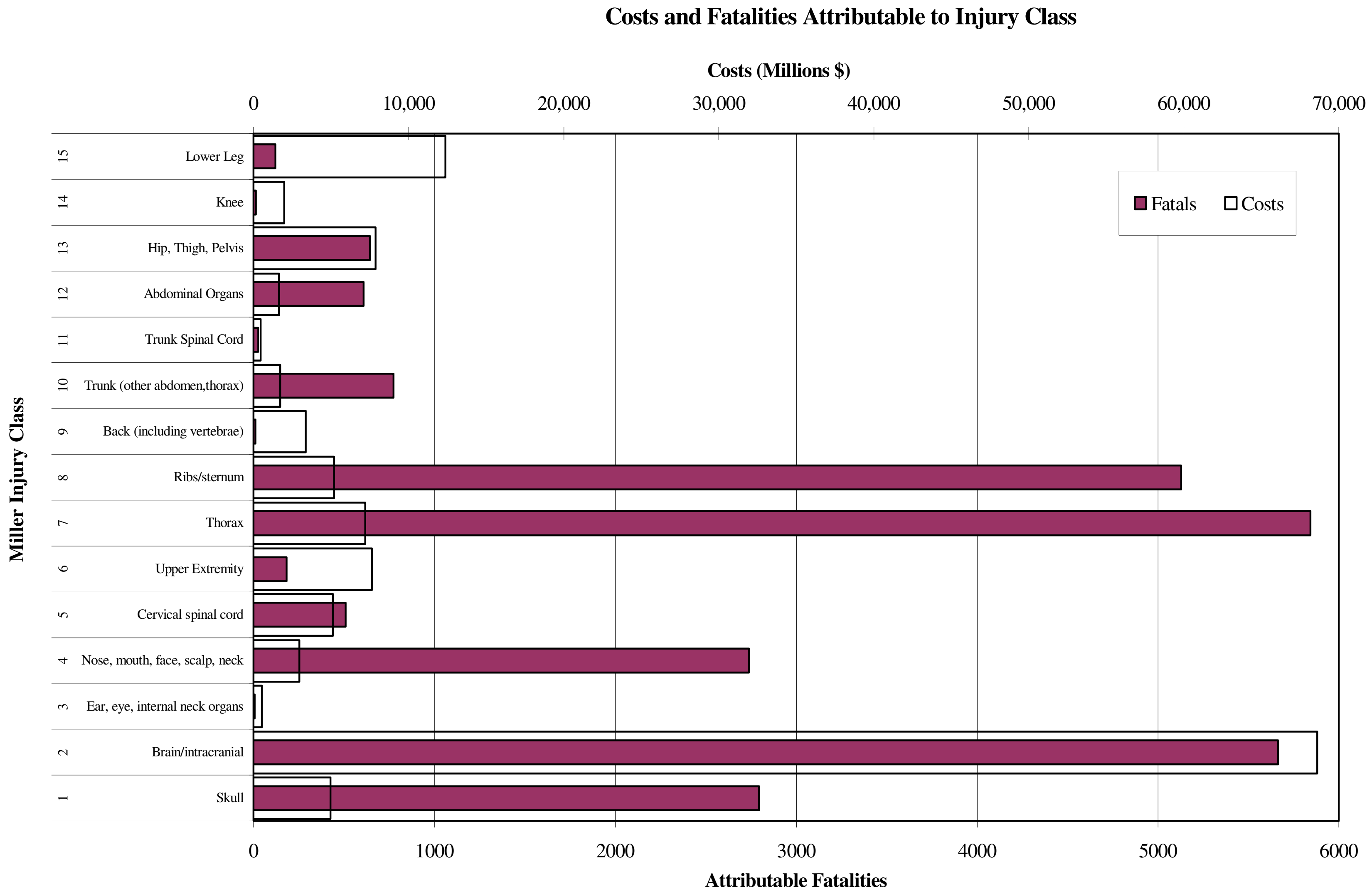

Figure 3.

Cumulative Costs and Weighted Fatalities Attributable to Injured Body Regions Passenger Vehicle Occupant MAIS 2+ Injuries Pursuant to a Tow Away Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

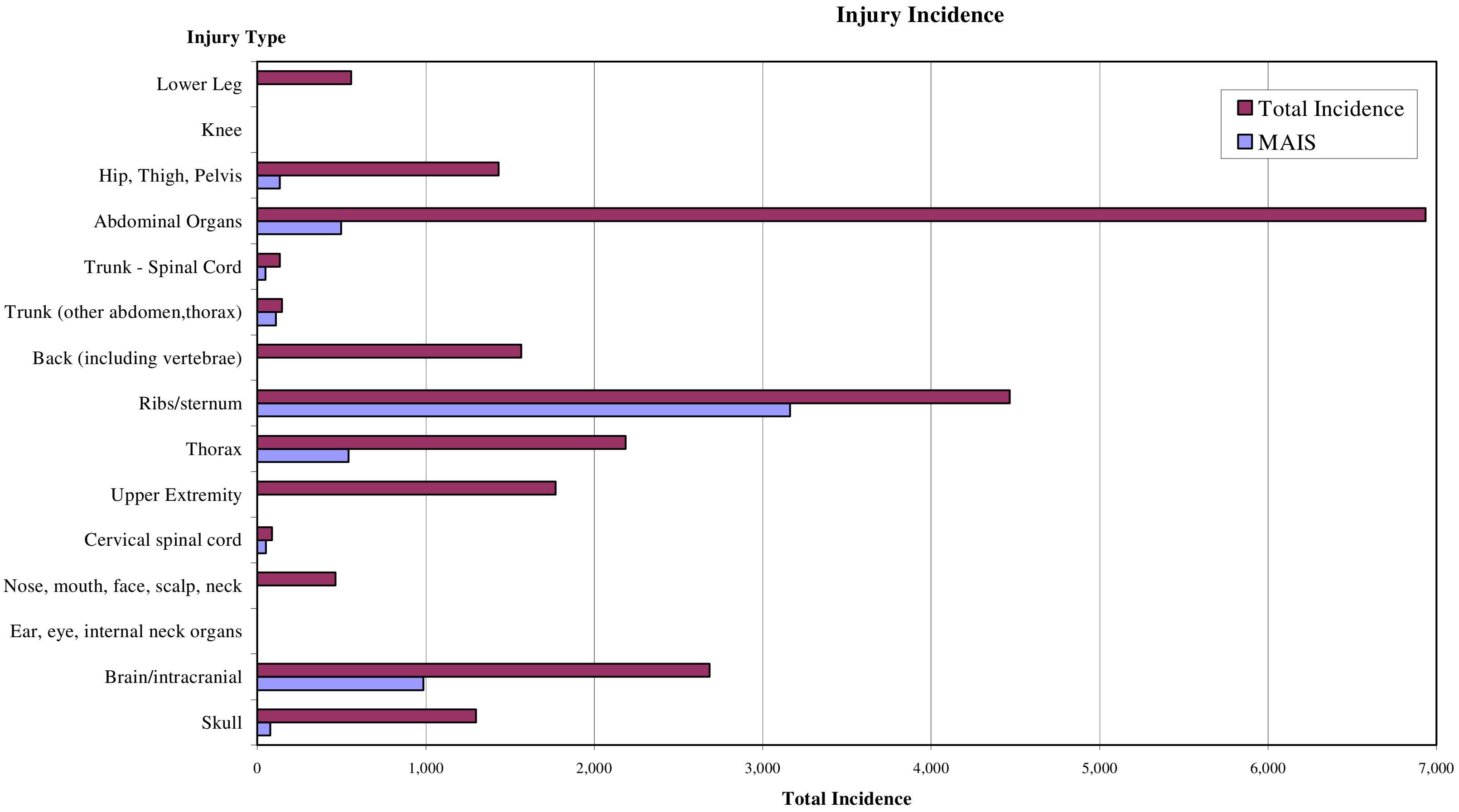

Figure 4.

Cumulative Weighted Incidence and Maximum Injury Severity by Injured Body Regions for Belted Front Seat Passenger Vehicle Occupant with at least one MAIS 2+ Abdominal Injuries Pursuant to a Tow Away Near Side Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

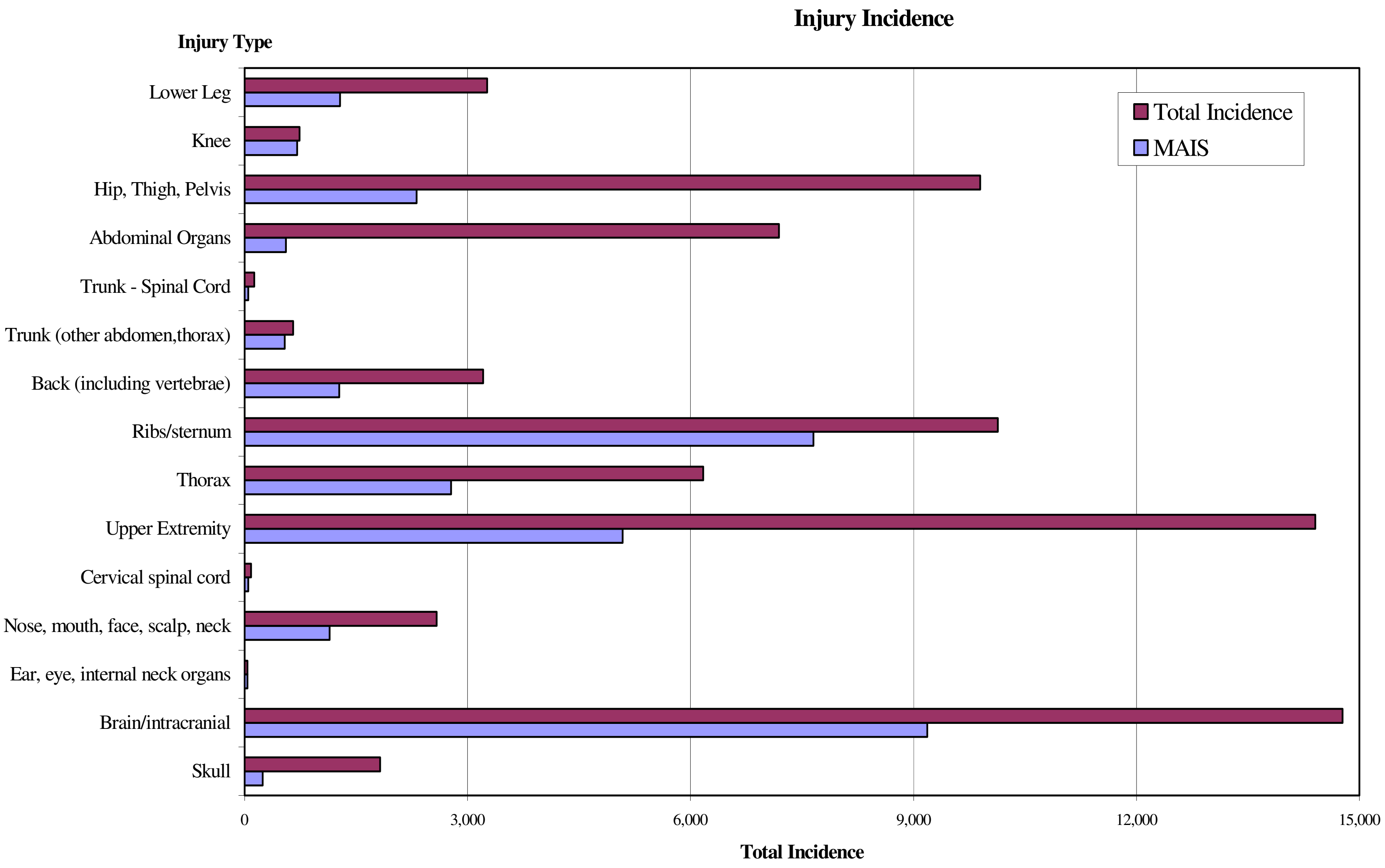

Figure 5.

Cumulative Total Weighted Incidence and Maximum Injury Severity by Injured Body Regions for Belted Front Seat Passenger Vehicle Occupant MAIS 2+ Injuries Pursuant to a Tow Away Near Side Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

SUMMARY

The dummy development of NHTSA is on going. This publication is meant to provide an update of the data analysis activity. This component is one of several activities occurring simultaneously and supporting the overall biomechanics effort within the Agency. The data analysis results have been presented on a regular basis. Subsequent results may be reported on an intermittent basis in the form of future research notes, technical reports, or conference papers.

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Appendix A: Attributable Fatality Calculation

Step 1. Examine the injury record of each case. Associated with each injury is a mortality rate, which was determined in the Martin (2003b). An overall fatality probability is computed from mortality rates as describe in the Martin (2003b). The product of the probability and the case weight is an estimate of the number of fatalities that occurred in the U.S. for occupants having those types of injuries. **Step 2.** Consider a particular type of injury -- say, e.g. injuries. Examine the injury record again, only this time *REMOVE* from the injury record all brain injuries. From the remaining list of injuries, compute a new estimate of the number of fatalities. **Step 3.** [Fatalities computed in Step 1] - [Fatalities computed in Step 2] = Fatalities attributable to brain injuries in the U.S. for all like-mannered cases.

Total fatals attributable is found by performing this **3-step** operation for every case, and summing the differences from Step 3. This sum is an estimate of the lives saved if all brain injuries could be eliminated.

Appendix B: Attributable Cost Calculation

Step 1. Examine the injury record of each case. Associated with each injury is a cost, which was determined in the Zaloshnja (2004). An overall case cost is taken as the cost corresponding to the most expensive injury. (This may or may not be the same as the MAIS injury or the injury having the highest mortality rate). **Step 2.** Consider a particular type of injury – e.g., brain injuries. Examine the injury record again, only this time *REMOVE* from the injury record all brain injuries. From the remaining list of injuries, find the case cost as in Step 1. **Step 3.** ([Cost computed in Step 1] - [Cost computed in Step 2]) x NASS CDS Case Weighting Factor = Costs attributable to brain injuries in the U.S. for all like-mannered cases.

Total costs attributable is found by performing this **3-step** operation for every case, and summing the differences from Step 3. This sum is an estimate of the costs saved if all brain injuries could be eliminated.

A METHOD TO ATTRIBUTE FATALITIES AND COSTS TO SPECIFIC INJURIES

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ABSTRACT

A data-driven procedure is presented to estimate the costs and the number of fatalities attributable to specific types of injuries. It continues Martin and Eppinger's work presented at the 2003 ESV conference. The procedure examines a crash victim's entire injury record in the process. All possible injuries are denoted by unique codes as described in the AIS Injury Coding Manual. The two most serious injuries – denoted as the primary injury and the secondary injury – are chosen from the injury record and are used to characterize a victim's entire set of injuries. When the mortality rate of the primary injury code is combined with that of the secondary injury, an overall fatality risk is obtained. Fatalities attributable to specific injuries may then be determined by considering the effect that a specific injury or set of injuries has on fatality risk. Attributable costs are estimated in a similar manner. Ultimately, this process – which singles out specific injuries – provides a means to determine the types of injuries NHTSA should strive to prevent, and to determine the capabilities needed of a crash dummy to ascertain whether such injuries are sustainable in a crash test.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) is responsible for reducing deaths, injuries, and economic losses resulting from motor vehicle crashes. This is accomplished in part by setting and enforcing safety performance standards for motor vehicles. The performance of a vehicle in mitigating injuries is assessed through the Federal Motor Vehicle Safety Standard (FMVSS) 200 series. Injury potential is measured through the use of a crash test dummy exposed to collision forces.

This paper focuses on the process and procedure of determining costs and fatalities attributable to specific types of injuries. A means of ranking the importance of specific types of real world injuries is presented. Such rankings are intended to be used to determine the types of injuries NHTSA should strive to prevent and the measurements required of a crash dummy to ascertain whether such injuries are sustainable in a crash test. Eventually, the methodology may be used to justify dummy requirements by providing estimates of lives saved and injuries prevented that may be achieved by implementing a new safety countermeasure.

OBJECTIVE

In searching for the appropriate metrics to be used in crashworthiness assessments with dummies, NHTSA takes a data driven approach to assure that its use in a federal regulation will lead to a significant reduction in injuries. Within NHTSA's biomechanics division, real-world data is used to help make three important determinations that are used to guide research priorities:

1. Determine the types of injuries that NHTSA should strive to prevent.

2. Determine the measurements required of a crash dummy to ascertain whether such injuries are sustainable in a crash test.

3. Provide an estimate of the number of lives that may be saved under a given performance requirement to prevent such injuries.

Generally, there must be enough existing data to show that a proposed vehicle performance requirement (such as implementing a new injury metric) will reduce the risk of injuries significantly. To aid in such assessments, NHTSA maintains epidemiological data on the nature, causes, and injury outcomes of crashes.

National Automotive Sampling System – Crashworthiness Data System

The Crashworthiness Data System (CDS) is one of the epidemiological databases maintained by NHTSA [1]. The CDS is a nationally representative probability sample of police-reported automobile crashes in the United States. CDS cases are limited to crashes that involve at least one passenger vehicle that was towed from the crash scene due to damage resulting from the crash. Each case is assigned a weighting factor that represents an estimate of the number of like-mannered cases that occurred during the sample year. This paper offers a new means with which to interpret CDS data by examining costs and fatalities attributable to specific types of injuries.

METHODS

Injury Coding.

Within the CDS, injuries to motorists are described by using a seven digit code in accordance with the CDS Injury Coding Manual [2]. This manual is adopted from a very similar manual developed by AAAM titled "The Abbreviated Injury Scale (AIS) Injury Coding Manual" [3]. The CDS manual provides codes for over a thousand distinct injury types. It gives synonyms, parenthetical descriptions of each code. In theory, the manual provides codes for every possible injury that one could sustain in a motor vehicle crash.

CDS injury codes may be cross-referenced with detailed nomenclature in the coding manual. The first digit of the code identifies the body region; the second digit identifies the general anatomic structure; the third and fourth digits identify the specific anatomic structure or, in the case of injuries to an external region, the specific nature of the injury; the fifth and sixth digits identify the level of injury within a specific body region and anatomic structure; the seventh digit is a general severity level referred to as the AIS score. AIS scores take on integer values of 1 (low severity) to 6 (maximum). If a motorist suffers an injury of an unknown severity, a score of 7 is assigned.

Computing Mortality Rates.

Determining the number of fatalities attributable to a particular type of injury is a multi-step process. The first step is to determine the mortality rate associated with each injury. The basis of determining the mortality rate values is fully described by Martin and Eppinger (2003b). mortality rate values are akin to the AIS severity scores of 1-6. But unlike AIS scores, unique mortality rate values ranging from 0 to 1 are computed for each 7-digit code (although some codes describing very similar injuries share the same values). Moreover, the basis of the values is the CDS data itself rather than the findings of an expert panel (who assign the severity scores to each of the six-digit codes). The mortality rate for a given code is: one minus the ratio of the number of times it was reported to be the cause of death over its overall incidence, as illustrated in Fig. 1.

Values of the mortality rates for all AIS codes used in the analysis presented herein are given in the Appendix. Mortality rates are given for injuries described by a condensed five-digit AIS code which is created by dropping the injury level identifiers (digits five and six) from the seven-digit code. In doing so, it is assumed that two or more injuries with different seven-digit codes but sharing the same five-digit code have the same mortality rate. The five-digit code is reasoned to sufficiently describe injuries that are unique in the context of crashworthiness research. That is, there is no need to discriminate among the injury levels (digits 5 and 6) when considering the impact of a safety countermeasure. More importantly, the condensed codes provide better statistical correlations in ranking the codes because more CDS observations are associated with fewer codes.

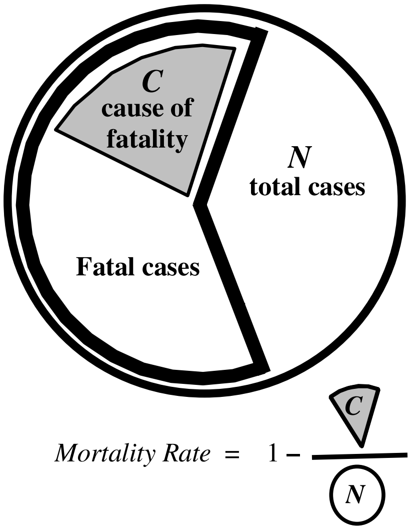

Figure 1. Computing mortality rates for individual injuries.

The overall fatality rate of a particular set of injuries is a function of the mortality rate of each injury sustained. Like the mortality rates themselves, the means to compute the overall fatality rate of a given accident victim who sustains several injuries is presented by Martin and Eppinger [4, 5]. In short, only the two most serious injuries – the primary injury and secondary injury – are used to characterize a victim's entire injury record. Thus, instead of using just a single maximum AIS (or MAIS) injury, the "Primary/Secondary" model uses two injuries. Whereas the primary injury sets the upper limit of the fatality probability, the secondary injury can be thought of as a "survivability modulator".

This two-injury approach uses the actual CDS outcomes to help select and sort injuries. So, not only are the mortality rates used to compute overall fatality rate, they are used to select which two injuries are chosen to represent the injured victim in the first place. Generally, all other injuries have very little effect on the overall fatality rate and are excluded from the fatality function. For example, a Primary/Secondary/Tertiary model produces only a slightly lower (though not significantly lower) deviance than the Primary/Secondary model alone.

Also, in the analysis described herein all injuries with severity scores of AIS=1 are assigned mortality rates of zero. That is, a victim with only AIS 1 injuries is treated as having no injuries at all. The mortality associated with crash victims having only AIS 1 injuries is known to be extremely low; this is not necessarily the case for all AIS 2+ injuries.

Computing Attributable Fatalities.

Attributable fatalities are the number of lives lost due to a particular injury. For example, consider a hypothetical five-case dataset shown in Table 1. Each case represents a CDS occupant who sustained up to five injuries, at least one of which was a head injury. The number of fatalities due to head injuries alone may be estimated by taking two "sweeps" through the dataset as described below:

Sweep 1. The upper table in Table 1 represents the actual five-case dataset. Examine the injury record of each case. Associated with each injury code is a mortality rate which can be found in the Appendix (head injuries have codes with a "1" as the first digit). By using the Appendix as a lookup table, select the code having the highest mortality rate (the primary injury, Pinj) and the code having the next highest rate (the secondary injury, Sinj).

Compute the overall fatality probability for the case, Pfatal. The form of the fatality rate function is given in Eq. 1. The values of the parameter estimates (β's in Eq. 1) are determined by optimization process that when given the actual mortality produces the best estimates (lowest deviance) of the probability of fatality.

$$Pfatal = (\mathrm{MR\_Pinj})\hat{}(\beta_1) * (\mathrm{MR\_Sinj})\hat{}(\beta_2) \qquad [1]$$

where MR_Pinj and MR_Sinj are the mortality rates associated with the top two injuries (from lookup table in Appendix), while $\beta_1 = 0.382$ and $\beta_2 = 1.014$ (from the optimization process).

In Table 1, "case wgt" is the CDS national expansion factor for each case. The product of the probability and the case weight is an estimate of the number of fatalities that occurred in the U.S. for occupants having those types of injuries during the sample year. The total fatalities involving head injuries is found by summing the five estimates. The sum, 1446, is an estimate of fatalities involving (by not necessarily attributed to) head injuries.

Sweep 2. Examine the injury record again, only this time strike from the injury record all head injuries, as shown in the lower table in Table 1. From the remaining injury codes, a new Pinj, Sinj, and Pfatal are found. A new estimate of 451 fatalities is also found.

CASE	i1	i2	i3	i4	i5	Pinj	Sinj	PFatal	CASE WGT	Fatals1
1	1406.4	5418.2	2508.2	4502.2		1406.4	5418.2	0.2689	2613.42	703
2	1402.5	1402.5	1406.4	4414.4	4502.3	1402.5	1402.5	0.7572	346.78	263
3	1402.5	1608.5	8518.3	2908.2		1402.5	1608.5	0.4659	394.10	184
4	1402.5	1402.5	8518.3	8520.2	8524.2	1402.5	1402.5	0.7572	210.28	159
5	1406.5	8306.2				1406.5	8906.1	0.1293	1062.97	137
									Total	1446

CASE	i1	i2	i3	i4	i5	New Pinj	New Sinj	New PFatal	CASE WGT	Fatals2
1	~~1406.4~~	5418.2	2508.2	4502.2		5418.2	2508.2	0.1603	2613.42	419
2	~~1402.5~~	~~1402.5~~	~~1406.4~~	4414.4	4502.3	4414.4	4502.3	0.0876	346.78	30
3	~~1402.5~~	~~1608.5~~	8518.3	2908.2		8518.3	2908.2	0.0011	394.10	0
4	~~1402.5~~	~~1402.5~~	8518.3	8520.2	8524.2	8518.3	8520.2	0.0010	210.28	0
5	~~1406.5~~	8306.2				8306.2		0.0012	1062.97	1
									Total	451

Table 1. Demonstration of the process to compute fatalities attributable to head injuries involving two sweeps thru the dataset: Sweep 1 (upper table) and Sweep 2 (lower table).

Finally, the fatalities attributable to head injuries is found by subtracting the results of Sweep 2 from Sweep 1: 1446 – 451 = 995. This is expressed mathematically by Eq. 2.

Attributable Fatalities =

$$\sum_{i=1}^{n}\left\{(PFatal)_i - (New\ PFatals)_i\right\}\cdot(casewgt)_i \qquad [2]$$

The result provided by Eq. 2, 995 lives, is an estimate of the number of fatalities attributable to head injuries in the U.S. for all like-mannered cases.

Computing Attributable Costs.

Computing the costs attributable to a particular injury follows a similar methodology as attributable fatals. The procedure starts with cost per injury estimates presented by Zaloshnja et al [6], who have reasoned that the cost associated with the MAIS injury is the approximate cost incurred by the victim. Their costing methodology is an averaging process: it is understood that most victims suffer multiple injuries, and all injuries contribute to the overall cost. Nonetheless, their methodology offers a reasonable means to account for injury costs.

The methodology described herein takes the Zaloshnja et al process a step further. For victims who sustain multiple injuries (such as the vast majority of CDS MAIS 2+ victims), it provides a means to isolate the costs due to a particular type of injury from costs borne by other injuries.

For example, consider head injuries again. The costs due to head injuries alone may be estimated by taking two "sweeps" through the dataset as described below:

Sweep 1. Examine the injury record of each case in the upper table of Table 2. Associated with each injury code is a cost figure which can be found in the Appendix. By using the Appendix as a lookup table, select the code having the highest cost. An overall case cost is taken as the cost corresponding to this most expensive injury. (This may or may not be the same as the MAIS injury or the injury having the highest mortality rate). The product of the case cost and the case weight is an estimate of the costs incurred in the U.S. for occupants having those types of injuries during the sample year.

Sweep 2. Examine the injury record again, only this time strike from the injury record all head injuries, as shown in the lower table of Table 2. From the remaining list of injuries, find the case cost as in Sweep 1.

Total costs attributable are found by performing this operation for every case, and summing the differences: 9.62 – 0.68 = $8.94 Million. Mathematically, this is expressed as shown in Eq. 3:

CASE	i1	i2	i3	i4	i5	Case Cost $k	Case Wgt	Cost1 $M
1	1406.4	5418.2	2508.2	4502.2		1201	2613.42	3.14
2	1402.5	1402.5	1406.4	4414.4	4502.3	3219	346.78	1.12
3	1402.5	1608.5	8518.3	2908.2		3219	394.10	1.27
4	1402.5	1402.5	8518.3	8520.2	8524.2	3219	210.28	0.68
5	1406.5	8306.2				3219	1062.97	3.42
							Total	9.62

CASE	i1	i2	i3	i4	i5	Case Cost $k	Case Wgt	Cost2 $M
1	~~1406.4~~	5418.2	2508.2	4502.2		139	2613.42	0.36
2	~~1402.5~~	~~1402.5~~	~~1406.4~~	4414.4	4502.3	259	346.78	0.09
3	~~1402.5~~	~~1608.5~~	8518.3	2908.2		244	394.10	0.10
4	~~1402.5~~	~~1402.5~~	8518.3	8520.2	8524.2	237	210.28	0.05
5	~~1406.5~~	8306.2				79	1062.97	0.08
							Total	0.68

Table 2. Demonstration of the process to compute costs attributable to head injuries involving two sweeps thru the dataset: Sweep 1 (upper table) and Sweep 2 (lower table).

Attributable Costs =

$$\sum_{i=1}^{n} \{Cost1)_i - (Cost2)_i\} \cdot (casewgt)_i \qquad [3]$$

Thus, \$8.94 Million is an estimate of the costs saved if all head injuries could be eliminated.

The overall fatality probability is also used in this analysis. Zaloshnja et al [6] provide a cost associated with a fatality that is the same regardless of the injuries. When evaluating a CDS case whose outcome is a fatality, the overall mortality rate is re-computed after "removing" the head injury from the record in Sweep 2. If the fatality rate decreases by more than 80%, it is assumed that the occupant would have lived, and the overall cost ("Cost2") is computed as such. If the fatality rate is more than 80% of the actual even after the head injuries are "removed", then the victim is assumed to still have suffered fatal injuries and no costs are attributed to the head injuries.

APPLICATION

To demonstrate the utility of the process, consider the costs due to and fatalities attributable to head injuries in side impacts. The study herein is based on a working data set extracted from 1997-2003 CDS files. The data set composition is limited to the following:

* Vehicles of model year 1998 or later
* Near-side occupants in a side impact collision (front or rear seat)
* Adults restrained by a properly worn seat belt.

In all, the working data set contains data on 313 crash victims – including records for more than 51 fatalities – over the seven-year span. When these figures are weighted to represent national totals, there are 30,737 crash victims and 2,164 fatalities over the seven years. Among the fatalities, 825 have head injuries of AIS ≥ 2.

RESULTS

Attributable Fatalities

The number of fatalities attributable to head injuries is found by taking two sweeps through the dataset as described earlier. In the first sweep, only the *n* cases where a head injury exists among the top two are retained. The mortality rates of these the injury codes are found in the lookup table (see appendix). In the second sweep, only the *n* cases are examined, but injury codes associated with head injuries are disregarded. This gives rise to a new fatality estimate, from which the number of fatalities attributable to head injuries is determined to be 651, as denoted in Table 3.

Attributable Costs

The costs attributable to head injuries may also be determined by taking two sweeps through the dataset as described earlier. In the first sweep, only the *n* cases where a head injury was the costliest of injuries are retained. The costs associated with these cases corresponds to the cost rates (found in the lookup table in the Appendix) of the *n* head injuries. In the second sweep, only the *n* cases are examined, but injury codes associated with head injuries are disregarded, and a new estimate of overall costs is determined. Costs attributable to head injuries are then found to be \$5,372 million.

The same methodology may also be used to determine costs and fatalities attributable to specific types of head injuries, like simply brain injuries as opposed to head injuries that include skull fractures. Table 3 provides the estimates for both instances when the two-sweep process is carried out.

1. Fatalities in which an AIS 2+ head injury was sustained.	825
2. Fatalities attributable to head injuries.	651
3. Costs due to head injuries (\$Million).	5,372
4. Fatalities attributable to brain injuries.	430
5. Costs due to brain injuries (\$Million).	4,948

Table 3. Cumulative costs and fatalities attributable to head and brain injuries in the U.S.; belted adults in near-side crashes, MY '98+ vehicles. Source: 1997-2003 CDS.

DISCUSSION

A simplistic analysis of CDS data merely provides frequency counts of injuries; it does not explicitly explain how many lives may be saved if a given type of injury could be avoided. For example, Table 3 shows that 825 fatal crash victims received a head injury of AIS ≥ 2. While the head injury probably contributed to the fatal outcome in most of the cases, there were injuries in other body regions, too. As such, the CDS does not provide a direct estimate of fatalities due to head injuries. For a more exacting estimate, the two-injury characterization (described earlier in the "Methods" section) may be used to find the number of fatalities that are directly attributable to head injuries

Aside from the example presented above for head injuries, this methodology may be carried out to examine a variety of injury types that may provide insights on safety priorities and research programs. Some additional ideas are given below.

1. Abdominal organ injuries. There is a lack of basic biomechanical knowledge of thresholds and mechanisms associated with abdominal injuries largely due to the difficulty in observing such injuries in laboratory experiments. As a result, it may be difficult to correlate ATD instrumentation with abdominal organ injuries per se. Under the scheme presented herein, one may examine costs and fatalities due to abdominal organ injuries that occur in the absence of other types of injuries (like rib injuries) that *are* well correlated with ATD instrumentation measurements. If significant costs are found to be borne by abdominal organ injuries alone, then it may justify a research program to investigate thresholds, injury mechanisms, and development of appropriate ATD instrumentation.

2. Thoracic injury types. Side impact ATD's use rib deflection sensors to assess potential for thoracic injury. Moreover, the criteria for thoracic injury potential as measured by ATD rib deflections is largely based on the number of broken ribs observed in tests with post-mortem human surrogates. With the methodology presented herein, one may look for thoracic organ injuries with and without significant rib fractures to gain insights into whether rib deflection measurements adequately gauge thoracic trauma.

3. Knee-Thigh-Hip injuries. NHTSA is monitoring and investigating occult injuries from frontal crashes. Knee-thigh-hip (KTH) complex injuries to belted occupants are one of the injury patterns being investigated. By singling out each of these three lower extremity body regions, one may examine the makeup of knee vs. thigh vs. hip and pelvis injuries in order to gain insights into biofidelity requirements of a dummy KTH assembly and the need for, say, acetabular measurements in an ATD.

4. Children in Child Restraint Systems. NHTSA has addressed the TREAD Act by incorporating new requirements into FMVSS No. 213, including improved child test dummies. Moreover, Anton's Law requires the development of an anthropomorphic test device simulating a 10-year-old child and an evaluation of integrated child restraint systems. The general injury distributions of children in CRS may be examined in frontal and side crashes in an effort to examine the body regions most apt to be injured. This may help pinpoint the performance requirements of child dummies under various test conditions.

Results of these example studies are beyond the scope of this paper, but may be presented in the future.

Ongoing Enhancements to the Methodology

Mortality Rates. As described earlier, an optimization process is used to determine the coefficients (β_1 and β_2) of the overall fatality function such that overall deviance is minimized when considering the actual outcomes of each case. Theoretically, the mortality rates may be optimized, too, and a process is being implemented to do so.

Costs per Injury. Similar to the optimization process used for mortality rates, a process to provide cost per injury estimates based on NHTSA epidemiological data is ongoing. Data from the Crash Injury Research and Engineering Network (CIREN) is being considered for this effort (CDS does not contain cost data).

While CIREN contains medical and rehabilitation costs, the costs described in the paper herein are comprehensive costs, which are more general and far-reaching. Nonetheless, Zaloshnja et al [6] also list the cost per injury for medical costs only (besides providing the comprehensive costs used herein.) It may be possible to compare CIREN-based costs with Zaloshnja's medical costs in an effort to better understand total costs to motor vehicle crash victims.

Cost of Fatalities. The current methodology uses the arbitrary decision to recode "fatalities" as "survivals". Recall Sweep 2 of the cost estimation process for fatal cases: if the overall fatality rate decreases by more than 80% once the "attributable" injuries are stuck, the outcome is assumed to be "nonfatal". An new approach is being worked out whereby the CDS case weight for a fatal case is prorated between "fatal" and "surviving" categories in proportion to the fatality rate decrease.

SUMMARY

The study presented herein provides a new means to interpret epidemiological injury data in a way that complements crashworthiness research. It is meant to help researchers predict how many lives may be saved by a prospective safety countermeasure that is designed to mitigate specific types of injuries. Specifically, this injury-accounting scheme has been developed to help fulfill three basic objectives:

1. Determine the types of injuries that NHTSA should strive to prevent.
2. Determine the measurements required of a crash dummy to ascertain whether such injuries are sustainable in a crash test.
3. Provide an estimate of the number of lives that may be saved under a given performance requirement to prevent such injuries.

One of the difficulties in using CDS data is that the characterization of injured motorists is not usually clear-cut. For each CDS occupant injury record, there are sometimes over twenty injuries spread over multiple body regions that are listed. This makes it difficult to judge how likely it is that a life will be saved if a specific injury is mitigated.

This paper offers a new perspective in interpreting CDS injury data. It describes a procedure to estimate the risk to life that multiple injuries pose to crash victims and to estimate the costs borne by and the number of fatalities attributable to specific types of injuries. For example, if one desires to estimate the number of lives saved if a particular injury is mitigated, it may be accomplished forthrightly under the scheme described herein. This is much harder to accomplish in the context of MAIS which does not account for multiple injuries.

Ultimately, this process – which singles out specific injuries – provides a means to determine the types of injuries NHTSA should strive to prevent, and to determine the capabilities needed of a crash dummy to ascertain whether such injuries are sustainable in a crash test.

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APPENDIX. Costs and mortality rates by injury.

5-Digit AIS Code	Nomenclature	Mort. Rate	Comprehen-sive Costs Year 2000 $
1130.6	Head Crush	1.000	3,158,552
1150.7	Closed head	0.961	3,218,776
1159.7	Closed Head	1.000	3,158,552
1204.5	Basilar artery	0.373	3,218,776
1210.3	Internal carotid	0.070	613,078
1212.4	Intracranial vessel	0.600	1,201,008
1214.3	Middle cerebral	0.150	613,078
1214.4	Middle cerebral	0.700	1,201,008
1216.4	Other head	0.654	1,201,008
1228.3	Vertebral artery	1.000	613,078
1228.5	Vertebral artery	1.000	3,218,776
1306.2	Optic nerve	0.001	289,674
1308.2	Oculomotor nerve	0.000	289,674
1310.2	Trochlear nerve	0.000	289,674
1314.2	Abducens nerve	0.001	289,674
1316.2	Facial nerve	0.000	289,674
1402.5	Brain stem	0.842	3,218,776
1402.6	Brain stem	1.000	3,158,552
1404.3	Cerebellum contus.	0.881	613,078
1404.4	Cerebellum contus.	0.881	1,201,008
1404.5	Cerebellum hematom	0.881	3,218,776
1406.3	Cerebrum contusion	0.068	613,078
1406.4	Cerebrum contusion	0.068	1,201,008
1406.5	Cerebrum contusion	0.220	3,218,776
1407.3	Pituitary injury	0.002	613,078
1500.2	Skull fracture	0.912	310,706
1502.3	Basilar skull	0.258	374,314
1502.4	Basilar skull	0.987	1,042,399
1504.2	Vault skull	0.000	310,706
1504.3	Vault skull	0.698	374,314
1504.4	Vault skull	0.976	1,042,399
1602.2	LOC	0.000	289,674
1604.2	Awake at scene	0.000	289,674
1604.3	Awake at scene	0.001	613,078
1606.2	Lethargic, Stuporous	0.001	289,674
1606.3	Lethargic, Stuporous	0.025	613,078
1608.3	Unconscious at scene	0.001	613,078
1608.4	Unconscious at scene	0.018	1,201,008
1608.5	Unconscious at scene	0.541	3,218,776
1610.2	Cerebral Concussion	0.000	289,674
1906.2	Scalp laceration	0.166	186,330
1908.2	Scalp avulsion	0.001	186,330
1908.3	Scalp avulsion	0.002	303,727
2150.7	Blunt Facial	0.000	303,727
2202.3	External cartoid	0.000	303,727
2404.2	Eye avulsion	0.001	246,807
2412.2	Sclera laceration	0.001	246,807
2502.2	Alveolar ridge	0.004	186,330
2506.2	Mandible fracture	0.000	88,575
2508.2	Maxilla fracture	0.001	88,575
2508.3	Maxilla fracture	0.035	119,096
2508.4	Maxilla fracture	0.350	520,070
2510.2	Nose fracture	0.001	88,575
2512.2	Orbit fracture	0.001	88,575
2512.3	Orbit fracture	0.001	119,096
2516.2	Temporomandibular	0.001	88,575
2518.2	Zygoma/malar fx	0.001	88,575
2906.2	Facial Skin	0.001	186,330
2906.3	Facial Skin	0.001	303,727
2920.3	Face Burn	0.001	787,813

5-Digit AIS Code	Nomenclature	Mort. Rate	Comprehen-sive Costs Year 2000 $
3150.7	Blunt neck/throat	0.000	460,991
3202.3	Carotid (common)	0.149	460,991
3208.2	Jugular vein	0.019	63,930
3210.2	Vertebral artery	0.002	63,930
3402.2	Larynx contusion	0.001	63,930
3406.2	Pharynx laceration	0.000	63,930
3414.2	Thyroid gland	0.004	63,930
3418.2	Vocal cord	0.001	63,930
3502.2	Hyoid fracture	0.001	63,930
3906.2	Neck/Throat Skin	0.001	186,330
4130.6	Chest Crush	1.000	3,158,552
4150.7	Blunt chest inj	0.664	674,183
4159.7	Blunt chest inj	1.000	3,158,552
4202.4	Aorta, thoracic	0.917	258,648
4202.5	Aorta, thoracic	1.000	536,993
4202.6	Aorta, thoracic	1.000	3,158,552
4208.5	Coronary artery	0.459	536,993
4210.3	Pulmonary artery	0.141	147,277
4212.3	Pulmonary vein	0.396	147,277
4212.4	Pulmonary vein	0.557	258,648
4214.3	Subclavian artery	0.148	147,277
4216.3	Subclavian vein	0.250	147,277
4216.4	Subclavian vein	0.719	258,648
4218.3	Vena Cava	0.203	147,277
4218.4	Vena Cava	1.000	258,648
4220.2	Chest vessel	0.000	107,754
4222.2	Chest vessel	0.002	107,754
4406.2	Diaphragm NFS	0.001	107,754
4406.3	Diaphragm lac.	0.101	147,277
4406.4	Diaphragm rupture	0.189	258,648
4408.5	Esophagus laceration	0.801	875,404
4410.3	Heart (Myocardium)	0.363	147,277
4410.4	Heart (Myocardium)	0.924	258,648
4410.5	Heart (Myocardium)	1.000	536,993
4410.6	Heart (Myocardium)	1.000	3,158,552
4412.5	Intracardiac valve	1.000	536,993
4413.5	Intraventricular	1.000	536,993
4414.3	Lung contusion	0.000	147,277
4414.4	Lung contusion	0.596	258,648
4414.5	Lung laceration	1.000	536,993
4416.2	Pericardium lac.	0.039	107,754
4416.5	Pericardium hernia	1.000	536,993
4418.2	Pleura laceration	0.000	107,754
4418.3	Pleura laceration	0.122	147,277
4422.3	Thoracic cavity	0.327	147,277
4422.5	Thoracic cavity	0.545	536,993
4424.2	Thoracic duct	0.000	107,754
4426.3	Trachea	0.000	460,991
4426.4	Trachea	0.040	258,648
4426.5	Trachea	1.000	875,404
4502.2	Rib cage	0.264	75,621
4502.3	Rib cage	0.264	103,822
4502.4	Rib cage	0.515	205,244
4502.5	Rib cage	0.970	421,043
4508.2	Sternum fracture	0.000	75,621
4906.2	Chest Skin	0.000	62,210
4920.2	Chest burn	0.000	64,198
5150.7	Abdominal trauma	0.131	261,395
5159.7	Abdominal trauma	0.001	3,158,552
5202.4	Aorta, abdominal	0.819	203,909

APPENDIX, cont. Costs and mortality rates by injury.

5-Digit AIS Code	Nomenclature	Mort. Rate	Comprehen-sive Costs Year 2000 $
5202.5	Aorta, abdominal	0.998	261,395
5204.5	Celiac Artery	0.800	261,395
5206.3	Iliac artery	0.142	132,993
5206.3	Iliac artery	0.142	132,993
5206.4	Iliac artery	0.638	203,909
5212.3	Vena cava	1.000	132,993
5212.4	Vena cava	1.000	203,909
5214.3	Abdominal vessel	0.375	132,993
5214.4	Abdominal vessel	0.375	203,909
5216.3	Abdominal vessel	0.001	132,993
5404.3	Anus laceration	0.082	132,993
5404.4	Anus laceration	0.082	203,909
5406.2	Bladder contusion	0.001	54,139
5406.3	Bladder laceration	0.004	112,077
5406.4	Bladder laceration	0.342	171,914
5408.2	Colon contusion	0.001	165,765
5408.3	Colon laceration	0.001	219,745
5408.4	Colon laceration	0.615	337,291
5410.2	Duodenum contusion	0.002	165,765
5410.3	Duodenum laceration	0.002	219,745
5410.5	Duodenum laceration	0.171	629,049
5412.2	Gallbladder lac.	0.008	165,765
5412.3	Gallbladder lac.	0.097	219,745
5414.2	Jejunum-ileum cont.	0.011	165,765
5414.3	Jejunum-ileum lac.	0.011	219,745
5414.4	Jejunum-ileum lac.	0.134	337,291
5416.2	Kidney contusion	0.001	102,009
5416.3	Kidney contusion	0.154	172,317
5416.4	Kidney laceration	0.154	240,085
5416.5	Kidney hilum	0.891	527,179
5418.2	Liver contusion	0.000	139,260
5418.3	Liver contusion	0.000	155,339
5418.4	Liver laceration	0.175	253,760
5418.5	Liver laceration	1.000	473,415
5418.6	Liver laceration	1.000	473,415
5420.2	Mesentery contusion	0.183	165,765
5420.4	Mesentery laceration	0.415	337,291
5422.2	Omentum contusion	0.002	54,139
5428.2	Pancreas contusion	0.001	165,765
5428.5	Pancreas laceration	0.716	629,049
5430.3	Penis laceration	0.000	112,077
5432.2	Perineum laceration	0.001	54,139
5432.3	Perineum laceration	0.001	112,077
5434.3	Placenta abruption	0.149	112,077
5436.2	Rectum laceration	0.001	165,765
5436.3	Rectum laceration	0.001	219,745
5436.4	Rectum laceration	0.200	337,291
5436.5	Rectum laceration	0.800	629,049
5438.3	Retroperitoneum	0.051	112,077
5440.2	Scrotum laceration	0.001	54,139
5442.2	Spleen contusion	0.000	109,687
5442.3	Spleen laceration	0.000	153,323
5442.4	Spleen laceration	0.134	256,896
5442.5	Spleen laceration	0.144	468,895
5444.2	Stomach laceration	0.001	165,765
5444.3	Stomach laceration	0.001	219,745
5444.4	Stomach laceration	0.250	337,291
5446.2	Testes laceration	0.000	54,139
5448.3	Ureter laceration	0.000	112,077
5450.2	Urethra laceration	0.003	54,139

5-Digit AIS Code	Nomenclature	Mort. Rate	Comprehen-sive Costs Year 2000 $
5450.3	Urethra laceration	0.015	112,077
5452.4	Uterus laceration	1.000	171,914
5906.2	Abdomen Skin	0.001	61,365
6150.7	Cervical Spine	0.862	4,371,935
6159.7	Cervical Spine	1.000	3,158,552
6302.2	Cervical Spine	0.001	186,330
6306.2	Lumbar Spine	0.000	31,372
6402.3	Cervical Spine	0.268	969,251
6402.4	Cervical Spine	0.233	3,305,283
6402.5	Cervical Spine	0.489	4,371,935
6402.6	Cervical Spine	1.000	3,158,552
6404.3	Thoracic Spine	0.055	104,511
6404.4	Thoracic Spine	0.084	2,340,375
6404.5	Thoracic Spine	0.393	2,771,402
6406.3	Lumbar Spine	0.052	104,511
6406.5	Lumbar Spine	0.272	2,771,402
6502.2	Cervical Spine	0.302	186,330
6502.3	Cervical Spine	0.302	119,096
6504.2	Thoracic Spine	0.001	267,061
6504.3	Thoracic Spine	0.001	262,311
6506.2	Lumbar Spine	0.001	31,372
6506.3	Lumbar Spine	0.001	262,311
7110.3	Upper Extremity	0.003	300,384
7130.3	Upper Extremity	0.000	300,384
7150.2	Upper Extremity	0.000	62,983
7150.7	Upper Extremity	0.000	217,029
7159.7	Upper Extremity	0.100	3,158,552
7206.2	Brachial artery	0.000	62,983
7206.3	Brachial artery	0.000	217,029
7210.3	Upper ext vessel	0.000	217,029
7304.2	Median, Radius	0.001	51,301
7404.2	Upper Ext muscle	0.001	62,983
7406.2	Upper Ext joint	0.000	62,983
7502.2	Acromioclavicle	0.001	47,445
7506.2	Elbow joint	0.000	22,808
7510.2	Shoulder joint	0.001	92,947
7510.3	Shoulder joint	0.001	168,999
7512.2	Sternoclavicular	0.001	92,947
7514.2	Carpus joint	0.001	47,445
7514.3	Carpus joint	0.149	47,445
7516.2	Acromion fracture	0.001	47,445
7518.2	Arm/wrist fx	0.044	47,445
7519.2	Forearm fracture	0.000	163,282
7520.2	Carpus fx	0.000	54,831
7522.2	Clavicle fracture	0.002	92,947
7524.2	Finger amputation	0.002	47,445
7525.2	Hand fracture	0.000	47,445
7526.2	Humerus fracture	0.000	92,947
7526.3	Humerus fracture	0.000	168,999
7528.2	Radius fracture	0.000	163,282
7528.3	Radius fracture	0.000	300,384
7530.2	Scapula fracture	0.001	92,947
7532.2	Ulna fracture	0.001	163,282
7532.3	Ulna fracture	0.001	300,384
7906.2	Upper ext skin	0.001	51,301
7908.2	Upper ext skin	0.001	51,301
7920.2	Upper ext burn	0.000	51,301
7920.3	Upper ext burn	0.139	468,162
7940.2	Degloving injury	0.001	51,301
7940.3	Degloving injury	0.001	223,097

APPENDIX, cont. Costs and mortality rates by injury.

5-Digit AIS Code	Nomenclature	Mort. Rate	Comprehensive Costs Year 2000 $
8110.3	Amput. below knee	0.239	237,203
8110.4	Amput. above knee	0.239	266,459
8130.2	Crush below knee	0.000	184,386
8130.3	Crush knee	0.020	266,459
8150.2	Lower Extremity	0.001	78,806
8150.7	Lower Extremity	0.001	25,501
8202.3	Femoral artery	0.000	71,388
8202.4	Femoral artery	0.300	550,548
8206.2	Popliteal artery	0.001	28,803
8206.3	Popliteal artery	0.021	185,689
8208.3	Popliteal vein	0.000	185,689
8210.3	Low ext vessel	0.001	120,078
8304.2	Sciatic nerve	0.001	78,806
8306.2	Femoral/tibal nerve	0.000	78,806
8404.2	Collateral ankle	0.001	122,139
8404.3	Posterior cruciate	0.001	185,689
8406.2	Lower Ext muscle	0.001	28,803
8408.2	Lower Ext tendon	0.000	78,806
8410.2	Patellar tendon	0.001	28,803
8502.2	Tarsus disloc	0.001	148,975
8506.2	Hip dislocation	0.000	36,053
8508.2	Knee dislocation	0.001	28,803
8514.2	Calcaneus fracture	0.000	148,975
8516.2	Fibula fracture	0.000	184,386
8516.3	Fibula fracture	0.001	237,203
8518.2	Femur fracture	0.115	205,639
8518.3	Femur fracture	0.115	237,203
8520.2	Foot/ankle fx	0.003	148,975
8522.2	Metatarsal fx	0.000	148,975
8524.2	Patella fracture	0.000	213,165
8526.2	Pelvis fracture	0.000	263,777
8526.3	Pelvis fracture	0.000	482,065
8526.4	Pelvis Crush	0.021	482,065
8528.3	Sacroilium fracture	0.001	482,065
8530.3	Symphysis pubis	0.000	482,065
8532.2	Talus fracture	0.000	148,975
8534.2	Tibia fracture	0.000	184,386
8534.3	Tibia fracture	0.000	237,203
8906.2	Lower ext skin	0.001	11,522
8908.2	Lower ext skin	0.001	11,522
8920.2	Lower ext burn	0.002	78,806
8940.2	Degloving injury	0.002	78,806
8940.3	Degloving injury	0.002	120,078
9192.3	Inhalation injury	0.177	147,277
9192.4	Inhalation injury	0.356	258,648
9920.3	Burn 2nd deg	0.046	787,813
9920.4	Burn 2nd deg	0.288	787,813
9920.5	Burn 2nd deg	0.964	844,289
9920.6	Burn 2nd deg	1.000	844,289

ARE EXPECTED AND OBSERVED EFFECTIVENESS OF EMERGENCY BRAKE ASSIST IN PREVENTING ROAD INJURY ACCIDENTS CONSISTENT?

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ABSTRACT

This paper proposes to estimate and to compare the expected and the observed effectiveness of the Emergency Brake Assist (EBA) in terms of reduction in injury accidents in France. The evaluation of the expected effectiveness of EBA is based on the simulation of the reduction in injuries in non-EBA cars which could result in lower collision speeds resulting themselves in higher mean deceleration, would EBA have been available and applied in those cars. A sample of fatal police reports, for which most of the vehicles involved in an accident, braking distance, collision speed and injuries outcome are available, is used for the simulation.

The evaluation of the observed effectiveness of EBA follows a 3-steps process:

- The identification, in the French National injury accident census, of accident-involved cars for which the determination of whether or not the car was fitted with EBA is possible. A sample of 917 cars involved in injury accidents occurred from January 2000 to June 2004 was selected.
- The identification of accident situations for which we can determine whether or not EBA is pertinent.
- The calculation, via a logistic regression, of the relative risk of being involved in an EBA-pertinent accident for EBA equipped cars versus unequipped cars, divided by the relative risk of being involved in a non EBA- pertinent accident for EBA equipped cars versus unequipped cars. This relative risk is assumed to be the best estimator of EBA effectiveness.

Both evaluations result in a good effectiveness of EBA. Furthermore, the rather consistent estimations out coming from expected (-7,5 % of car occupants fatalities, -10 % of pedestrian fatalities) and observed (-11 % of overall injuries) effectiveness of EBA validates the methodology used for the expected effectiveness.

INTRODUCTION

Emergency Brake Assist (EBA) detects the speed or the brake force at which the driver presses the brake pedal, and applies all available power boost if this speed or this force exceeds a certain threshold, considering that the driver is in an emergency situation. ABS regulation is then reached sooner. Therefore, Emergency Brake Assist can potentially reduce overall stopping distance by eliminating the delay caused by a common human tendency of not braking hard enough or soon enough. This reduction might end up with a reduced collision speed and thus with a crash avoidance or a mitigation of its consequences..

EBA is being a topic of considerable interest since the late 1990s because it might likely concern a high number of accidents. In 2004, in Europe (25 countries), more than 2 000 000 road users were slightly or seriously injured and 50 000 lost their lives (source: CARE database, 2004). It is unknown how many of these crashes resulted from lack of braking performance, i.e. EBA-pertinent crashes. The CARE database does not record such information. Consequently, the magnitude of these accidents is not accessible from European intensive databases and must be estimated from National data and accident in-depth databases. Based on French estimates, out of the 90 081 injury accidents recorded in 2003, 75 352 (83 %) involved at least a passenger car. On the other hand, Alleaume et al. showed that about 70 % of the car drivers that should have braked before the crash effectively did (Alleaume et al., 1998), the others 30 % did not. And last, Kassaagi et Perron showed that, in an emergency situation, about 50 % of the drivers reach the ABS regulation whereas 50 % would need to be helped (Kassaagi et Perron, 2001). Consequently, we estimate that approximately 0.83 * 0.7 = 0.58 (58%) of all injury accidents could be concerned with effective braking, out of these 0.58 * 0.5 = 0.29 (29 %) could be concerned with EBA, i.e. roughly 580 000 injured persons and 14 500 fatalities in Europe.

As for ESP for which the literature is now abundant (Zobel et al., 2000; Sferco et al., 2001; Langwieder et al., 2003; Aga et Okada, 2003; Tingvall et al, 2003; Unselt et al., 2004; Becker et al., 2004; Page et Cuny, 2004; Farmer, 2004; Dang, 2004), and as EBA is more and more fitted in modern cars, its effectiveness in terms of its capacity to avoid accidents and save lives must be addressed.

We have found only two published studies addressing, at least partially, this issue. Actually, they are addressing more specifically the safety benefits expected from pedestrian protection crash tests (Hannevald et Kauer, 2004, Lawrence et al., 2004). But they also state that, in any case, EBA is expected to be a good complement to these tests in preventing pedestrian and pedal cyclists injuries.

Evaluating the expected effectiveness of a safety measure (before it is brought to the market) is obviously interesting as it can eventually help stakeholders in deciding whether or not a technology is promising. That kind of evaluation is nevertheless demanding simulation techniques and sometimes heavy assumptions that can be, to a certain extent, questionable. They have to be validated. On the other hand, evaluating the observed effectiveness of a safety measure is by no means prospective but can help stakeholders in deciding the generalization of this measure if it is proved to be effective for a fleet of cars that have effectively been equipped with such a technology. Both types of evaluation are then pertinent.

Our aim, in this paper, is first to propose an evaluation of the observed effectiveness of EBA on any kind of injury accidents and not only on accidents involving vulnerable road users. But we also aim at comparing the observed and the expected effectiveness of the Emergency Brake Assist (EBA) in terms of reduction in injury accidents in France. This comparison will serve as a validation of the expected effectiveness techniques.

EXPECTED EFFECTIVENESS OF EBA

Data

This part of the study is based on French fatal road traffic accidents involving non-ABS equipped passenger cars for which the presence of skid marks (a vast majority were on a dry road surface) was reported by the Police. The database is constituted with police reports collected by the LAB in 1991. An update of this database is currently on course with the collection of fatal accidents occurred in 2002 and 2003 but was not completely available at the time of study and could not be used for our purpose.

Method

From the length of the skid marks (*db* – braking distance), the mean deceleration (*a*) and the impact speed (*Si*) estimated from vehicle photos and contents of the police reports, it is possible to calculate vehicle speed (*Sb*) at the start of the skid marks and at brake pedal action (*Sa*).

We assume that EBA can reduce brake activation time by 50%. It is then possible to calculate a new impact speed using the existing speed Sa and applying the reduced brake activation time. The new, reduced impact speed Si obtained with EBA results in, with the exception of extremely violent crashes, a decreased risk of being fatally injured for the vehicle occupants. This decreased risk is calculated, according to the different crash types considered, by using the observed fatality rates for the impact speed concerned.

This method is applied to accidents involving a vehicle which left skid marks prior to impact, as shown in the following example : in a fatal front to side collision, impact speed is estimated at 70 km/h (Si) and dry road surface skid marks prior to impact are measured to be 15 meters long (db). The following hypotheses are made:

- The braking deceleration (a) on this 15 meter distance (db) is 7 m/s² (mean value for non ABS vehicles from the 1990s).

- The brake activation time (t) is 0.7 s (mean time measured during driver behavior tests in emergency situations).

Si, Sa and total distance (*dt*) traveled between the point of impact and the vehicle's position at the time of brake activation (which is the sum of the braking distance db and the distance traveled during brake activation (*da*)) can then be calculated using the following formulae:

$$Sb^2=Si^2 + 2.a.db \qquad (1).$$

$$Sa=Sb + a/2.t \qquad (2).$$

$$dt= db + da = db + (Sa - Sb).t \qquad (3).$$

We then make the hypothesis that the time needed to reach maximized braking is halved, corresponding here to 0.35 seconds. From the speed Sa we can then calculate, with the reduced brake activation time, the new speed Sb1 corresponding to the start of maximum braking and the new position of the vehicle relative to the point of impact (which is also the new braking distance db1) and hence the new impact speed Si1, <u>using the same deceleration as before</u>.

$$Sb1=Sa - a/2.t/2 \qquad (4).$$

$$da1= (Sa - Sb1).\ t/2 \qquad (5).$$

$$db1= dt - da1 \qquad (6).$$

$$Si1^2= Sb1^2- 2.a.db1 \qquad (7).$$

In our example, the impact speed with EBA (Si1) drops to 64 km/h from 70km/h without EBA (Si) (Table 1).

Table 1.
Example of calculation of new impact speed due to EBA

Without EBA	
Impact speed (Si)	70 km/h
Braking distance (db)	15 m
Speed at start of skid marks (Sb)	87.3 km/h
Brake activation time	0,7s
Distance traveled during brake activation (da)	17,8 m
Speed at start of brake pedal action (Sa)	96.1 km/h
With EBA	
New brake activation time	0.35 s
Distance traveled during brake activation (da1)	9.1 m
Speed at start of skid marks (Sb1)	91.7 km/h
Braking distance (db1)	23.7 m
Impact speed (Si1)	64.1 km/h

Figure 1 gives the percentage (or the fatality risk) and cumulative percentage of fatalities for vehicle occupants seated on the impact side of laterally impacted vehicles in fatal front to side collisions involving two passenger cars. For collision speeds in excess of 100 km/h, the 5 km/h or 10 km/h speed decrease due to EBA will obviously have no risk reduction effect on the occupants of laterally impacted vehicles. However, if the speed decrease with EBA brings this value below 90 km/h (corresponding to between 85 and 90% of cases in this crash configuration), fatality reductions may be obtained.

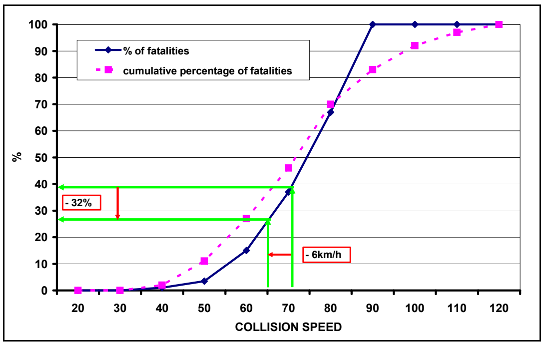

Figure 1. Distribution of fatalities and fatality risk curve according to collision speed (Source: LAB).

In the example given above, where impact speed is reduced by 6 km/h from 70 to 64 km/h, the fatality risk is reduced by 32% (38% to 26%). The same speed reduction will have a different effect on the fatality rate according to the violence of the crash, diminishing as impact speed increases, before disappearing altogether for the most serious impacts.

This method was applied case by case for each crash configuration. For a given impact speed and with the calculated reduction in this speed with EBA, the reduction (or not) of the risk of being fatally injured can be inferred.

Results

This method was applied to all accidents in which a car left skid marks before hitting an obstacle head on (other vehicle or fixed obstacle) and in which a car occupant was fatally injured.

For all fatal accident configurations (with the exception of crashes involving pedestrians and two-wheelers), frontal impact (with or without skid marks) is observed in 60% of cases (figure 2).

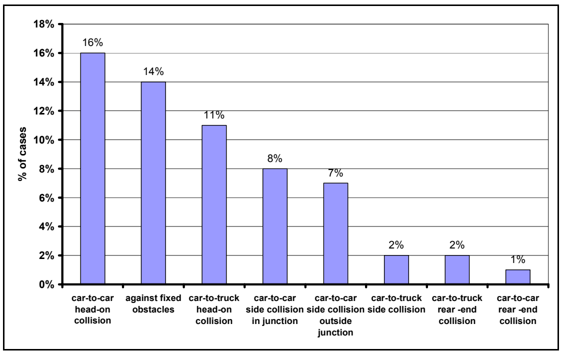

Figure 2. Distribution of fatal crashes resulting in Frontal impact (Source: LAB).

The percentage of cases occurring on dry roads varies from 44% (front to side non-junction impacts) to 81% (front to side junction impacts).

- The percentage of cases in which one or both vehicles leave skid marks on a dry road varies enormously in fatal accidents. In frontal impacts against fixed obstacles, skid marks are found in only 10% of cases whereas in front to side junction crashes involving two cars, skid marks are found in 54% of cases. This difference is mainly due to the high proportion of drivers under the influence of alcohol in fatal crashes against fixed obstacles (50%) compared to junction collisions. In head-on collisions between two cars, skid marks are observed for one vehicle in 28% of cases and for both vehicles in 3% of cases.

Of all fatal accidents involving non-ABS equipped cars, regardless of crash configuration, 11% involve skid marks on a dry road leading to a frontal impact against an obstacle (figure 3).

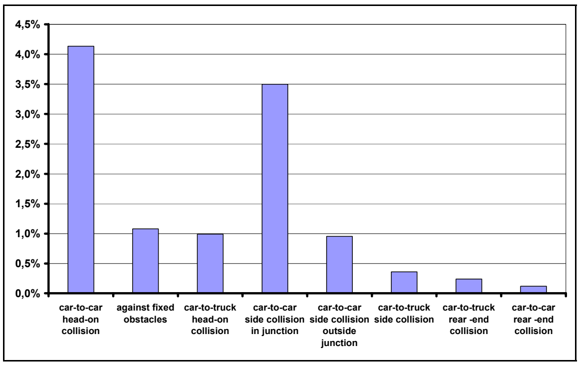

Figure 3. Distribution of fatal crashes with skid marks (Source: LAB).

Assuming that on wet road surfaces the braking distribution (without skid marks) is similar to that on dry roads, the percentage of cases where EBA would be beneficial rises from 11 to 16%.

The study was carried out on 203 fatal accidents for which vehicle photos enabled the estimation of crash violence. The potential reduction in fatalities, estimated using all the aforementioned hypotheses, is between 19% and 38%, depending on the different crash types, as shown in tables 2.

Tables 2.
Potential reduction in fatalities by EBA

Crash type	Number of cases analyzed with skid marks on dry road	% of victims saved for the analyzed cases
Front to side junction collision between two cars	66	36%
Front to side non-junction collision between two cars	17	19%
Head-on collision between two cars	98	24%
Collision against fixed obstacle	32	38%

Crash type	Proportion of all fatal accidents	Proportion of cases with braking	% of all fatalities saved
Front to side junction collision between two cars	8%	54%	1,6%
Front to side non-junction collision between two cars	7%	31%	0,4%
Head-on collision between two cars	16%	31%	1,2%
Collision against fixed obstacle	14%	10%	0,5%

We can thus estimate a reduction of between 25% and 30% of occupant fatalities for all accidents where braking is observed, which corresponds to a reduction of between 4% and 5% of the total number of fatalities in road accidents (25% to 30% of the 16% of cases involving a frontally impacted car which braked prior to impact).

Furthermore, as stated in the introduction, various studies of driver behavior tests in emergency situations with non-EBA equipped vehicles have shown that, for 100 cases where braking was observed, between 20 and 30% of drivers do not apply sufficient pressure on the brake pedal to reach the full braking potential. If, in an emergency situation, EBA reduces brake activation time and also allows maximized braking in the case of driver "failure", larger fatality reductions are possible.

Let us now suppose that, for fatal accidents involving non-ABS equipped vehicles which have not left skid marks on the road, the drivers who braked only reached a deceleration of 4 or 5 m/s^2 and that EBA would have given sustained 7 m/s^2 braking. When compared with identical fatal accident situations (impact speed and braking distance) where braking was maximized, the increased deceleration with EBA (from 4 or 5 to 7 m/s^2) would give greater reductions in impact speeds and thus a potential gain of between 45% and 75% in the number of fatalities.

Working with the hypothesis that the distribution of accident characteristics (braking distance at "reduced" deceleration) for the different collision types is similar to that for maximized braking, the potential gain in fatalities is around 2.5 to 4% (approximately a 60% gain for between 4% and 7% of the cases). **When we consider all car occupant fatalities, EBA with maintained maximum braking force during the emergency phase would reduce the number of fatalities by between 6.5 % and 9 %.**

A similar study was carried out on pedestrians who were hit and killed by cars. 25% of cases occurred on dry roads with skid marks reported. Using the measured length of the pre-crash skid marks and calculated speeds, the potential gain with **EBA for pedestrians hit and killed by all vehicle types is around 10 to 12%.**

OBSERVED EFFECTIVENESS OF EBA

Method and data

As in the ABS and ESP studies carried out in the past by Evans (1998), Kullgren et al. (1994), Tingvall et al. (2003), and Page et Cuny (2004), we used a method that refers only to accident data independent of exposure data. As in our ESP study (2004), our method consists of 3 steps:

- The identification, in the French National injury accident census (Gendarmerie Nationale only), of accident-involved cars for which EBA equipment or non-equipment is known.

- The identification of accident situations for which we can determine whether or not EBA is pertinent (e.g. EBA is pertinent for cars coming up at a junction, with the right of way, whereas another road user is pulling out of the stop whilst it is not pertinent for cars hit by the rear).

- The calculation, via a logistic regression, of the relative risk of being involved in an EBA-pertinent accident for EBA-equipped cars versus non-equipped cars, divided by the relative risk of being involved in a non EBA-pertinent accident for EBA-equipped cars versus non-equipped cars. This relative risk is currently assumed to be the best estimator of EBA effectiveness.

First step

In France, the identification of cars involved in an injury accident is not that easy. Cars are recorded in the national accident census via a code, the so-called CNIT code, which the police copies from the vehicle registration document. Unfortunately, 50 % of the codes are not directly identifiable due to errors in the completion of the statistical form. Furthermore, for the remaining 50 %, there is no bijection between the code and the determination of whether a car is or is not equipped with a given device. Consequently, instead of identifying whether a car, selected from the accident-involved cars is EBA-equipped, we had to choose a set of cars for which the information was easily accessible and then identify these cars in the accidents according to their make and model, which is easier via the CNIT. This data limitation led us to retain only two makes and models: the Renault Laguna and the Peugeot 406. There are two versions of the Laguna. The Laguna 1, was produced in the late 1990s and early 2000s without EBA. In January 2001, Renault launched the Laguna 2, with EBA as standard equipment. It was then possible to distinguish the two Lagunas in the accident census using the CNIT (make and model) and the first registration date. Regarding the Peugeot 406, EBA has been fitted on the car since 2000.

We selected a sample of 2061 Renault Laguna and Peugeot 406 cars involved in injury accidents occurring from January 2000 up to mid 2004 in France. These are all the Lagunas and 406 we were able to identify in the national accident census. We therefore had to assume that the residual unidentifiable chosen cars, due to errors in typing the car identification code, were randomly distributed among EBA-pertinent and non-pertinent accidents. These accidents are assumed to be very few as we did our utmost to identify all the Lagunas and 406.

Second step

The method requires the allocation of accidents into EBA-pertinent and non-pertinent accidents. We took this information from the national census by combining several variables such *pre-accidental maneuver*, *number of vehicles involved*, and *type of obstacle*. We ended up with a list of 34 accidental situations (table 3). We were not actually interested in the accidents per se, but rather the accident situations, the difference being that the accident situation is linked to a driver-vehicle unit (Page et al., 2004). A single vehicle accident has a single situation. In a two-vehicle accident, each driver has a specific accident situation corresponding to the circumstances in which he finds himself. For example in a crossing accident at a junction, the first situation corresponds to the user who pulls out of the intersection after stopping at a stop sign. The second situation corresponds to the driver with right of way who has to cope with a vehicle suddenly crossing his carriageway. This is the reason why we chose to build an accident situation list rather than an accident list (Table 3).

Table 3.
Accident situations and
EBA pertinent-situations

Accident situation	Main relevance
Loss of control and guidance problem	
Single car accident. Loss of control on a straight road	EBA pertinent if frontal impact
Loss of control on a straight road. Collision with an opponent	EBA pertinent
Single car accident. Loss of control in a bend	EBA pertinent if frontal impact
Loss of control in a bend. Collision with an opponent	EBA pertinent
Single car accident. Loss of control at a junction	EBA pertinent if frontal impact
Accident involving a pedestrian	
Car confronted to a pedestrian walking, playing, running, along the roadway, crossing the road or hidden by an obstacle	EBA pertinent
Car moving backward and hurting a pedestrian	
Car-to-vehicle accident out of junctions	
Adverse to the vehicle that looses control in a bend	EBA-pertinent
Adverse to the vehicle that looses control on a straight road	EBA-pertinent
Rear-end collision. Hitting car	EBA-pertinent
Rear-end collision. Hit car	

Car changing his lane	EBA-pertinent
Car facing an obstacle	
Overtaking car	EBA-pertinent
Parking or parked car	
Car making a left turn	
Car in which an occupant opens his door	
Car making a U turn or crossing the road	
Car-to-vehicle accidents at junctions	
Car driver in insertion or turning left or right in around about	
Car driver confronted to a vehicle in insertion or turning left or right in a round about	EBA-pertinent
Crossroads. Driver at fault going straight ahead	
Crossroads. Driver not at fault going straight ahead confronted to driver at fault going straight ahead in the perpendicular direction	EBA-pertinent
Crossroads. Driver going straight ahead confronted to driver at fault turning left or right to the perpendicular road	EBA-pertinent
Crossroads. Driver turning left or right	
Same road. Different directions. Car driver at fault confronted to not at fault driver going straight ahead	EBA-pertinent
Same road. Different directions. Car driver not at fault confronted to at fault driver going straight ahead	EBA-pertinent
Same road. Different directions. Car driver confronted to a driver turning left or right	EBA-pertinent
Same road. Different directions. Car driver turning left or right confronted to a driver going straight ahead	
Same road. Same directions. Car at fault hitting another vehicle going straight ahead	EBA-pertinent
Same road. Same directions. Car driver not at fault going straight ahead hit by another vehicle	
Same road. Same directions. Car driver hitting another vehicle turning left or right	EBA-pertinent
Same road. Same directions. Car driver turning left or right hit by another vehicle	
Car driver not at fault hitting another vehicle making a U turn	EBA-pertinent

For each accident situation, we stated whether it was EBA-pertinent or ESP-pertinent, or neither ESP nor EBA pertinent. We made this distribution on the basis of our LAB expertise with respect to in-depth analysis of accidents investigated on-scene.

EBA-pertinent accidents belong to one of the four following accident groups:

- Single car accidents with a frontal impact against a fixed obstacle. Single car accidents with roll over were assumed to be alcohol or drowsiness related and in those cases, braking doesn't appear to be relevant.

- Accidents involving a pedestrian, except those where the car was moving backward.

- Car-to-vehicle accidents situations where the collision is supposed to be frontal. The hitting cars involved in a rear end collision are also part of the EBA-pertinent accident situation.

- Car-to-vehicle accidents situations occurring at a junction mainly where a right-of-way car is confronted to an at-fault car going straight ahead or turning left/right, whatever the cars are on the same road or not.

There are two kinds of Non EBA-pertinent accidents: those for which ESP is pertinent and those for which it is not. Because ESP was the other main active safety innovation on Laguna 2 compared to Laguna 1 and because the Peugeot 406 taken into consideration in the analysis are not ESP-fitted, integrating ESP-pertinent accidents in the sample of non EBA-pertinent situations could have generated a bias in the estimation of EBA effectiveness.

We finally decided to limit Non-EBA pertinent accidents to a subset of accidents for which ESP does not apply. Furthermore Non-EBA pertinent accident situations, such as U-turn, which concern only a small number of drivers and which were found to be quite negligible have not been taken into account in the analysis.

The influence of passive safety enhancements will be covered in the discussion section.

Third step

Effectiveness is highly dependent on the effectiveness indicator. We must therefore choose it carefully, according to available data. Concretely, in our study, the effectiveness E is estimated by (8).

$$E = 1\text{-}OR = 1 - [(A*D) / (B*C)] \qquad (8).$$

With OR, the odds ratio, A, B, C, D being the numbers of accidents with respect to EBA, as explained in table 4.

Table 4.
Distribution of accidents for the calculation of the odds ratio (OR)

	EBA-equipped cars	Non EBA-equipped cars
EBA-pertinent accidents	A	B
Non EBA-pertinent accidents	C	D

After several assumptions, and noticeably the assumption that the accident sample is drawn randomly from the accident census, we can show that (e.g. Hautzinger, 2003) :

$$OR = \frac{R_{AS}}{R_{A}} = \frac{\dfrac{R_{AS-S}}{R_{AS-NS}}}{\dfrac{R_{ANS-S}}{R_{ANS-NS}}} \qquad (9).$$

With:

- Ras-s is the risk of being involved in an accident where EBA is assumed to be pertinent for an EBA-equipped car.

- Ras-ns is the risk of being involved in an accident where EBA is assumed to be pertinent for a non EBA-equipped car.

- Rans-s is the risk of being involved in an accident where EBA is assumed not to be pertinent for an EBA-equipped car.

- Rans-ns is the risk of being involved in an accident where EBA is assumed not to be pertinent for a non EBA-equipped car.

In other words, the odds ratio OR, formulated by (9), has a comprehensible interpretation. Assuming that EBA has no effect at all on accidents in which it is not assumed to be pertinent, (Rans-s / Rans-ns) is assumed to be equal to 1. This commonly supposes no driver adaptation to EBA with for example higher risk taking or higher driving speed. Consequently, the odds ratio measures the relative risk of being involved in an EBA accident for EBA-equipped versus non-equipped cars.

In practice, table 4 only enables the calculation of the crude odds ratio, irrespective of potential other explanatory variables. The adjusted odds ratio is then estimated via a logistic regression. It enables confounders such as: Driver age and gender; Vehicle age and Year of accident; Pavement status (whether the pavement was dry or wet); Location of accident … to be taken into consideration. No reliable information about seat belt use was available.

Results

Simple statistics

The limitation of the accident situations to those related specifically to EBA and those related to neither ESP nor EBA lowered the number of situations to be considered. Selections were also applied to retain only ABS-fitted cars. Accidents occurring on motorways were excluded from the sample. We finally retained 917 out of the initial 2061 cars. Unfortunately, the small sample size can generate unstable coefficients in logistic regression and/or large confidence interval of the odds ratio. We'll come back to this issue in the discussion section.

Tables 5 to 10 show the distributions of each explanatory variable. For most of them, the distribution does not show cells sufficiently unbalanced to disturb the analysis.

Table 5.
Location of accidents according to EBA status

Location	EBA not fitted in the car	EBA fitted in the car	Total
inside urban areas	143 (26%)	106 (29%)	249 (27%)
outside urban areas	410 (74%)	258 (71%)	668 (73%)
Total	553	364	917

Table 6.
Pavement status according to EBA status

Pavement status	EBA not fitted in the car	EBA fitted in the car	Total
Dry	127 (23%)	74 (20%)	201 (22%)
Wet	426 (77%)	290 (80%)	716 (78%)
Total	553	364	917

Table 7.
Gender of the driver according to EBA status

Gender	EBA not fitted in the car	EBA fitted in the car	Total
Female	116 (21%)	73 (20%)	189 (21%)
Male	437 (79%)	291 (80%)	728 (80%)
Total	553	364	917

Table 8.
Driver age according to EBA status

Driver age	EBA not fitted in the car	EBA fitted in the car	Total
18-24 years old	43 (8 %)	19 (6%)	62 (7%)
25-34 years old	115 (21%)	55 (15%)	170 (19%)
35-44 years old	113 (20%)	100 (27%)	213 (23%)
45-54 years old	127 (23%)	80 (22%)	207 (23%)
55-64 years old	82 (15%)	59 (16%)	141 (15%)
65 years old and over	73 (13%)	51 (14%)	124 (13%)
Total	553	364	917

Table 9.
Vehicle age according to EBA status

Vehicle age	EBA not fitted in the car	EBA fitted in the car	Total
Less than 1 year old	53 (10%)	187 (51%)	240 (26%)
1 year old	115 (21%)	110 (30%)	225 (24%)
2 years old	161 (29%)	46 (13%)	207 (23%)
3 years old	108 (19%)	19 (5%)	127 (14%)
4 years old	78 (14%)	2 (1%)	79 (9%)
5 years old and over	38 (7%)	-	38 (4%)
Total	553	364	917

Table 10.
Year of accident occurrence
according to EBA status

Year of accident	EBA not fitted in the car	EBA fitted in the car	Total
2000	178 (32%)	46 (13 %)	224 (24%)
2001	156 (28%)	97 (27%)	253 (28%)
2002	151 (28%)	117 (32%)	268 (29%)
2003	45 (8%)	67 (18%)	112 (12%)
January-June 2004	23 (4%)	37 (10%)	60 (7%)
Total	553	364	917

Tables 9 and 10 show an evidence of unequal distribution of EBA status according to the age of the vehicle and the year of the accident. The EBA fitted cars are newer than the cars not fitted with EBA. This is not surprising, EBA being a new system not fitted on car before the year model 2000 or 2001 according the model of the car.

It is then expected that Year of accident and Vehicle age would be significant explanatory variables in the regression.

Crude odds ratio

Table 11 displays the repartition of accident situations according to EBA equipment.

Table 11.
EBA status of cars according to their involvement in EBA pertinent situations

	EBA fitted on the car	EBA not fitted on the car	Total
EBA pertinent accident situations	277	436	713
Non EBA pertinent accident situations	87	117	204
Total	364	553	917

From this table, we can calculate the crude odds ratio, OR = (277*117) / (436*87) = 0.85. We can also calculate the confidence interval of the odds ratio [0.62;1.16]. The effectiveness is then calculated by (8): 1-0.85=15 %. The risk of being involved in an EBA-pertinent accident for EBA-equipped cars is 15 % lower than the same risk for non-equipped cars. However, as expected, this result is not statistically significant because of the small sample size.

This first result has to be validated by a more sophisticated analysis taking possible confounders into consideration. This was done using logistic regression.

Logistic Regression

Logistic regression enables the estimation of the adjusted odds ratio and its confidence limits. The crude odds ratio is then *adjusted* by the values of the explanatory variables. The variable of greatest interest is, needless to say, the presence of EBA in the car. The other variables are taken into consideration as confounders and also to counter the potential bias due to the limitation of data.

Table 12 presents the results of the logistic regression. It should be remembered that logistic regression requires the fixing of a reference point for each variable (i.e. one of the values of the variable), which is then used to explain the results across the entire variable. The reference points for each explanatory dimension are highlighted *in italics* in Table 12.

Table 12.
Results of the Logistic Regression

Number of observations = 917
EBA-pertinent cases : 713 / Non EBA-pertinent cases : 204
AIC : 967 --- SC : 1064 --- -2LogL : 927

	Odds ratio	min	max
EBA			
EBA fitted on the car	**0.81**	**0.48**	**1.38**
EBA not fitted on the car	-	-	-
Driver age			
18-24 years old	2.36	1.04	5.34
25-34 years old	1.59	0.95	2.67
35-44 years old	-	-	-
45-54 years old	1.36	0.84	2.18
55-64 years old	0.95	0.58	1.57
65 years old and over	0.86	0.51	1.45
Gender			
Female	0.76	0.51	1.13
Male	-	-	-
Car model			
Peugeot 406	1.24	0.84	1.77
Renault Laguna	-	-	-
Vehicle age			
less than 1 year old	-	-	-
1 year old	1.18	0.72	1.95
2 years old	1.18	0.66	2.11
3 years old	0.82	0.41	1.66
4 years old	0.72	0.30	1.71
5 years old and over	0.72	0.22	2.33
State of the pavement			
Dry	-	-	-
Wet	1.44	0.94	2.20
Location			
Inside urban areas	-	-	-
Outside urban areas	2.05	1.46	2.88
Year of the accident			
2000	-	-	-
2001	0.80	0.49	1.32
2002	1.10	0.63	1.93
2003	1.40	0.65	2.98
January - June 2004	0.76	0.31	1.87

Percent concordant pairs : 64.6 Somers'D=0.3 Gamma=0.3 Tau-a=0.1 c=0.65

The adjusted odds ratio correspondent to EBA is estimated 0.81 and its confidence interval [0.48;1.38]. It is not very different from the crude odds ratio. **Based on the crude and on the adjusted odds ratio, we can then confirm that EBA is apparently effective in reducing the risk of being involved in an EBA-pertinent accident for EBA-equipped cars versus non-equipped cars. Effectiveness is estimated to be 19 % of pertinent crashes. However, this estimation is not statistically significant** and holds only for our selection of cars: the Renault Laguna and the Peugeot 406.

DISCUSSION

Our aim, in this paper, was to propose an evaluation of the observed effectiveness of EBA on any kind of injury accidents and to compare the observed and the expected effectiveness of the

Emergency Brake Assist (EBA) in terms of reduction in injury accidents in France.

To estimate EBA expected effectiveness, we selected a sample of fatal accidents involving a passenger car occurred in France in 1991 for which we knew the impact speed, the initial speed, and the braking distance before the crash. Applying some assumptions about the EBA functioning (reduction in brake activation time, sustained braking, non behavioral adaptation), it is possible to estimate the reduced crash speed due to EBA. Then the use of fatality risk curves allows estimating the reduction in fatalities due to the reduction in collision speed for a series of types of collisions. Our result states that EBA with maintained maximum braking force during the emergency phase would reduce the number of car occupant fatalities by between 6.5% and 9% and pedestrian fatalities by about 10 % to 12%.

To estimate EBA observed effectiveness on all kind of accidents, we used a method that only refers to accident data irrespective of exposure data. The method consisted of 3 steps. First we selected makes and models of cars involved in injury accidents in France, from January 2000 to June 2004, for which the determination of whether or not the car is fitted with EBA is possible. It led us to conserve only Renault Laguna cars and Peugeot 406.

Then we identified 34 various accident situations and also split these accident situations into four groups according to whether they were ESP-pertinent, EBA-pertinent, ESP and EBA-pertinent or neither ESP nor EBA-pertinent. The identification of ESP as a potential avoidance or injury mitigation maneuver is necessary because the Laguna 2 are also equipped with ESP that could also be effective and act in combination with EBA. As we wished to measure only the effectiveness of EBA, we had to withdraw the ESP-pertinent accident situations from the analysis. Finally, we ended up with a sample of 917 accident situations, 713 being EBA-pertinent and 204 being non EBA-pertinent.

The estimation of the effectiveness of EBA was carried out using the adjusted odds ratio, which can be interpreted as the relative risk of being involved in an EBA-pertinent accident for a car fitted with EBA versus a car non fitted with EBA, divided by the relative risk of being involved in a non EBA-pertinent accident for a car fitted with EBA versus a car not fitted with EBA. This relative risk is assumed to be the best estimator of the EBA effectiveness.

The analysis focused on injury accidents only (injury accidents and fatal accidents combined). Braking pertinent accidents account for approximately 60 % of injury accidents in France. As the expected effectiveness is 19 % of pertinent crashes, the overall effectiveness, if 100 % of the fleet would be equipped with EBA, would be a 11 % reduction in overall injuries.

A series of implicit or explicit assumptions were made during the course of the evaluation and a few difficulties also arose from the data and method.

- The effectiveness indicator, i.e. the odds ratio, supposes that there is no driver adaptation to EBA, and especially that the non EBA-pertinent accidents are not affected by the presence of EBA.

- The effectiveness depends heavily on the breakdown of accident situations into EBA-pertinent and non-pertinent situations. Apart from classification errors due to the use of imprecise national accident census, we took care to withdraw accident situations that could be pertinent to another safety system such as ESP. On the other hand, this resulted in a small accident situations sample that reduced the stability and the accuracy of the effectiveness estimation (large confidence interval). A larger sample should be sought. In time, the number of identifiable cars in the national census will grow and we will be able to update our result.

- The effectiveness holds only for two makes and model of the M2 segment: the Renault Laguna and the Peugeot 406. This does not mean that the effectiveness holds for other cars and other segments.

We should seek for ways to integrate more cars into the sample while taking into consideration the differences in car makes and models. Once again, the increase in sample size and the variety of identifiable cars could be of great help in the future.

- That raises another crucial issue. The cars that we have compared, although identical in make and model for two of them, are completely different thanks to the dramatic improvements on the Laguna 2 concerning active and passive safety. It is natural (and proven) to consider that the likelihood of sustaining injuries in Laguna 2 is dramatically reduced compared to Laguna 1. The only problem that arises is to state whether or not this reduction is identical for EBA-pertinent and non-pertinent accidents. If it is the case, no bias is generated in the analysis. We haven't tested this hypothesis so far. We implicitly considered that it is true. Further work should address this important matter, especially regarding the types of impact subsequent to EBA-pertinent or not pertinent accident situations.

- EBA systems fitted in cars are not identical. EBA configuration depends on the suppliers as well as the instructions given to suppliers by the car manufacturers. It is impossible to state from our analysis which EBA system provides better results.
- We evaluated the short-term effect of EBA. The long-term effect might be different as drivers increase their awareness of EBA benefits. This could generate a driver adaptation and then a likely reduction of the EBA effect. Once again, an update of the study within a few years would eventually highlight this issue.

- As our sample size is small, we haven't been able to estimate the effectiveness of EBA for different car sizes and different weather conditions. We highlighted an overall effect while being unable to attribute this effect to certain types of cars or certain accident situations.

Now, we must answer the second of our questions: are expected and observed effectiveness of EBA consistent? The data available and the methodology choices are of course different: on one hand, we estimated a reduction in fatalities with simulation techniques and fatality risk curves, on the other hand, we used epidemiological techniques able to estimate a reduction in all injury accidents (and not only fatal, the sample size would have been too small). Assumptions are of course needed in both cases, and especially the absence of driver behavior adaptation that surely holds true at least in the short term. We ended up with estimates which are rather close but apply to accidents with different severities. The drop in fatalities was however expected to be higher than the drop in injury accidents as the fatality curve shows up promising effectiveness at high collision speeds (but less than 90 km/h). This is certainly due to the reduction of our sample to accidents for which skid marks were reported by the police. An extension of accidents for which braking could have been suspected by the police would have resulted in an higher effectiveness (but this information is not available).

In any case, EBA (and also ESP for which Sferco et al. anticipated in 2001 a high potential confirmed in 2003 and 2004 by epidemiological studies) efficiencies are very high and as the equipment rate is growing rapidly, these systems will definitely be a major contribution to further reductions in the road toll. They have already proven effectiveness and should be considered as major safety devices in the coming years, especially in combination with passive safety devices, for example pretensioners, load limiters and airbags, which have also proven a very high efficiency (-80 % of fatal thoracic injuries) and with other active safety devices.

From a purely research perspective, our ambition is now to go beyond the evaluation of one system independently of the others, to overcome the methodological difficulties and assess the effectiveness of passive and active safety systems acting in combination with one another.

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INFLUENCE OF CRASH SEVERITY ON VARIOUS WHIPLASH INJURY SYMPTOMS: A STUDY BASED ON REAL-LIFE REAR-END CRASHES WITH RECORDED CRASH PULSES

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ABSTRACT

Whiplash injuries resulting from rear impacts are one of the most important injury categories with regard to long-term consequences. Most rear impacts lead to no injury or to symptoms that are temporary. Impacts where the duration of symptoms differs need to be separated in analyses in order to isolate representative rear impact conditions in which more long-lasting whiplash injuries occur.

The aim of this study was to evaluate the influence of crash severity on symptoms duration of Whiplash Associated Disorders, WAD, separated for males and females, and for different grades of WAD (1-3) according to Quebec Task Force.

Since 1995, approximately 60 000 vehicles on the Swedish market have been equipped with crash pulse recorders measuring the acceleration time history in rear impacts. With the inclusion criteria of single rear-end crashes with a recorded crash pulse, and front seat occupants with no previous long-term AIS1 neck injury, 207 front-seat occupants in 150 crashes remained to be analyzed in this study, where the change of velocity and the crash pulse were measured.

A correlation was found between duration of symptoms and crash severity measured as mean acceleration and change of velocity. The risk of WAD symptoms for more than one month was found to be 20% at a change of velocity of approximately 8 km/h and at a mean acceleration approximately 5 g. A correlation was also found between grades of WAD and crash severity measured as mean acceleration and change of velocity. Out of all crashes with a recorded crash pulse only one out of 207 occupants sustained WAD symptoms for more than one month at mean acceleration below 3.0 g. Given the same crash severity, females had a higher risk of initial WAD symptoms than males.

INTRODUCTION

In the last decade some studies have been presented showing influence of duration of symptoms on crash severity in rear impacts. Regarding initial neck symptoms, the following studies describe the impact severity when no injury or short-term consequences occur. Hell and Langwieder (1998) found that most occupants sustained symptoms in impacts where the change of velocity was 10-15 km/h. Mc Connell et al (1995) performed low-speed rear impacts with seven male volunteers, with velocity changes of up to 10.9 km/h. None of the volunteers reported whiplash symptoms after a few days. Ono and Kaneoka (1997) and Siegmund et al (1997) found similar results from volunteer tests. In another study with volunteers (Eichberger et al 1996), where the sled impact velocities were 8-11 km/h and the mean deceleration 2.5g, the volunteers suffered whiplash symptoms for approximately 24 hours.

The influence of crash severity on more long-lasting symptoms is rarely studied. Based on a follow-up questionnaire with 65% answering frequency, Jakobsson (2004) found that 21% sustained long-term consequences in rear impacts with Volvo cars where the impact severity was defined as moderate. The impact severity "moderate" represented impacts in which the WHIPS recliner would have been activated. When the Volvo data was grouped according to whether the impact area involved rear members (reflecting a probable increase in the crash pulse amplitude) there was a tendency of higher initial AIS 1 neck injury risk for those with engaged rear members as compared to those with impact area outside rear members. Another study that tried to reflect the influence of the crash pulse on the injury outcome was Krafft (1998). It was found a relationship between the crash pulse on the neck injury risk in rear impacts, by showing that a longitudinally mounted engine (compared with a transversal one) in the striking car also increased the risk of long-term consequences in the struck car.

The influence of the crash characteristics on whiplash injury based on crash recording in real life rear impacts, has been presented earlier (see for example Krafft et al. 2002, and Kullgren et al. 2003). In these studies it was found that for the vast majority occupants that sustained symptoms for more than one month, mean acceleration was more than 4.5g and change of velocity higher than 10 km/h. Mean acceleration was found to be the best candidate to predict duration of symptoms compared to change of velocity and peak acceleration.

There is a need to further study the influence of crash pulse characteristics on AIS1 neck injury risks in rear impacts, both regarding kind of whiplash symptoms and duration of these symptoms. Furthermore, there is a need to separate the injury risk for gender. Several studies have shown that whiplash injuries occur more frequently among females than males (Berglund 2001, Maag et al 1993). However, there is always a problem with real-life data to handle the exposure problem concerning crash severity. With crash recorder data the outcome will be controlled for crash severity.

Based on more data from crash recorded rear impacts, the aim of this study was to evaluate:

- the influence of crash severity on the duration of symptoms of AIS1 neck injury in rear impacts.
- the influence of crash severity on whiplash symptoms classified according to Quebec Task Force.
- the influence of crash severity on the neck injury risk separated for males and females.

MATERIAL AND METHODS

Since 1995 crash recorders have been mounted under the driver or front passenger seat to document rear impacts in 60,000 vehicles in eight different car models of the same make. The models do not share the same seat type but are not separated in the analysis. All rear impacts since 1995 were reported to the insurance company Folksam, irrespective of repair cost. The inclusion criteria were single rear-end crashes with a recorded crash pulse, and front seat occupants with no previous long-term AIS1 neck injury. Out of 254 reported crashes, 150 crash pulses were recorded, in where 207 front seat occupants were involved. Out of these, 90 were men, 105 women, and in 12 cases the sex was unknown (10 were front seat passengers that were uninjured and 2 were drivers with initial symptoms but recovering within one month).

The remaining 104 rear impacts the trigger level of the CPR was not reached. In these crashes no acceleration pulse was measured, and they were not included in the analysis of this study.

Injury details were obtained from medical notes and interviews with the occupants. The interviewer had no information about the crash severity in each individual case. A follow-up of possible medical symptoms was carried out at least six months after the collision. The questionnaire of symptoms and the process of defining injury severity were structured in co-operation with a medical doctor. The symptoms noted were those associated with pain, stiffness and musculoskeletal signs, and with neurological symptoms, such as numbness. The duration of symptoms was defined as follow: no injury, symptoms less than one month, symptoms between one and six months, and for more than 6 months. The symptoms were also defined according to the Quebec Task Force on Whiplash associated Disorders (Spitzer et al. 1995).

WAD 0 – No complaints
WAD 1 – Neck complaints: pain, stiffness, or tenderness only
WAD 2 – Neck complaints and musculoskeletal signs
WAD 3 – Neck complaint and neurological signs

The Crash Pulse Recorder measures the acceleration time history in the principal direction of force during the time of impact. The crash pulses were filtered at approximately 100 Hz. The crash pulse recorder (CPR) has a trigger level of approximately 3g.

The development and accuracy of the CPR is described by Kullgren et al. (1995). Change of velocity and mean and peak accelerations were calculated from the crash pulse.

To visualize the influence of impact severity on risk of WAD, two kinds of plots were used. Injury risk versus impact severity was calculated for occupants with different duration of symptoms and for occupants classified in different grades of WAD. Injury risk was calculated as the proportion of injured occupants in each interval of impact severity. Intervals with less than 3 observations were excluded in the plots. In order not to force the injury risk curve into a specific shape, no mathematical function was used. The risk values for all intervals were connected using “smooth” curve fit in the software KaleidaGraph (Synergy software 2000).

In the second type, injury status in terms of duration of symptoms and grades of WAD, was, for all occupants, correlated with both change of velocity and mean acceleration in one plot.

RESULTS

Out of 207 front seat occupants in 150 rear impacts where the acceleration pulse was measured, 132 were uninjured, 75 reported initial symptoms whereof 51 recovered within a month, 7 sustained symptoms between one and six months and 17 had symptoms for more than six months after the impact. Out of the 207 occupants 49 were classified as WAD Grade 1, 20 as Grade 2 and 6 as Grade 3. In Table 1 the occupants are also divided according to seating position.

Table 1. Numbers of drivers and front seat passengers with different duration of symptoms and grades of WAD.

	Driver	FSP	Total
All	150	57	207
Uninjured	98	34	132
Symptoms < 1m	34	17	51
1m<symptoms<6m	7**	0	7
Symptoms > 6m	11*	6*	17
WAD grade 1	31	18	49
WAD grade 2	17	3	20
WAD grade 3	4	2	6

* One lumbar spine injury
** Two thoracic spine injuries

The occupants were also separated according to gender and seating positions. Table 2, 3 and 4 presents the number of male and female drivers, fronts seat passengers and front seat occupants together. It was found that the average impact severity was significantly higher for those occupants, both males and females, with symptoms for more than one month compared to the uninjured occupants.

Table 2. Numbers of male and female drivers and front seat passengers and average Δv and mean acceleration for different symptom durations.

	Males			Females		
	N	Δv	Mean acc.	N	Δv	Mean acc.
All	90	10.6	3.7	105	10.4	3.7
Uninj.	64	9.0	3.4	58	9.0	3.5
< 1 m	17	12.5	4.2	32	9.6	3.6
1-6 m	2	13.5	4.6	5	17.3	5.6
>6 m	7	19.9	5.2	10	17.6	5.1

Table 3. Numbers of male and female drivers and average Δv and mean acceleration for different symptom durations.

	Males			Females		
	N	Δv	Mean acc.	N	Δv	Mean acc.
All	75	10.3	3.7	73	10.2	3.6
Uninj.	55	9.2	3.4	43	8.9	3.3
< 1 m	13	12.3	4.2	19	8.9	3.5
1-6 m	2	13.5	4.6	5	17.3	5.6
>6 m	5	15.7	5.0	6	18.3	4.8

Table 4. Numbers of male and female front seat passengers and average Δv and mean acceleration for different symptom durations.

	Males			Females		
	N	Δv	Mean acc.	N	Δv	Mean acc.
All	15	12.3	3.8	32	10.9	4.0
Uninj.	9	7.8	3.2	15	9.4	3.9
< 1 m	4	13.2	4.2	13	10.8	3.7
1-6 m	0	-	-	0	-	-
>6 m	2	30.4	5.9	4	16.8	5.3

In the 104 rear impacts where the trigger level of the CPR was not reached and no crash pulse was recorded, one of the occupants had symptoms for more than six months, and one had symptoms between one and six months. None of the occupants was classified as WAD grade 3, but two as WAD grade 2. All other occupants were either uninjured or reported initial symptoms, but recovered within a month. As the trigger level of the CPR is approximately 3 g, the mean acceleration must in these crashes be below 3 g.

The numbers of occupants with different duration of symptoms and those classified in different grades of WAD, is presented in intervals of impact severity in Figures 1 to 4. The information in these figures is used to calculate the injury risk in each interval of impact severity, presented in Figures 5 to 8. In the interval 5-10 km/h 7 occupants had symptoms for more than 1 month. Out of these occupants 6 had a mean acceleration above 3.3 g, and all had a mean acceleration above 2.8g, see Figure 9. From the information in Figures, 1, 2 and 9 it appears like mean acceleration to a higher extent than change of velocity influences risk of WAD.

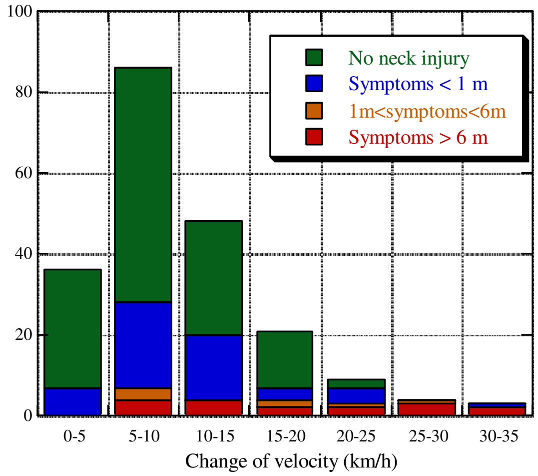

Figure 1. Numbers of injured and uninjured occupants in intervals of change of velocity.

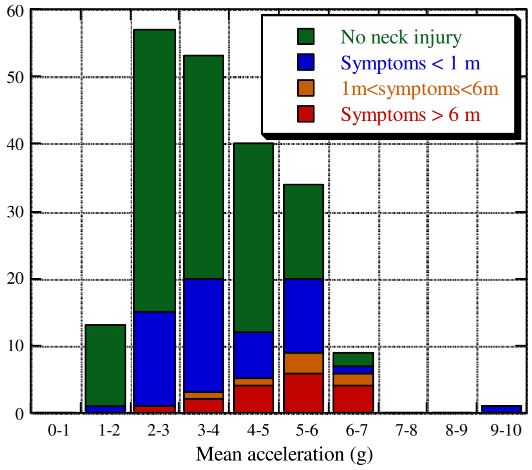

Figure 2. Numbers of injured and uninjured occupants in intervals of mean acceleration.

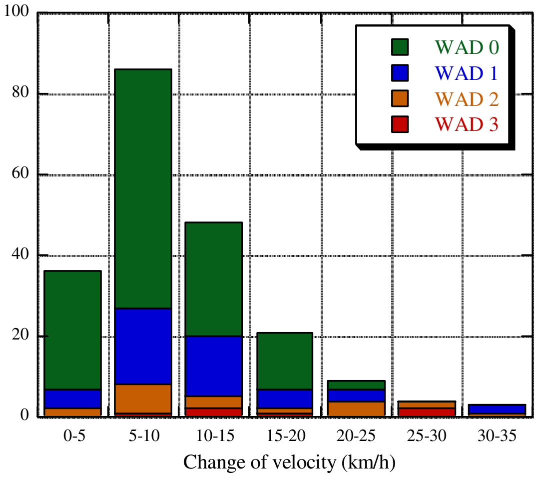

Figure 3. Numbers of injured and uninjured occupants in intervals of change of velocity.

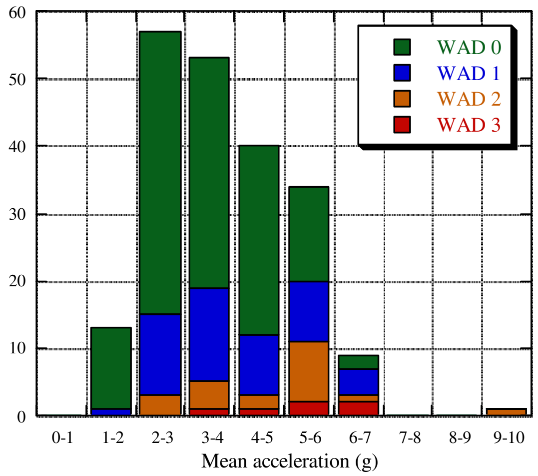

Figure 4. Numbers of injured and uninjured occupants in intervals of mean acceleration.

A correlation between injury risk and change of velocity was found for initial and more long lasting symptoms, see Figure 5. At a change of velocity above 20 km/h the risk of long lasting symptoms increase with a high rate. Risk of symptoms for more than one month was found to be 20% at approximately 18 km/h.

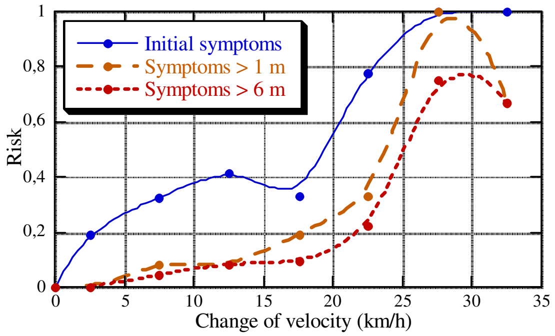

Figure 5. Injury risk in intervals of change of velocity for occupants with initial and long-term symptoms.

Injury risk and mean acceleration was also found to be correlated, see Figure 6. The risk of symptoms for more than one month was 20% at a mean acceleration of 5 g. Above 5 g the risk increases with a higher rate than below 5 g. In Figure 6 the occupant with initial symptoms at a mean acceleration of 9.1 g is not included.

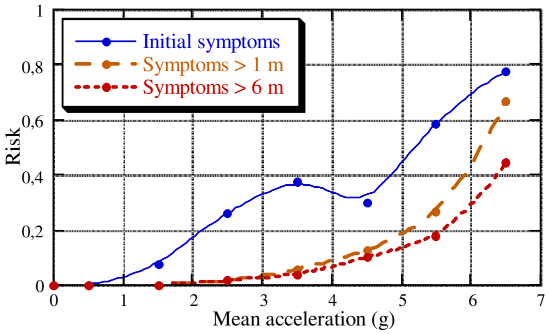

Figure 6. Injury risk in intervals of mean acceleration for occupants with initial and long-term symptoms.

Increased impact severity, both in terms of change of velocity and mean acceleration, was found to increase the risk of WAD symptoms, see figures 7 and 8. Furthermore, the risk of neurological symptoms of WAD, grade 3, was found to be lower than for grade 1 and 2 for the whole range of both change of velocity and mean acceleration. The risk of symptoms of grade 2 appears to increase above 17 km/h or 4.5 g.

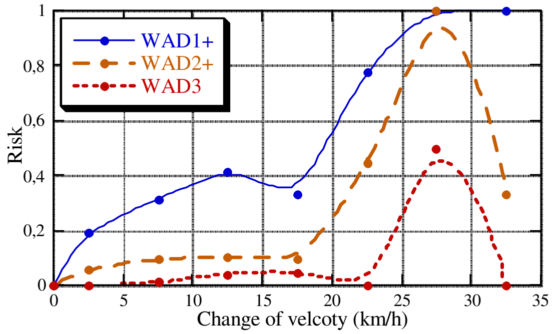

Figure 7. Injury risk in intervals of change of velocity for occupants classified as different grades of WAD.

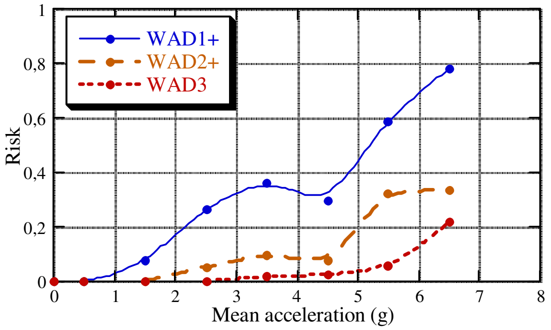

Figure 8. Injury risk in intervals of mean acceleration for occupants classified as different grades of WAD.

Only one of the 24 occupants with symptoms more than one month had a mean acceleration below 3 g (2.8 g). All other occupants with symptoms for more than one month had a mean acceleration above 3.3 g, see Figure 7.

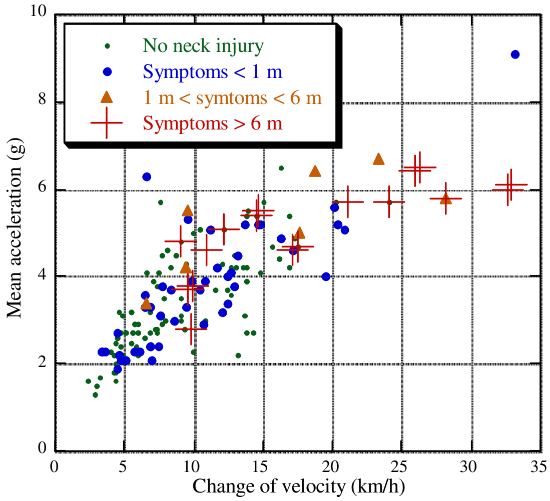

Figure 9. Change of velocity versus mean acceleration for occupants with different duration of symptoms.

Most occupants defined as WAD grade 3 had a mean acceleration above 4 g, see Figure 10. Occupants with a WAD defined as grade 2 seem to occur in a wide range of both change of velocity and mean acceleration.

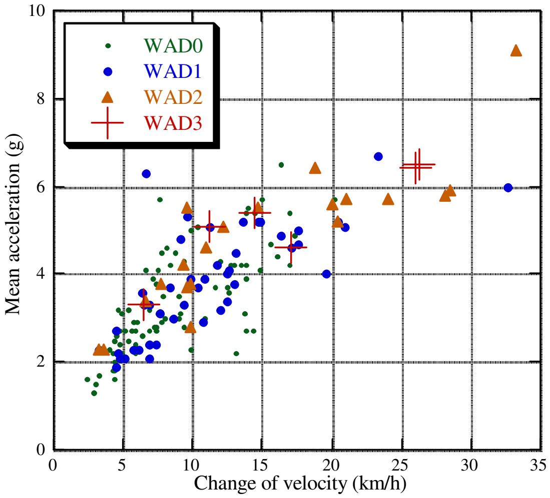

Figure 10. Change of velocity versus mean acceleration for occupants classified in various grades of WAD.

The risk of initial symptoms was found to be higher for females than males, both regarding change of velocity and mean acceleration, see Figures 11 and 12. Females appear to more often sustain initial symptoms at lower impact severity than males, especially regarding mean acceleration.

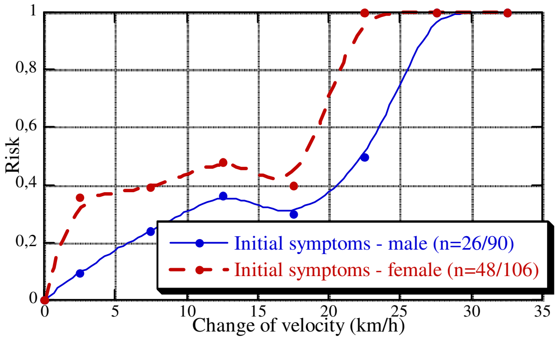

Figure 11. Risk of initial symptoms in intervals of change of velocity for males and females.

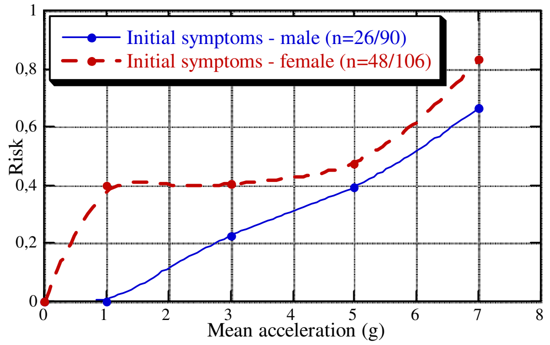

Figure 12. Risk of initial symptoms in intervals of mean acceleration for males and females.

DISCUSSION

Knowledge about the correlation between crash severity and injury risk is essential to more effectively prevent injuries in car crashes. The data used in this study mean a unique opportunity to analyze how acceleration influences the risk of whiplash injury. In a previous study (Krafft et al 2002) the crash pulses from 66 rear impacts have been presented, but in this study the data is more comprehensive and therefore more reliable conclusions can be drawn. The combination of valid and reliable impact severity measurements and prognostic injury data made it possible to study relations that would otherwise be difficult to obtain.

It is not possible to objectively determine the diagnosis of WAD, therefore the credibility of these injuries is often raised. In this study the injury data were mainly obtained by interviews with the occupants, which might influence the outcome. Better significance could be expected if only symptoms verified by a medical doctor were used. However, to minimize the risk of biased data, the interviewer had no knowledge about the crash severity in each case.

The results are based on seven different models from one car manufacturer. The limits in crash severity for different injury levels may therefore be different for other vehicles.

In all figures, the results were based on the rear impacts where fully crash pulses were recorded. This fact influences the results where the correlation between crash severity and injury outcome was analyzed. The results in Figure x-xx show no difference in crash severity for the occupants that sustained no injury and those with symptoms for less than one month. However, the impacts where no crash pulse could be recorded were not included in the study. A difference in crash severity could therefore be expected between the uninjured occupants and those with short-term consequences.

A correlation between crash severity and duration of symptoms was found. Other studies (Jakobsson 2004, Olsson et al 1990) did not find a relationship between impact speed (EBS) and the initial spectrum of symptoms or duration of symptoms. However, EBS or change of velocity calculated with retrospective methods has too low accuracy to predict the crash severity (Kullgren 1998), especially in low speed impacts (Lenard et al. 1998).

When designing test methods for evaluating vehicle crashworthiness with regard to whiplash, the results show that the acceleration pulse differs considerably, depending on whether the focus is on short- or long-term consequences. If too low crash severity is chosen, there is a risk of sub-optimization against short-term consequences. To create conditions for a robust anti-whiplash system it is advisable to have at least two tests at different crash severity levels: one test representing the crash severity where the risk of long-term consequences is high, and another one representing a lower limit above which most of the whiplash injuries occur (symptoms more than one month).

The severity of the initial neck injury was classified according to the Quebec Task Force injury scale WAD 1-3. The duration of symptoms appears to better correlate with crash severity than WAD. This is logical since the WAD-scale is supposed to predict long-term injury outcome. Using the WAD-scale is a round-about way of describing the duration of symptoms, but less reliable. At least when the WAD classification was based on interviews with the occupants. The quality of the classification would probably be better if it was based on medical examination of the occupants. In this study, the WAD 2 were found at all crash severity levels, but WAD 0 and 1 predominated in the lower severity segment. Whiplash injuries with neurological signs, WAD 3, occurred mostly at higher mean accelerations (above 4.5g), but they represented only six occupants.

Given the same crash severity level, females were found to have a higher risk of initial symptoms. If focusing long-lasting symptoms there is a need of more data to separate risk curves for males and females. Most studies, controlled for position, show a higher injury risk (long-term) for females (Jakobsson 2004, Krafft 1998) than males but there is no control for the exposed crash severity in the impacts. However, given the same crash severity there is a high probability that females still have a higher risk. It is important for preventative measures to determine critical crash severity levels mainly based on data related to females, ant not based on mean values for the total population.

CONCLUSIONS

- A correlation was found between duration of symptoms and crash severity measured as mean acceleration and change of velocity. The risk of WAD symptoms for more than one month was found to be 20% at a change of velocity of approximately 8 km/h and at a mean acceleration approximately 5 g.
- A correlation was found between grades of WAD according to Quebec Task Force and crash severity measured as mean acceleration and change of velocity.
- Out of all crashes with a recorded crash pulse only one out of 207 occupants sustained WAD symptoms for more than one month at mean acceleration below 3.0 g.
- Given the same crash severity, females had a higher risk of initial WAD symptoms than males.

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APPLICATION OF THE CIREN METHODOLOGY TO THE STUDY OF PEDESTRIAN CRASH INJURIES

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ABSTRACT

The Crash Injury Research Engineering Network, CIREN, was initiated by NHTSA as a collaborative forum for detailed investigation of motor vehicle crashes. This arrangement brings together experts from medicine, academia, industry, and government to perform detailed analyses of the injuries sustained in specific collision modes. The CIREN program has typically focused on vehicle occupants, but in 2002 the Honda Inova Fairfax Hospital CIREN Center established a special program for pedestrian crash investigations. The goal of the center has been to – complete detailed crash investigations for impacts between a pedestrian and a passenger car or light truck. Detailed medical and anthropometric data are collected at the level one trauma center and expert investigations of the vehicle and crash scene are conducted. Multi-body simulation models are sometimes used to estimate impact kinematics for the pedestrian and to validate vehicle speed estimations and initial position of the pedestrian. An interdisciplinary team analyzes the data and develops a consensus for the most likely impact scenario and injury mechanisms. This paper presents our initial experience from investigating over twenty pedestrian collisions. We will discuss the challenges associated with collecting and analyzing this data as well as initial observation of injury trends and mechanisms encountered.

INTRODUCTION

Crash Injury Research & Engineering Network (CIREN)

To understand motor-vehicle crashes and mitigate the resulting fatalities and injuries, crash investigation and reconstructions have long played an important role. Government entities, safety researchers, automotive suppliers, and vehicle manufactures have put a significant effort into studying these crashes in order to understand the injuries that occur and the mechanisms involved.

In the 1990's, the US National Highway Traffic Safety Administration (NHTSA) identified a need to collaborate with medical personal, university researchers, and vehicle engineers in the detailed investigation of motor-vehicle crashes. From this vision, the CIREN program was established.

The CIREN program currently includes ten centers around the country that are based at hospitals with level 1 trauma centers. Funding for many of these centers is provided by NHTSA, but due to valuable information developed there are additional centers supported by industry.

The primary focus of the CIREN program is to investigate and analyze front, side, and rollover crashes. In some cases, the program has sought the collection of special cases to look at specific areas of highway safety that are of particular concern.

Honda Inova Fairfax Hospital CIREN Center

The Inova Regional Trauma Center (IRTC) is the only Level One Trauma Center in Northern Virginia. It is a component of Inova Fairfax Hospital, a 753-bed facility located in Fairfax County, Falls Church, Virginia. Fairfax County is a diverse urban county and the most populous jurisdiction in both Virginia and the Washington metropolitan area. In 1999, the IRTC became the 9th CIREN center and the only non-university based CIREN center in the United States. This center operates as collaboration between the IRTC, University of Virginia, Fairfax County emergency medical services, and Honda R&D.

CIREN centers typically study only passenger vehicle crashes. In 2002, Honda partnered with the IRTC center, and the study of pedestrian and motorcycle crashes was added as an area of special investigation. An average of 32,000 car crashes occurs in Fairfax County annually. The IRTC treats approximately 3,400 critically injured patients each year and 140 of these are pedestrian crashes. Pedestrian injuries in Fairfax County have the highest average hospital charges and longest hospital stays when compared to other motor vehicle caused injuries. This CIREN Center is currently the only Level One Trauma Center in the United States that studies pedestrian and motorcycle crashes.

Pedestrian Injury

Pedestrian crashes present a universal challenge for public health, trauma medicine, and traffic safety professionals in all motorized societies throughout the world. More than a third of the approximately 11.2 million people that are killed or injured in road traffic crashes every year are pedestrians (Crandall et al., 2002). Considering fatalities only, approximately 760,000 (65%) are pedestrians (World Bank, 2001). In the US alone, approximately 70,000 (2.4%) of the 2,889,000 who were injured and 4,749 (11.1%) of the 42,643 who were killed in road traffic crashes during the year of 2003 were pedestrians (NHTSA, 2005). The abovementioned statistics support Brainard et al. (1989), who stated that pedestrian casualties sustain more multi-system injuries with concomitant higher injury severity scores and mortality rates than vehicle occupants.

Automotive safety research has traditionally focused on developing knowledge, systems, and devices for protecting vehicle occupants. The lack of development and implementation of automotive countermeasures for pedestrian safety has stemmed primarily from a societal view that the injury caused by a large, rigid automobile striking a small, fragile pedestrian cannot be substantially reduced by altering the vehicle structure. Automotive safety researchers are now exploring the theory that the same safety design principles that have resulted in substantial safety benefits for occupants might be extended to reduce the aggressiveness of motor vehicles to pedestrians. Based on these principles, several concepts of pedestrian safety countermeasures for minimizing the frequency and severity of injuries to the lower extremities (Aldman et al., 1985; Harris and Grew, 1985; Ishikawa et al., 1992, 1994; Nagatomi et al., 1996; Detweiler and Miller, 2001) and head (Okamoto et al., 1994; Fredriksson et al., 2001) have been proposed. A further step towards reducing the frequency and severity of injuries to pedestrian victims is the pedestrian test protocol included in the European New Car Assessment Programme (EuroNCAP). As part of a program to provide consumers and manufacturers with information on the impact performance of new cars sold in Europe, EuroNCAP evaluates the vehicle aggressiveness towards the pedestrian lower extremity and head by measuring the impact response of mechanical leg and head forms propelled into the vehicle front and hood structures.

CIREN Pedestrian Crash Investigations

As vehicle manufactures are working on the development of vehicle based systems to mitigate the extent and severity of pedestrian injuries, it has become evident that continued pedestrian crash investigations are necessary. These continued investigations are necessary for gaining a detailed understanding of pedestrian injuries and their injury mechanisms as well as for identifying the effects of changing vehicle fleets.

Application of the CIREN program methodology to pedestrian crash investigations presents a unique opportunity to gain a detailed understanding of injuries and injury mechanisms from a limited number of pedestrian crashes. These investigations provide information about impact kinematics, vehicle interactions and injury response trends.

METHODOLOGY

Case Selection

All pedestrian cases that arrive at IRTC are reviewed on a daily basis to identify those that meet the enrollment criteria for being part of the CIREN pedestrian crash investigation program. Each case must meet the following criteria to be eligible for enrollment:

- Hospital admission with AIS 2+ injury
- Pedestrian is struck by the front of the vehicle and is upright upon impact
- Striking vehicle is a passenger vehicle, SUV, minivan or small pick up truck

Screening, Enrollment & Consent

The medical record for each identified case is reviewed to determine injury and crash criteria. The study coordinator visits eligible patients and/or family members, explains the study, and requests consent. Potential study participants are required to sign an Informed Consent, a six-page document that explains the study, risks, benefits and patient rights. Patients are assured that their treatment will not be affected in any way whether they choose to participate or not. Once informed consent is obtained, the patient is interviewed, measurements are taken and photos of contusions, abrasions and lacerations are made. The crash reconstructionist is notified of the date and location of the crash. He contacts the proper jurisdiction's police department and attempts to obtain the crash report in an effort to identify the vehicle owner. The crash reconstructionist works with local police departments to obtain scene photos and additional crash information. He then visits the vehicle owner's residence in an effort to obtain Informed Consent. When consent is obtained, the vehicle can then be inspected.

Data Collection

Data collection for pedestrian cases collected at the CIREN center follows the guidelines of the National Highway Traffic Safety Administration's Pedestrian Crash Data Study (PCDS).

Medical Data

Medical information is collected from both the detailed hospital records and records of the pre-hospital care providers. The Fire and Rescue department that treated the pedestrian at the scene is notified, and pre-hospital information is obtained from their records. The full medical record is also reviewed in detail to obtain additional medical information. Injuries and procedures are assigned AIS, IDC-9 and CPT codes consistent with the patient's injuries and procedures. A research fellow and trauma surgeon review radiological records and select the best images to be included in the CIREN case file. Once all the medical data is collected, the data is entered into a database and the case can be prepared for Case Review. A social worker affiliated with the CIREN Center contacts the study participant at 6 months and 12 months following the crash to obtain outcome data.

Vehicle & Crash Data

When a suitable case has been identified, the crash investigator attempts to obtain a copy of the police crash report. Information on the crash report provides information about date, time, and location of the crash, the vehicle involved, and identifies the owner and driver of the involved vehicle. Scene diagrams, photos, witness statements, and notes are also collected from this report.

In order to do a detailed inspection of the involved vehicle, the crash investigator attempts to make contact with the vehicle owner. If the vehicle owner agrees to the study, a signed consent form is completed. The involved vehicle is located, and the crash investigator conducts a detailed examination of the vehicle in accordance with the protocols employed by PCDS. The vehicle is documented by photographs, diagrams and video imaging; with special attention to damage at and under the surface of the vehicle. Photographs are sanitized, and data points obtained from the vehicle, crash scene and police crash reports are placed in the database**.**

The crash scene is also examined for physical evidence following the PCDS protocols. A scene diagram is prepared, and the crash investigator estimates an impact speed from the pedestrian throw distance and skid mark evidence.

Reconstruction & Simulation

Using a mathematical dynamic modeling software program, MADYMO (TNO, 2004), a selection of cases is reconstructed using the crash data. Each reconstruction selected is simulated using the following prioritization for matching criteria.

Vehicle Model Selection

There are three options for vehicle model selection. The optimal choice is a model already available within the current vehicle database. If a model is not available, then a vehicle of appropriate make and model may be digitized and surface model built. The digitization of the vehicle consists of point collection of the front half of the vehicle, and then a mesh generation of these points. Due to limited availability of vehicle data, basic suspension and stiffness characteristics are used. This method is similar to that discussed by Rooij et al. (2003). If neither option is available, a vehicle model of similar geometry to the case vehicle will be used.

Pedestrian Model Selection

There are five validated human pedestrian models available in MADYMO that are used for selecting an appropriate anthropometry: a 3 year-old, 6 year-old, 5th percentile female, 50th male, and 95th percentile male (Figure 1).

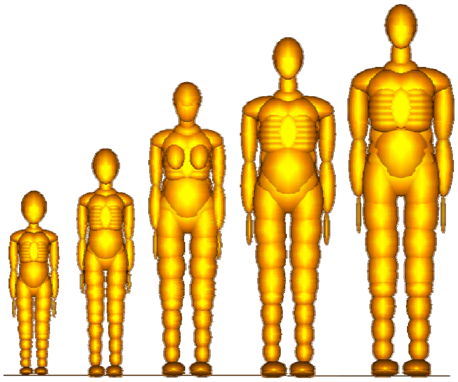

Figure 1: MADYMO Pedestrian Anthropometries

Pedestrian & Vehicle Dynamics

The pre-impact and avoidance dynamics of the pedestrian are taken into account. The vehicle, walking speed, possible orientation, and possible impact avoidance are simulated. The pre-impact and any avoidance dynamics of the driver are taken into account based on data from the police report. This includes vehicle speed, orientation, and braking.

Simulation Matrix

After a suitable vehicle model and pedestrian anthropometry have been selected, an initial simulation run is performed. The vehicle is positioned perpendicular to the pedestrian at the driver reported speed with no braking involved. Nose dive is also not accounted for in the initial run, since the majority of the cases do not indicate any driver initiated pre-impact avoidance maneuver.

The pedestrian is initially orientated with an arbitrary walking stance crossing in front of the vehicle at the noted possible vehicle contact points. This base stance is an initial guess resulting from pedestrian or witness reported observations. Using previous simulation studies from Meissner et al. (2004), this stance is further evaluated in future runs.

Once a suitable initial simulation is run, modifications to the pedestrian stance are performed to better match the lower extremity injury points to vehicle contact and/or damage points. This includes, but is not limited to, lower limb orientation (struck limb forward, struck limb back or feet together), weight bearing extremity, and knee flexion. Since lower limb injury may not be from the direct contact with the vehicle, the contact points are used as guidelines for pedestrian stance.

After the pedestrian stance modification, if the kinematics do not sufficiently reproduce a desired result, further simulation modifications are performed. The next step is to verify vehicle dynamics, such as speed, orientation, braking, and associated brake-dive. Other simulation factors considered are upper extremity orientation, torso orientation, head and neck orientation, pedestrian speed and orientation toward vehicle, vehicle weight, etc.

Case Review

A pedestrian case review takes place approximately every three months, at which three pedestrian crashes are reviewed. To protect patient privacy, participation in the review of the cases is by invitation only and includes the treating physicians, scene responders, engineers and representatives from NHTSA and the automobile industry. A three-page case summary of each case and corresponding PowerPoint presentation are prepared.

Prior to CIREN Case Review, the principal investigator, research fellow, crash reconstructionist and study coordinator meet for an internal review to discuss the scheduled cases. Following the internal review, the crash reconstructionist and study coordinator meet with researchers from the University of Virginia – Center for Applied Biomechanics, who serve as biomechanical consultants to the CIREN Center. The case is reviewed, and kinematics are discussed extensively. After the initial reviews, the cases are then presented for a full case review, including physicians, medical students, engineers from the automobile industry, first responders, and safety researchers from NHTSA, IIHS, and University of Virginia.

Each case is presented in detail, including scene photos, vehicle photos, interior and exterior vehicle movies, pre-hospital information, hospital information, rehabilitation information, patient photos, and scans of radiographs. Relevant biomechanical information, simulation results and test data are also presented. The attending group reviews all information presented and participates in a discussion to determine pedestrian kinematics and injury mechanisms. Each injury is reviewed in detail, and review of the vehicle damage, an injury source is assigned.

RESULTS

Screening & Enrollment

Screening of pedestrian cases at the CIREN Center began in 2002. Since that time over 350 cases have been screened and over 30 pedestrian cases were enrolled for detailed investigation. Nearly half of the cases screened did not meet the minimum injury criteria level necessary for enrollment. About 50 cases were excluded due to lack of patient and vehicle owner consent and over 100 cases did not meet the requisite crash criteria or were excluded for other reasons.

The cases enrolled have encompassed a wide range of pedestrians, vehicles, and impact configurations. The pedestrians include an age range from young children to the elderly with a wide range of anthropometries. The vehicles cover a broad spectrum including numerous cars, vans, and light trucks built between 1990 and present. The impact configurations are largely of lateral pedestrian orientation, but cover a broad speed range with variations in impact point, vehicle movement, and pedestrian kinematics.

Sample Case

Included here is a sample case to illustrate the typical result of the pedestrian crash investigation, reconstruction, and Case Review.

Event Information

Striking Vehicle:	*1992 Mid-size Sedan*
Crash Type:	*Frontal*
Time of Day:	*19:35*
Weather:	*Clear*
Road Conditions:	*Dry*
Posted Speed:	*35 mph*
Police Reported Speed:	*35-40 mph*
Witness Reported Speed:	*None*

Pedestrian Data

Age:	*55*
Gender:	*Female*
Clothing:	*Pants/sweater/medium length coat*
Shoes:	*Medium heels (< 1")*
Eyewear:	*None*
Other object:	*Purse over left shoulder*
Weight:	*150 lbs*
Height:	*168 cm*
Ground to center of knee cap:	*43 cm*
Ground to top of hip bone:	*92 cm*
Ground to top of shoulder:	*136 cm*

Patient Interview

The patient only remembered that she was walking across the street when she was struck at the right side. She does not remember seeing the vehicle, and only remembers waking up when the paramedics were cutting off her coat.

Injury Severity

ISS Score	*17*
Maximum AIS:	*3*
Caused by injury:	*Humerus fracture*

Injury Analysis:

The case participant is a 55-year-old female who attempted to cross a four-lane roadway. The vehicle was traveling in the left through lane in a westbound direction. The pedestrian crossed the eastbound lanes and was struck on the right side upon entering the westbound left through lane (Figure 2). The weather was clear, and the roadway was dry. The posted speed is 35 mph.

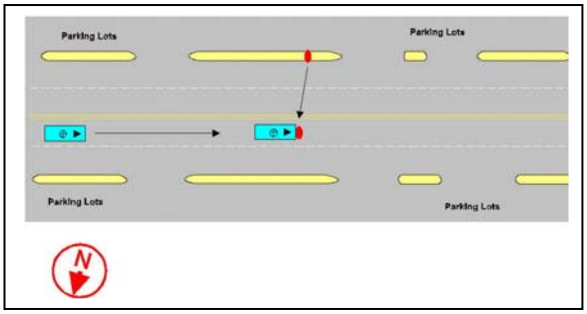

Figure2. Pedestrian Scene Diagram

Upon arrival of pre-hospital personnel, the pedestrian was alert and oriented. It was noted that there was significant depression to the hood and windshield of the vehicle. The pedestrian was noted to have multiple abrasions and was immobilized and intravenous fluids started. She was transported to the trauma center by ground.

On initial presentation in the trauma bay, the patient was amnesic to the event and complaining of pain to her head, shoulder and leg. She was hypertensive, with oxygen saturation on non-rebreather of 92% and had a GCS of 15. She was noted to have some abrasions, deformity of her right shoulder and edema of her right ankle. Radiological evaluation identified a right humerus fracture, right tibial plateau and fibula fractures and lateral malleolus fracture. CT of the head was negative for intracranial injury, but clinical examination was consistent with a concussion. She was admitted to the floor and taken to the operating room on hospital day # 2 for open reduction/internal fixation of the humerus fracture and application of a long leg cast.

Her hospital course was uneventful, and she was discharged home with her family on hospital day # 7. At the time of discharge, she was non-weight bearing on her right lower and right upper extremities.

Modeling of the crash suggested that the pedestrian had the right foot forward when she was struck which caused her to rotate backward as she falls onto the hood of the vehicle. Her head struck the base of the windshield causing the scalp contusion and concussion. Her arm suffered a direct blow as she struck the hood resulting in the transverse humerus fracture and possibly the abrasion to her hand. The bumper of the vehicle struck her right leg which bends around the bumper causing the tibial plateau and fibula fractures. It was estimated that the position of her foot on the road in combination with the bumper striking the extremity was the cause of the lateral malleolus fracture.

Table 1.
Pedestrian Injury Analysis.

Injuries (ICD)	**AIS Severity**	**Contact Area (Bumber, hood)**	**Confid. Level**
Scalp contusion (920)	190402.1	Base of windshield	Certain
Concussion w/o LOC (850.0)	161000.2	Base of windshield	Certain
Arm laceration (880.03)	790602.1	Unknown	Unknown
Humerus fracture (812.21)	752604.3	Hood	Probable
Hand abrasion (914.0)	790202.1	Hood	Possible
Tibial plateau fracture (823.00)	853406.2	Bumper	Certain
Fibula neck fracture (823.01)	851606.2	Bumper	Certain
Distal fibula fracture (823.21)	851606.2	Bumper	Certain
Lateral malleolus fracture (824.2)	851608.2	Positioning on road – bumper	Probable

DISCUSSION

Data Collection

Limitations of the CIREN approach

Retrospective analyses of pedestrian crash scenarios are difficult to perform because much of the critical information must be inferred from forensic evidence. When compared to vehicle occupant cases, pedestrian crashes are particularly challenging because of the wider range of pedestrian contact areas (bumper area, hood, windshield, and road surface) and initial pedestrian stances. These factors increase the uncertainty of hypothesized kinematics and injury mechanisms.

Due to the injury inclusion criteria and the fact that IRTC is a Level I Trauma Center, the cases included in the project are skewed toward the most severe pedestrian impacts. It needs to be emphasized that the cases are not a representative sample of all pedestrian impacts, and this fact must be considered during data analysis.

Case Enrollment

One of the most basic challenges in performing in-depth investigation of pedestrian crashes is the enrollment of study participants. The overall enrollment rate for pedestrian crashes at the Honda Inova Fairfax Hospital CIREN Center is approximately 22% for eligible cases meeting the initial screening criteria.

Although some patients agree to take part in this study after the first contact, multiple visits are required in most instances. The socioeconomic situation of many pedestrians is different from motor vehicle or motorcycle crash victims. Working with patients who are homeless, have psychological issues or who have drug/alcohol dependencies is often very difficult. However, all patients or their family members face multiple concerns, which may include:

- Feelings of being overwhelmed by the event and the desire to avoid making additional decisions
- Advice of attorney or concern about legal issues
- Concern about insurance issues
- Feelings of guilt
- Repercussions related to immigration status
- Psychological status related to illness, addiction
- Family unavailable and patient incompetent to give consent

Establishing contact with the vehicle owner is another challenge in enrolling cases into the study. Since both the patient and the motor vehicle owner should agree to participate in order to obtain the necessary data, it is important that the motor vehicle owner also consents. Initially the identity of the vehicle owner is difficult to determine because the owner does not have a relationship with the hospital or the patient. Also, the patient usually has not obtained an accident report or made contact with the police. The crash reconstructionist has to establish relationships with local police departments that are willing to participate in this study. Once the identity of the vehicle owner is established the crash reconstructionist attempts to contact the vehicle owner by visiting the residence. Several visits at different times are often required and many vehicle owners refuse to participate, due to:

- Feelings of guilt
- Fear of reliving the experience
- Concern about legal issues

It is important to note that only the medical staff has direct contact with the patient. For all other parties reviewing the case medical data is sanitized before viewing and there is no contact with the patient or access to personal information.

CONCLUSIONS

Application of the CIREN methodology to pedestrian crash research has proven to be a valuable tool for improving understanding of the complex interaction that occurs when a pedestrian collides with a vehicle. The combination of detailed medical knowledge with in-depth crash investigations and biomechanical expertise is helping to identify some of the injury producing mechanisms associated with pedestrian injuries and fatalities.

There is currently a minimal amount of pedestrian impact data on recent model vehicles that include pedestrian protection features, and a limited number of cases which we are able to collect at the Honda Inova Fairfax CIREN Center. Therefore, in the future, it is hoped that NHTSA will allow other CIREN centers that are interested in pedestrian safety to begin to collect pedestrian crash cases as a part of their CIREN case load.

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INJURY IDENTIFICATION: PRIORITIES FOR DATA TRANSMITTED

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ABSTRACT

The objective of this study was to prioritize the variables that could be transmitted with an ACN (Automatic Crash Notification) signal. The main purpose of transmitting these variables is to assist in early identification of those occupants with time critical injuries. For the purposes of this study, all MAIS 3+ injuries were classified as time critical. The basis for prioritizing crash variables was based on their ability to identify MAIS 3+ injured occupants in the National Automotive Sampling System- Crashworthiness Data System (NASS/CDS) dataset.

In this study, multivariate models to represent crash events were developed based on historical crash data from the years 1997-2003. The analysis established a relationship between crash attributes and crash outcomes for all passenger vehicles in the database.

The resulting analysis provided a ranking of crash variables in order of importance. Crash severity (Delta-V) was found to be the most important variable for all planar crash directions. The addition of other crash variables improved the accuracy of the injury prediction algorithm.

For frontal crashes important secondary crash variables include: 3-point belt usage, multi-impact crashes, occupant age and the presence of more than 6" of intrusion. For near-side crashes, the most important secondary variables were occupant age, narrow object crashes, and the presence of intrusion. For far side crashes, the most important secondary crash variables were 3-point belt usage and the occurrence of a narrow object crash. Rollover was found to be a high risk event that predicted high injury risk independent of Delta-V if 3-point belts were unused.

The paper will show the relative importance of the crash and occupant variables by crash direction.

INTRODUCTION

The emergence of Automatic Crash Notification (ACN) Systems provides the ability to rapidly determine the location of motor vehicle crashes. When a crash occurs that is severe enough to cause injuries, the ACN system automatically transmits GPS position data to a telematics service provider. The exact location of the crash is immediately determined by the service provider who, in turn, notifies the closest rescue center. If the occupants of the crash involved vehicle can communicate verbally, the telematics service provider may interact with them to determine their emergency needs. ACN systems have the potential to greatly reduce notification time and improve the accuracy of location data transmitted to rescue teams [1,2,3].

Improved safety systems in motor vehicles are protecting crash victims from many of the injuries that are recognizable from physiological responses making the detection of residual injuries more difficult [4,5,6]. A growing challenge to acute care providers is the identification of those crash victims who suffer from time critical injuries.

Modern motor vehicles are equipped with sensors to measure a number of factors to permit decisions regarding the deployment of safety systems. Much of the information used to deploy safety systems would also be useful in determining the risk of injury to occupants. The information measured may vary from vehicle to vehicle. However, it generally includes a measurement of the crash severity such as the change in velocity during the crash and the direction from which the vehicle was impacted.

Ongoing research first initiated by the National Highway Traffic Safety Administration (NHTSA) investigated methods to interpret crash attributes that could be recorded in the vehicle and transmitted with an ACN call to assist in identifying the crashes and crash victims that are most likely to suffer time critical injuries [7,8,9].

The transmitted information would be examined by care providers and compared with injury experience in similar crashes to estimate the risk of a time critical injury and a series of injuries which may be present. When the emergency crew arrives on scene, additional information can be obtained and transmitted.

Based on crash circumstances, the potential for occupant injury in the event of a motor vehicle collision depends on three key attributes.

- the magnitude of loading experienced by the occupant
- the means through which the load is transferred to the human body
- individual characteristics of occupants which effect their tolerance for injury

To formulate an algorithm which estimates the potential for injury in the event of a collision, crash attributes must be selected which best characterize the conditions cited above. The methodology used to interpret these crash conditions for prioritization of rescue services is called the URGENCY Algorithm.

Current Automatic Crash Notification Systems (ACN) are triggered following crashes severe enough to deploy airbag systems. This is an approximate severity threshold. If a notification of emergency services was made for every crash exceeding these thresholds, a percentage of the population requiring help would benefit from rapid notification of rescue and subsequently receive care. At the same time, a group of occupants who were not severely injured may also receive care in the event that their crash exceeds this approximate threshold. For many, high level rescue care may not be necessary at all.

It should be noted that additional characteristics regarding crash severity may be obtained by current ACN systems from verbal communications with crash involved occupants as well as on-lookers. For this reason, it should not be assumed that rescue is dispatched for every ACN call exceeding airbag deployment thresholds. For the purpose of this study, the prioritization of crash variables presented below assumes that no other information other than airbag deployment is available from which crash severity can be assessed.

For frontal crashes, the approximate severity necessary for airbag deployment corresponds to a 12 mph deltaV for first generation airbag systems. In recent model year vehicles, the threshold for airbag deployment could vary based on the use of 3-point belts as well as seating position and occupant size. If an adult is properly seated and belted during a frontal crash, the threshold for airbag deployment may be higher due to decreased need for a supplemental restraint. The deltaV may be approximately 16 mph or higher for frontal crashes. Seat belt usage is an example of a factor which may influence the risk of serious injury in a crash. For side impact crashes, the threshold for deployment may be as low as 7-8 mph. Using these approximations, a baseline estimate of injured occupants who would be correctly identified in the field can be made.

Table 1 below shows annual counts for injured occupants by crash mode. Table 2 identifies the percentage of injured and non-injured occupants whose crashes fall above the approximated airbag deployment thresholds described above. This data was derived from tow-away crashes in NASS/CDS from 1997-2003 where crash direction is known.

Table 1. Annual tow-Away Crash injuries by crash direction (NASS/CDS 1997-2003 average)

Crash Mode	MAIS3+ Injured	Non-MAIS3+ Injured
Frontal	54,508	2,165,571
Nearside	14,124	260,382
Farside	7,025	257,386
Rear	2,451	339,077
Rollover (w/o planar deltaV)	22,744	336,443

Table 2. Injured and non-injured occupants at or above airbag deployment thresholds by crash direction (NASS/CDS 1997-2003 average)

Crash Mode (cutoff value)	MAIS3+ Injured Exceeding Cutoff DeltaV	Non-MAIS3+ Injured Exceeding Cutoff DeltaV
Frontal (16 MPH)	69.7%	22.5%
Nearside (8 MPH)	98.8%	67.8%
Farside (8 MPH)	98.9%	69.0%
Rear (16 MPH)	78.9%	20.6%
Rollover	0.0%	0.0%

The data shown in Table 2 serves as a baseline for this study. Next, the usefulness of including additional characteristics during the transmission of an ACN signal is quantified through a comparison with the accuracy of current technology.

METHODOLOGY

The goal of this study was to quantify the frequency that today's ACN systems would accurately distinguish occupants who need immediate medical attention from those who do not. Additional parameters were identified that could be transmitted by future ACN systems to refine the criteria used to distinguish occupants in need. The relative rate that occupants are correctly flagged as likely to be severely injured versus non-severely injured are presented with the inclusion of each of these additional variables.

This study addresses passenger vehicle occupants over the age of 16 who may have severe or time critical injuries following a crash. This category includes occupants who sustained at least one or more AIS3 injury or those who were fatally injured during a crash due to trauma. Throughout this text, these occupants will be referred to as MAIS3+ injured occupants.

Source Data

Data including occupant injury severity as well as all details describing the crash event were derived from the National Automotive Sampling System-Crashworthiness Data System (NASS/CDS) [10]. Within NASS/CDS, specific injuries sustained, including their severities, are recorded allowing for the direct association of crash conditions with crash outcomes as used in this study.

NASS/CDS case data has been collected since 1988 by the National Center for Statistics and Analysis and is a sample of tow-away crashes that occur within the US. The data is used to monitor the effectiveness of traffic safety programs and to provide a resource to understand the relationship between the type and seriousness of crashes and their associated injuries. To qualify for inclusion, the crash must have a police report, be reported to the state, involve a "harmful event" (defined as property damage, personal injury, or both) and occur as a result of a non-stable situation deemed accidental (non-intentional, non-disease related or not due to a natural disaster).

Each investigated crash must involve a motor vehicle in transport on a public roadway and must involve at least one towed vehicle. At each sampling site the research team investigates a subset of police reported crashes. One of 24 teams of crash researchers throughout the country investigates the each crash and collects all relevant data. For this investigation, detailed review of police accident reports, hospital records, out-of-hospital care records, photographs of the vehicles, and the vehicles themselves are conducted. With the sampling process, the data are weighted to represent the nationwide incidence of crashes and resulting injuries. Based on the probability of sampling, a weighting factor is assigned to each case so that its characteristics may be projected to the total population.

Model Creation

A review of crash characteristics as well as occupant characteristics available within the NASS/CDS dataset was conducted to identify the most influential variables for crash severity assessment. These characteristics were compiled based on findings from available literature as well as the real life experience of the University of Miami CIREN team during crash case collection since 1991.

In order to take into account multiple factors influencing crash severity and the likelihood of injury, multiple regression techniques were used. Since the outcome of interest could fall into one of two categories (MAIS3+ injured or non-MAIS3+ injured), binary logistic regression is ideally suited for the analysis. In addition, certain high severity crash attributes like the occurrence of complete occupant ejection were assumed to indicate high probability of severe injury even in the absence of other crash factors.

Binary logistic regression relates the contribution of independent predictor variables (crash conditions) with dependant outcomes (injury). Using the Principle of Maximum Likelihood, an estimate of the likelihood of the outcome (injury) is derived on a scale from 0 to 100% probability.

Equations 1-2 show the mathematical relationship between crash characteristics and injury outcome probability following logistic regression model creation. The regression parameters including the *Intercept*, β_1, β_2… shown below are based on a least squares fit of existing historical crash data from NASS/CDS.

Eq. 1: $$w = (Intercept) + \beta_1 * deltaV + \beta_2 * factor_2$$

Eq. 2: $$P(MAIS3+) = \frac{1}{(1+\exp(-w))}$$

Each logistic regression model was trained using NASS/CDS 1997-2001 data. 2003 and 2003 datasets were used to evaluate the accuracy of the resulting models. As an example, Table 3 below lists parameter estimates for a model relating the deltaV continuous variable deltaV to the likelihood of MAIS3+ injury. This model assumes average values for all other crash factors which may influence the risk of injury.

Table 3. Logistic Regression model parameters including deltaV only by crash direction

Crash Mode	Parameter	Estimate
Frontal	Intercept	-4.2052
	DeltaV	0.1157
Nearside	Intercept	-4.0652
	DeltaV	0.181
Farside	Intercept	-4.5426
	DeltaV	0.1384
Rear	Intercept	-5.5143
	DeltaV	0.1303

Figure 1 shows the resulting risk of MAIS3+ injury which may be calculated using Equations 1-2 for crashes by deltaV. DeltaV estimates the difference between pre-impact and post-impact velocity as a function of the damage of a vehicle involved in a crash. Figure 1 shows that as deltaV increases, the risk of injury increases from 0 to 100% risk. Crash direction influences these relative values considerably due to differences in available occupant protection, crush space and human tolerance to injury.

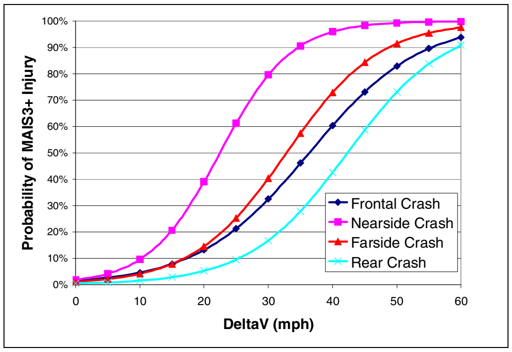

Figure 1. MAIS3+ injury risk by deltaV and crash direction

With the knowledge of additional parameters, logistic regression may be used to simultaneously interpret multiple pieces of crash data in addition to deltaV as shown above. Logistic regression uses the method of least squares to simultaneously consider crash factors that may be influential. As additional parameters that are influential to injury outcome are added to the model, the fit and predictive accuracy will increase. This accuracy includes the correct classification of both injured and uninjured occupants.

Before the creation of each logistic regression model, all relevant crash attributes were reviewed for consistency and reconditioned when appropriate using SAS version 8.2. All regression models were created using SAS callable SUDAAN. SUDAAN is a statistical package which allows for the analysis of complex sample data like NASS/CDS. It allows for the correct interpretation of sample variances for multi-stage, clustered samples.

As previously mentioned, the binary outcome variable MAIS3+ was used in the analysis to distinguish injured from non-injured. For this study MAIS 7 were considered unknown unless a fatality occurred. These occupants were discarded from the analysis. Cases where missing values exist for any model variable are unusable for model training as well as testing and were therefore discarded as well.

Criteria for the Recognition of Injured Occupants

For the purpose of this study, any occupant whose risk of injury exceeds 10% will be classified as potentially injured. This threshold was selected so that any potential improvements in data transmitted could be directly compared with the current performance of existing ACN systems.

As previously explained, current ACN systems are typically triggered at crash severities corresponding to the threshold for airbag deployment. Figure 1 indicates that the risk of MAIS3+ injury for frontal crashes at 16 mph (frontal airbag deployment threshold) is slightly less than 10%. The goal of this study is to identify that additional crash parameters should help to refine a crash severity estimate currently based on a deltaV threshold alone. This threshold corresponds to a 10% risk of MAIS3+ injury. As model improvements are made with the addition of relevant crash characteristics, crashes that may be incorrectly classified above or below this threshold value will be better described and, in turn, more accurately categorized.

As additional data is made available for crash severity assessment by ACN systems, the relative improvement to the classification of injured versus non-injured occupants can be easily evaluated using a similar threshold for ACN triggering.

Crash Characteristics Evaluated

A review of relevant crash characteristics was conducted to identify factors which influence the risk of injury given that a motor vehicle crash has occurred. The review is broken into four primary sections defining impact characteristics, crash outcomes in terms of vehicle performance, occupant attributes and the influence of restraint systems on injury severity.

These characteristics include impact speed or deltaV, crash direction, degree and location of vehicle damage. Some of these characteristics can be measured by existing on-board vehicle sensors, however, verbal collection of many of these crash attributes is possible. Additional information describing occupant characteristics and restraints used during an event provide further insight into an occupant's likelihood for severe injury.

Below, a discussion of the importance of each variable is presented. Additionally, relevant findings of other studies are presented in support of variable selection for further modeling.

DeltaV- Pre impact speed has been recognized as an indicator of injury severity due to its direct relationship with occupant loading during a crash. In order to estimate the change in vehicle speed that occurs during a crash, the delta velocity or deltaV is calculated by crash investigators. This parameter quantifies the magnitude of impact energy absorbed by a vehicle structure in the lateral and longitudinal directions during a collision. For this calculation, post crash vehicle measurements of deformation are used in conjunction with vehicle stiffness values and post impact trajectory to estimate the impact energy absorbed. Based on the mass of the vehicle, the energy absorbed may be used to estimate the pre-impact vehicle speed or deltaV.

DeltaV in the longitudinal and lateral directions have been identified as the best general predictors of crash severity. All calculations using deltaV are in MPH.

Crash Mode- The ability to manage the kinetic energy of a vehicle and occupant depends largely on the primary direction that decelerating forces are applied. For example, frontal crush zones, seatbelts and frontal airbag systems help to manage energy along the longitudinal axis of the vehicle. Similarly, these features like seatbelts and frontal airbags do not provide significant protection or benefit for high severity lateral crashes.

For this study, crash mode has been categorized using Collision Deformation Classification (CDC) data collected by NASS/CDS investigators. Each mode is categorized as follows:

Frontal: (PDOF≥11 and PDOF≤1, Any Seating Position) or (PDOF=10 or 2 where General Area of Damage is Front)

Nearside: (PDOF≥2 and PDOF≤4, Right Seating Position, General Area of Damage is Right) or (PDOF≥8 and PDOF≤10 and, Left Seating Position, General Area of Damage is Left)

Farside: (PDOF≥2 and PDOF≤4, Left or Middle Seating Position, General Area of Damage is Right) or (PDOF≥8 and PDOF≤10 and, Right or Middle Seating Position, General Area of Damage is Left)

Rear: PDOF≥ 5and PDOF≤7

These crash categories were published and applied by NHTSA during the Final Economic assessment of the FMVSS Advanced Airbag Final Rule [11].

3-Point Belt Use- The kinetic energy of the occupant, which is also proportional to his or her mass, must be similarly transferred or dissipated. The goal of energy absorbing restraint systems is to match the deceleration of the occupant closely with the controlled deceleration of the vehicle structure but also to absorb a portion of the occupant's kinetic energy such that their overall deceleration and force distribution falls below their threshold for injury.

The influence of safety belt usage on injury and fatality outcomes has been well documented. In a 2000 report by NHTSA, 3-point belt effectiveness was evaluated using the double-pair comparison method [12]. The study examined fatality counts for drivers and right front passengers where one, neither, or both occupants are wearing safety belts during a crash event. Fatality differences for the belted population vs. the unbelted population provide an accurate means to assess seatbelt effectiveness based on individual case outcomes. Overall, the total reported value for seatbelt effectiveness was 45.2% for all impact types combined.

Of particular interest is the variation in 3-point belt effectiveness for frontal, rear and rollover crash types when compared with nearside and farside crashes. Findings of the NHTSA study identify that different mechanisms of injury occur by crash type. According to these findings, the contribution of belt usage varies in its influence of outcome based on impact direction and seating position. This data further supports the need for separate predictive models based on crash mode. This approach takes into account considerable differences between occupant kinematics or loading and crash mode.

Other studies support the effectiveness estimates shown in the NHTSA study. Three-point belt usage was reported to reduce fatality risk by over 50% by Bedard et. al. for all crash modes combined [13].

For the purpose of this study, any occupant (16 years and older) whose manual belt use is coded as lap and shoulder is considered to be belted. The use of automatic belts is considered belted as long as both lap and shoulder systems are used.

Rollover- Following ejections, the occurrence of rollover is the second most prominent crash attribute leading to occupant injury per occurrence. Yet rollovers are far more numerous. Occupant involvement in rollover crashes exceeds 350,000 annually with 224,000 injured or killed during these events. Of these, 200,000 occupants suffered minor to moderate injuries, 14,100 suffered from serious to critical injuries, and approximately 9,000 occupants are killed annually. Further, rollover crashes were found to constitute 2.2% of the crashes, but 33% of all costs due to injury [14].

In some US counties, the independent use of rollover as a mechanism of injury meeting trauma criteria further supports its importance in the prediction of crash injury. Based on NASS/CDS 1997-2003 data, nearly 8% of unbelted occupants involved in a rollover crash sustained MASI3+ injuries.

A rollover crash event is defined as any crash involving one or more quarter turns about the roll or pitch axis of the vehicle. When a rollover crash occurs in combination with a planar crash before or after the roll occurs, the risk of injury is compounded in proportion with each significant event that has occurred. For the purpose of this study, if a planar crash event is coded as the highest severity event where the CDC indicates front, side or back damage, yet a rollover has occurred, the crash is classified as a planar event. If no damage due to a planar impact is coded, and a rollover has occurred, the collision is considered a rollover.

Multiple Impacts- To correctly estimate the risk of injury during motor vehicle crashes, it is necessary to recognize when multiple impacts have occurred. By neglecting other impacts which may be considered less severe, an occupant's total crash exposure and exposure to crash energy is not accurately established.

In order to accurately estimate the risk of injury as a result of a crash event, the primary direction of loading is fundamental. The correct classification of crash type has traditionally been based on the principle direction of force (PDOF) and general area of damage (GAD) for the most harmful event. This event typically corresponds to the highest deltaV collision if multiple impacts occur. If a second event occurs where its severity is considered less than the first, the added risk due to this second impact would often go unnoticed during most analyses. If this second event occurs in a crash direction which is different than the first (i.e. front then side), occupants would be exposed to a new set of risk factors between events. It is necessary to consider each distinct event which occurs during a crash to estimate injury potential.

Fay et. al. recognized that multiple impacts represent the greatest proportion of serious injury accidents in German data and the second highest proportion in UK data. It was suggested that the effectiveness of restraint systems could decrease due to multiple impacts [15]. A 2002 study by Digges et. al. indicates that injury risk increases if multiple consequential events have taken place [16].

To address the occurrence of multiple impacts, models must account for this added risk. Ideally, a deltaV value for each impact event could be analyzed to estimate injury risk by crash direction. Unfortunately, only the highest deltaV value is recorded for publicly available NASS/CDS cases. For this reason, a dichotomous variable indicating that more than one damage causing event has taken place is used.

Narrow Object Impacts- Impacts with narrow objects including posts, poles and trees are more likely to lead to serious injury due to an inability of the vehicle structure to safely absorb impact energy. With little structural interaction between narrow objects and structural features of vehicles, greater crush depths and potential for compartment intrusion are significantly more likely.

A 1998 study by Pilkington found that pole crashes were six times more likely than other crashes to lead to fatality and three times more likely to lead to an injury when compared with car-to-car crashes [17]. Side impact crashes with posts and poles are particularly devastating due to limited crush space and close proximity of occupants to these intruding features.

During frontal collisions, narrow object impacts pose a significant threat to occupants due to short duration high severity decelerations of vehicle structures. This more dangerous crash pulse results because narrow objects often do not interact with structural members designed to absorb impact energy. Rather, poles and trees easily penetrate engine compartments until contact with the engine and other non-energy absorbing structures occurs.

Once this interaction takes place, the vehicle and occupant inside are rapidly decelerated. This short duration, high magnitude deceleration often exceeds the expected performance of energy absorbing interior components designed to protect occupants. Injury often results under these conditions.

Intrusion- During collisions where intrusion into the occupant compartment occurs, the risk for serious injury greatly increases. In the event of a collision with a fixed or non-fixed object, the principle direction of force experienced by the occupant is often in a direction exactly opposite from the trajectory of intruding interior components. For this reason, the reduction in "flail space" is particularly important due to increased risk of contact with the component by the occupant.

This risk is especially evident in nearside crashes where little distance separates the occupant's head, thorax and pelvis from potentially intruding structures. During frontal and rear crashes the likelihood that intrusion will occur is somewhat reduced; however, motion of the toepan, steering column, a-pillar, instrument panel and roof header toward the occupant can greatly increase chances of severe injury.

Within NASS/CDS, intrusion is coded in ranges of 1-3 inches, 3-6 inches, 6-12 inches, 12-18 inches and 18-24 inches. This data is collected in centimeters equivalent to these ranges. Because these classifications are not continuous, adapting them to a continuous scale is not straight forward. Further, the contribution of intrusion to injury potential for some crashes may have different implications for some crash modes versus others. For example, use of intrusion as a continuous variable for frontal and nearside collisions seems reasonable. For farside and rear impact crashes, intrusion levels do not become critical until large values are reached. This behavior suggests different treatment of this variable based on crash direction.

In order to select the best cutoff criteria for intrusion for farside and rear crashes, the correlation of 6", 12" and 18" intrusion ranges were examined as they relate to outcome. The result of this analysis indicates that intrusion greater than 12" should be used for farside and rear crashes to account for the possibility of occupant loading by intruding structures. For frontal and nearside crashes, intrusion on a continuous scale is used.

Ejection- Each year 7,800 people are killed and 7,100 are seriously injured due to partial or complete occupant ejections [18]. The majority of those fatally injured are unbelted and many are ejected during rollover crashes. An investigation of rollover crashes and associated risk identified that 65 percent of rollover fatalities occur in the 8 percent of rollovers involving either complete or partial ejection. A 1996 analysis of state data by NHTSA identified that the relative risk of fatality is 72% less for non-ejected drivers versus those ejected and 68% less for non-ejected front seat passengers versus those who are ejected.

Like rollover crashes, complete occupant ejection injury mechanisms automatically meet trauma criteria in most jurisdictions. Due to the great threat of serious injury for ejected occupants, knowledge of ejection occurrence is important to capture high risk occupants during even minor collisions.

Occupant Age- A number of studies have identified occupant characteristics which directly impact the seriousness of crash related injury. It has been established that the elderly driving population has a significantly higher risk of injury and subsequent complications compared with younger drivers [19,7,20,21]. Miltner et. al. recognized increased risk for abdominal, thoracic and extremity injury for the restrained elderly population in frontal crashes [22]. A 1997 study by Farmer et. al. found that occupants age 65 and older are three times as likely to be injured in all collisions compared with occupants 25 and younger [23].

Increased fatality risk for elderly populations has been shown in a number of studies including those by Evans, Miltner and Bedard. The Miltner study reported a 30-45% increased fatality rate for occupants older than 59 when compared to those under 20. Finelli established that trauma mortality rates increased at age 55 (15% compared to 10% for those < 54 years of age) and doubled at age 75 (20%). Bedard reported an odds ratio of 4.98 for the driving population over 80 compared with those who are 40-49 years old. Both Evans and Malliaris report fatality risk to increase linearly as a function of age while others suggest that the true nature of this relationship exhibits some non-linearity particularly for the very old.

For this study, occupants 16 years and older were included. The study by Zhou et. al. indicated that occupants ages 16-35, 35-65 and 65 years and higher showed similar thoracic injury tolerances. These age categories were considered to simplify age evaluations that may take place in the field; however, age used on a continuous scale provides a better estimate of increasing injury risk with age.

Occupant Gender- Occupant gender and its relationship with injury has been evaluated by many. Differences in the relative frequency of involvement by gender for each crash type and crash severity often mask the true nature of injury risk for males versus females. An early study by Evans, using the double pair comparison method, provides a good indication of outcome differences seen by gender given that each group is exposed to the same crash environment. This study identified that fatality risk is 25% greater for females compared with males who are 15-45 years old.

More recent findings by Bedard support those of Evans showing an increased fatality risk for female drivers with an odds ratio of 1.54 when compared with males for single vehicle crashes [13]. In the 1997 study by Farmer, increased odds for AIS3+ injury were reported for nearside crash involved females while a decreased odds ratio was reported for far-side crash involved females. The far side findings were not shown to be statistically significant [23].

Height and Weight- Mock et. al. investigated the combined effect of occupant body weight and height using the Body Mass Index (BMI). This study identified an increased risk of mortality with increasing BMI during serious crash events [24]. The odds ratio for fatality was reported to be 1.013 for each kilogram increase in body weight using a 60 kg reference category. An odds ratio of 1.037 was found for each unit increase in BMI (reference value BMI=20). BMI is calculated by dividing body weight in kilograms by the square of body height in meters. A BMI < 27 is considered normal, BMI > 27 and BMI < 31 is considered overweight while a BMI > 31 is considered obese. Findings of the Mock study support the concept that overweight and obese vehicle occupants are at a higher risk for injury than occupants with a normal body mass index. Augenstein et. al. identified increased risk for occult liver injury for obese occupants based on investigation of injury patterns for CIREN crash cases [5].

Based on NASS/CDS analysis results, no conclusive evidence of the influence of BMI on injury was found when odds ratios for MAIS2+ and MAIS3+ injuries were reviewed. Unlike the odds ratio for injury, the fatality estimates comparing occupants who have a BMI > 31 and those having a BMI < 31, showed that the obese group had fatality odds 1.42 (95% CI 1.393,1.449) times that of the non-obese group.

RESULTS

During this study, crash factors that are not currently in use by ACN systems were evaluated to understand the degree to which they could improve accuracy of MAIS3+ injury recognition. Changes in accuracy can be assessed by comparing the sensitivity and specificity for the baseline criteria including only a deltaV threshold by crash direction to potentially enhanced models including other crash attributes. Those variables which directly increase the number of injured occupants recognized were prioritized ahead of those variables whose impact on increasing model specificity was more significant.

Model sensitivity is defined as the number of correctly identified injured occupants divided by the complete population of injured occupants. A sensitivity of 75% would indicate that three quarters of all those injured were correctly identified. While one quarter of the injured population were incorrectly flagged as uninjured. The specificity of a model indicates the percentage of a population which is correctly diagnosed as uninjured when they are, in fact, not injured. High sensitivity and high specificity are desirable characteristics for a predictive model.

Table 4 shows the baseline capture rates for a model including only deltaV, crash direction and knowledge of occupant seating position. A 10% threshold for serious injury is applied here.

Table 4. Baseline model performance by crash mode: includes deltaV, crash direction, seating position

Crash Mode	Sensitivity	Specificity
Frontal	63.0%	82.0%
Nearside	92.1%	53.9%
Farside	54.1%	85.4%
Rear	41.6%	95.8%
Rollover	0.0%	0.0%

An evaluation of models including baseline data (i.e. deltaV and crash direction) was conducted plus each of the following crash attributes individually. Each variable combination was applied against NASS/CDS data from 2002 and 2003 for frontal, nearside, farside and rear crashes.

Crash Attributes:

3-Point Belt Usage
Rollover Occurrence
Complete Occupant Ejection
Occupant Age
Multiple-Impact Crash Events
Narrow Object Collision
Occupant Compartment Intrusion

Table 5 shows the performance of a model including deltaV, crash direction, occupant seating position and seatbelt usage. The addition of 3-point belt usage to the baseline model showed the highest improvement in model sensitivity and specificity across all planar crash modes. The addition of seatbelt usage was also critical for subsequent variables like rollover occurrence to be effectively interpreted.

Table 5. Baseline plus seatbelt usage model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	69.8%	84.2%
Nearside	93.1%	55.4%
Farside	73.2%	85.9%
Rear	62.5%	95.9%
Rollover	0.0%	0.0%

Due to the high rate of injury for rollover crash involved occupants, the occurrence of rollover was the next most influential variable in capturing MAIS3+ injured occupants. As discussed above, unbelted occupants involved in rollover crashes make up a large percentage of the severe and fatally injured occupants for this mode. Without knowledge of seatbelt usage, a rollover crash in the absence of other information does not exceed the 10% threshold for injury as applied in this study. However, if seatbelt usage is known, the occurrence of rollover for an unbelted occupant identifies over 2/3 of the MAIS3+ injured occupants with a 73.3% specificity as shown in Table 6. Current technology relies on verbal information to recognize that a rollover has occurred in the absence of a significant planar crash.

Table 6. Baseline, seatbelt usage and rollover model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	68.8%	85.1%
Nearside	92.4%	60.2%
Farside	64.3%	86.6%
Rear	60.6%	96.3%
Rollover	67.4%	73.3%

Table 7 shows the effect of monitoring and recording more than one significant impact event.

Table 7. Baseline, seatbelt usage, rollover and multiple impact model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	69.9%	84.4%
Nearside	92.4%	60.2%
Farside	64.3%	86.6%
Rear	60.6%	96.3%
Rollover	67.4%	73.3%

In Table 8 below, occupant age was introduced. The effect on improved model sensitivity and specificity is noticeable for all modes, however this information is not readily available from sensor systems currently used in vehicles. This information can be derived from verbal communication between telematics service providers if occupants are present and alert following a crash.

Table 8. Baseline, seatbelt usage, rollover, multiple impact and occupant age model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	70.8%	83.5%
Nearside	96.8%	62.2%
Farside	66.7%	88.6%
Rear	62.7%	95.6%
Rollover	67.4%	73.3%

The occurrence of a narrow object impact was added next. Table 9 shows the relative effect on injured occupant capture rate with this variable. Like occupant age, knowledge that a narrow object collision has occurred is not readily available from vehicle sensor information. This data may be provided through verbal exchange with crash involved occupants or eyewitness reports. Use of crash pulse may not be an effective way to derive crash partner (i.e. trees, poles, posts) information at this time.

Table 9. Baseline, seatbelt usage, rollover, multiple impact, occupant age and narrow object impact model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	72.2%	84.1%
Nearside	93.8%	65.5%
Farside	79.7%	88.6%
Rear	63.1%	96.4%
Rollover	67.4%	73.3%

Occupant compartment intrusion was added next. The effect of compartment intrusion knowledge leads to an increase in sensitivity for side impact crashes while reducing the capture rate for frontal crash occupants.

Table 10. Baseline, seatbelt usage, rollover, multiple impact, occupant age, narrow object and intrusion model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	70.5%	87.1%
Nearside	96.2%	71.5%
Farside	79.8%	88.7%
Rear	68.7%	95.8%
Rollover	67.4%	73.3%

Next, knowledge that an occupant has been ejected was most influential in capturing additional injured occupants for each crash mode. This information should raise rescue priority considerably, however knowledge of seatbelt usage and the occurrence of rollover effectively captures over 68% of the ejected population without direct knowledge that an ejection has occurred. These occupants would be flagged as high risk rollover occupants due to non-belt usage.

Table 11 identifies the improvement in model sensitivity and specificity based on knowledge of ejection.

Table 11. Baseline, seatbelt usage, rollover, multiple impact, occupant age, narrow object crash, intrusion and ejection occurrence model performance by crash mode

Crash Mode	Sensitivity	Specificity
Frontal	70.6%	87.9%
Nearside	94.4%	73.1%
Farside	81.2%	88.6%
Rear	73.4%	96.1%
Rollover	72.4%	71.2%

DISCUSSION

The use of airbag deployment by crash direction as an approximate threshold for ACN system triggering currently provides a highly sensitive criteria for the recognition of MAIS3+ injured occupants. Based on the information presented in Tables 1 and 2, nearly 61,000 (60.3% of total) tow-away crash involved occupants who sustain MAIS3 and higher injuries would be correctly identified each year based on this criterion alone. This calculation assumes that all vehicles are equipped with ACN technology and no additional information is available from which to make rescue decisions.

Table 2 also indicates that this simplified filtering method is only 54% specific for frontal crashes and only 31% specific for nearside crashes. This corresponds to a 16 mph deltaV for frontal and rear crashes and an 8 mph threshold for side impacts as evaluated.

In the absence of additional information, a large percentage of occupants will be classified as potentially injured when, in fact, they may not be. If all vehicles were equipped with ACN technology, and dispatch decisions were based only on transmitted data, over 910,000 (27% of all non-MAIS3+ injured) tow-away crash involved occupants would exceed ACN system deployment thresholds each year without any AIS3 or higher injuries. It should be mentioned that tow-away crash occupants make up only ¼ of the total crash population across all severities. A large number of property damage crashes occur that were not included in this study. Without improved information describing crash events, an unnecessary waste of resources may result.

As the prevalence of ACN technology increases, greater numbers of these non-injured calls will take place if more accurate assessments of crash severity are not made. Without using readily available crash information like the use of seatbelts, the occurrence of multiple impacts or that a rollover has occurred, ACN calls may not receive the highest priority necessary.

If each of the parameters listed in Table 11 were available for use during the dispatch of rescue, 75,816 MAIS3+ injured occupants (75.1% of total) could be recognized remotely without the introduction of other information. Even with these known parameters, 471,000 tow-away crash involved occupants would exceed ACN system deployment thresholds each year without any AIS3 or higher injuries.

Use of Crash Information for Medical Treatment

So far, the primary focus of this text has been to highlight the potential benefit of transmitting an expanded set of crash attributes to remotely identify occupants in need. However, in-hospital medical staff and rescue providers may also significantly benefit from additional information describing an occupant's mechanism of injury. This information may be valuable during on-scene triage of occupants, in preparation for occupants in transport to emergency rooms/trauma centers and during decision making for in-hospital diagnostic testing.

A subset of injuries, known as occult injuries, go undetected by rescue providers where no external signs of occupant trauma (i.e. external bleeding, lacerations, abrasions, bruises and broken bones) are observed on-scene or even during preliminary in-hospital assessment. Without overt signs of trauma, occupants who have sustained these potentially life threatening and occult injuries could be improperly triaged to medical care facilities not equipped to diagnose or adequately treat these injured occupants. Also, life threatening delays in treatment may take place before some serious injuries are diagnosed.

Ongoing research by the 10 centers of NHTSA's Crash Injury Research and Engineering Network (CIREN) has focused on the identification of occult injuries and crash characteristics that could be associated with them. A series of injuries have been studied and documented in detail.

Among these is the occurrence of occult liver or abdominal injury common during some frontal and farside crashes. Crash characteristics which lead to heart and aortic injuries were studied in detail. These injuries are common during certain nearside crash events and severe injury risk was found to increase for the elderly and often lead to fatality if undetected and untreated. During farside crash events involving unbelted occupants, severe head injuries are prominent. Recognition that this injury mechanism may have occurred is important so that necessary diagnostic testing can be performed followed by treatment before irreversible damage occurs.

In an effort to improve recognition of serious injuries in the field and improve in-hospital medical care, the William Lehman Injury Research Center has compiled a series of crash descriptors in order to improve rescue care decisions and to help educate practitioners about these common injury mechanisms. The pneumonic "SCENE" has been suggested to help rescue providers screen for crash conditions associated with certain occult injuries.

These criteria are as follows:

S teering wheel deformation- Lift the air bag and look for a bent steering wheel rim. Internal injuries to the abdomen, thorax may be likely.

C lose proximity of the driver to the steering wheel- Occupants of small stature or large girth sitting close to the steering wheel are at greater risk of internal injuries particularly during frontal collisions with airbag deployment.

E nergy of the crash- Twenty or more inches of vehicle crush indicate high crash forces that can cause serious internal injuries.

N on-use of seat belts- Non-use of lap or lap/shoulder belts in combination with high energy events could result in multiple impacts within the occupant compartment and greater probability of internal injuries.

E yewitness reports including accounts of the object struck and the principle direction of crash force- This data suggests that verbal reports, photos, and video images of the interior and exterior of the crash vehicle graphically conveys the severity of the crash, and can indicate the probability and type of internal trauma.

CONCLUSIONS

Current ACN technology aids dispatch and rescue care providers to effectively identify and accurately locate occupants who may be injured in the event of a crash. The introduction of additional crash parameters during the transmission and interpretation of crash characteristics has the potential to improve this recognition process significantly. The following information has been identified as important for the recognition of seriously injured occupants:

1. crash severity (deltaV)
2. impact direction
3. use of 3-point belts for each occupant
4. occurrence of a rollover crash
5. occurrence of multiple impact events
6. age of occupants involved in the collision
7. narrow object impact
8. extent of compartment intrusion
9. occupant ejection

If the use of 3-point belts, occurrence of rollover and the occurrence of multiple impact events is supplied in addition to the fact that an airbag has occurred, ACN systems could identify 73.1% of the MAIS3+ injured occupants with full deployment across the vehicle fleet. This assumes knowledge of crash direction as well.

The inclusion of additional parameters as shown above would aid to improve this capture rate for injured occupants however this data may not be available through on-board vehicle sensors in the near term for use by remote dispatch personnel.

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CHARACTERISTICS OF MULTIPLE IMPACT CRASHES THAT PRODUCE SERIOUS INJURIES

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ABSTRACT

Researchers analyzed the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) 1998-2002 to examine the characteristics of single and multiple impact crashes. In addition to a statistical analysis, individual cases were studied to determine factors that contributed to injury risk.

Multiple impact crashes (MICs) make up 42 percent of all tow-away crashes that occurred on US roadways between 1998 and 2002. The risk for high-severity injuries is about 1.5 times greater in MICs than single impact crashes in moderate and high-range delta velocities. The average delta velocity values of single impact crashes (SICs) and MICs are similar in all tow-away crashes. Impact speeds for MICs resulting in MAIS3+ (Maximum Abbreviated Injury Scale: level 3 or greater) injuries are lower than that for SICs. A frontal crash followed by a second frontal crash occurs most often, followed by near-side/near-side and front/near-side multiple impact crashes.

After the initial investigation of MICs, belted drivers became the focus of this study, because the kinematics of unrestrained occupants is often too complicated. The most harmful category is front followed by front MICs for the population of belted drivers analyzed.

Based on case reviews, the researchers found that multiple impact crashes could be better described by separating them into two categories – incidental and consequential. For the incidental cases, only one impact was influential in the injury outcome. In consequential cases, both impacts were 15 mph (24 km/h) or greater delta velocity. Cases with higher severity secondary impacts were also classified as consequential.

The following were associated with increased injury severity in consequential MICs: more than one injurious impact; initial injury exacerbated by the second impact; the first impact caused the occupant to be out of position for subsequent impacts; crumple zones exhausted by the first impact; safety devices deployed during the first impact making them unavailable for subsequent impacts.

The frequency and injury risks for each combination of MICs are shown in this paper.

INTRODUCTION

A multiple impact crash is one in which a vehicle undergoes two or more impacts during a single crash sequence. Neither the initial impact nor the subsequent impact(s) is limited in any direction, sequence, or impacted object. After the initial investigation, the data analysis portion of this research considers only multiple impact crashes that do not involve rollover, where the drivers were not ejected, and where the drivers were belted. This population of multiple impact crashes will be referred to as “MICs”. The population of crashes that involve only one impact will be referred to as single impact crashes or “SICs”.

Several recent statistical studies of multiple impact crashes have been published (Digges, 2003 and Lenard, 2004). The purpose of the present study is to build on the past statistical analysis and introduce in-depth reviews of accident cases involving multiple impacts in order to better understand these crashes.

From 1998 through 2002, approximately 5,333,129 multiple impact, tow-away crashes occurred on U.S. roadways, based on NASS/CDS data. This is approximately 42 percent of all tow-away crashes. These crashes contributed 43 percent of all drivers’ MAIS3+ injuries and 47 percent of all driver fatalities. The fatality equivalent is almost 11,000 lives per year (all occupants). The average yearly cost of this phenomenon is about $37 billion.

The economic impact and human toll of multiple impact crashes is significant, therefore further research, analysis, and testing are needed to adequately address this issue.

ANALYSIS OF MULTIPLE IMPACT CRASHES

The researchers queried the NASS/CDS database to tabulate how often each direction of impact occurred during the first and second impacts. This query includes those crashes involving two or more impacts, but only the first and second most significant impacts were considered.

The "most significant impact" indicates the most severe impact whether it is the first, second or any other subsequent impact. The "other significant impact" indicates the second most severe impact. In a crash where the first and the third events are the most significant, the second event is not considered in the discussion to follow. Most MICs (59 percent) consist of two impacts while the remaining (41 percent) represent two or more impact MICs.

Table 1 shows the distribution of the 5.3 million multiple impact crashes by crash direction of the first and second significant impacts. The side impacts have been separated according to their direction. The near category indicates the impact was on the driver's side. The far category indicates the impact was on the passenger's side.

Table 1.
Percent Frequency of
Collision Sequence for All MICs

		2nd Impact				Total
		front	**near**	**far**	**rear**	
1st Impact	**front**	16%	12%	11%	6%	45%
	near	4.0%	6.0%	4.0%	1.0%	15%
	far	5.0%	4.0%	8.0%	1.0%	18%
	rear	20%	0.5%	2.0%	1.0%	24%
		45%	23%	24%	9%	

The most frequent first impact is the frontal impact at 45 percent of the total. The most frequent second impact is also a frontal impact at 45 percent. A rear impact, as the first impact, followed by a frontal impact (rear-front) is the most frequent collision combination at 20 percent. This collision sequence is a typical rear-end collision followed by a frontal impact. The front-front, at 16 percent, is next most frequent. The least frequent collision sequence is the rear-near MIC at 0.5 percent.

The researchers used the same method to find the frequency of MIC collision sequences with regard to restrained drivers. The population of MICs with restrained drivers from 1998 to 2002 is 3.2 million. Belted drivers became the main focus of the research because often times the mechanics of an unrestrained occupant in multiple impacts is too difficult to analyze. Table 2 shows the percent frequency outcomes for collision sequence in this population.

Table 2.
Percent Frequency of Collision Sequence
For Belted Drivers

		2nd Impact				Total
		front	**near**	**far**	**rear**	
1st Impact	**front**	17%	13%	11%	7%	48%
	near	5.4%	6.5%	4.1%	0.68%	17%
	far	5.3%	4.5%	8.2%	1.2%	19%
	rear	15%	0.61%	0.73%	0.63%	17%
		42%	24%	24%	9%	

The collision sequence occurring most often in this dataset is the front-front collision at 17 percent. This category is followed by the rear-front (15 percent), front-near collisions (13 percent) and front-far collisions at (11 percent).

The total number of MAIS3+ injured and belted drivers in MICs is 89,125 (973 unweighted). Table 3 is the corresponding percent frequency by MIC collision sequence for this population. The front-front sequence is most common (20 percent) when MAIS3+ injuries result. Next is near-near (15 percent), front-far (13 percent) and front-near (11 percent). The near-near category is seventh most common in frequency for belted drivers, but second most common in resulting MAIS3+ injuries.

Table 3.
Percent Frequency of MAIS3+ Injured and Belted Drivers by Collision Sequence

		2nd Impact				Total
		front	**near**	**far**	**rear**	
1st Impact	**front**	20%	11%	13%	3.9%	48%
	near	8.5%	15%	9.2%	2.1%	35%
	far	4.3%	2.4%	7.5%	0.4%	14%
	rear	2.2%	0.2%	0.2%	0.2%	3%
		35%	28%	30%	7%	

The total number of AIS3+ (Abbreviated Injury Scale: level 3 or greater) injuries for belted drivers in MICs is 129,168 or 48 percent of all AIS3+ injuries.

Figure 1 shows the breakdown by body region for MICs and SICs.

MICs result in more than one-half of the serious head injuries reported for belted drivers. The trunk and extremities make up close to one-half of the serious injuries in each body region. These findings are remarkable in that MICs are 42 percent of the total crash population, but result in almost one-half, if not more, of the reported serious injuries.

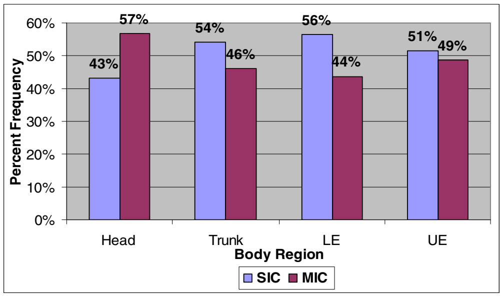

Figure 1. Percent Frequency of AIS3+ Injuries by Body Region For Belted Drivers - NASS/CDS 1998-2002.

Risk of Injury

Risk is a calculation that reveals the chances that something will occur given certain conditions. For instance, the risk of injury in a frontal crash is the total number of injuries sustained in a frontal crash divided by the total number of occupants who were exposed to a frontal crash.

The researchers calculated the risk associated with tow-away single and multiple impact crashes where the driver was belted and no rollover or ejection occurred. Almost 2 (± 0.34 percent) out of 100 drivers involved in an SIC will sustain an MAIS3+ injury. Over 4 (± 1.1 percent) out of 100 drivers involved in an MIC will sustain an MAIS3+ injury. For this population, the trend shows that the risk of an MAIS3+ injury in an MIC is higher than that in an SIC.

The relative risk for MAIS3+ injuries in this populations is 2.2, indicating that a driver is 2.2 times more likely to sustain an MAIS3+ injury in an MIC compared to an SIC.

Figure 2 shows the belted drivers' risk of AIS3+ injuries by body region for both MICs and SICs. Note that the risks for the head and the trunk in MICs are both statistically significantly higher than those for SICs. Although multiple impact crashes occur less frequently on U.S. roadways, they represent a higher risk of serious injury than single impact crashes.

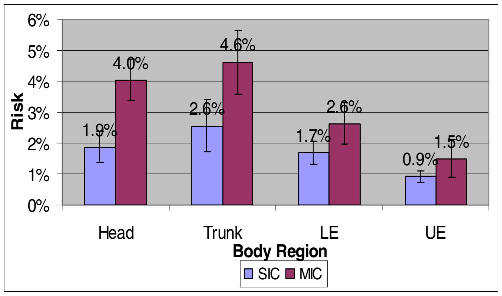

Figure 2. Risk of AIS3+ Injuries by Body Region For Belted Drivers - NASS/CDS 1998-2002.

Table 4 shows that of the 16 MIC categories, the greatest risk of MAIS3+ injury to belted drivers is in the near-rear MIC at 11 percent. This is followed by rear-far (9.7 percent), near-near (8.3 percent), and near-front (7.9 percent). Three of the top four risk categories have a near-side component. Risks for each collision sequence and the associated confidence intervals are shown in Table 4.

Table 4.
Risk of MAIS3+ by Collision Sequence
For Belted Drivers
with Associated Confidence Interval

		2nd Impact			
		F	N	Far	R
1st impact	F	5.2 % (±2.9 %)	5.6 % (±1.7 %)	5.3 % (±2.1 %)	2.0 % (±1.4 %)
	N	7.9 % (±6.1 %)	8.3 % (±3.6 %)	7.6 % (±4.6 %)	11 % (±11 %)
	Far	3.9 % (±2.9 %)	4.8 % (±2.0 %)	4.3 % (±2.5 %)	4.1 % (±5.0 %)
	R	0.52 % (±0.26 %)	3.2 % (±2.8 %)	9.7 % (±9.9 %)	1.8 % (±2.8 %)

For the sake of comparison, Table 5 shows the risks associated with SICs for belted drivers with MAIS3+ injuries. A near-side impact poses the greatest risk at 3.8 percent and is lower than that of 10 MIC categories.

Table 5.
Risk of MAIS3+ by Collision Sequence
For Belted Drivers in SICs
with Associated Confidence Intervals

Front	Near	Far	Rear
2.2%	3.8%	1.9%	0.4%
±0.5%	±1.4%	±0.81%	±0.26%

Delta Velocity

The researchers divided the MICs and SICs from NASS/CDS 1998-2002 into three groups of delta velocity values: <15 mph (24 km/h); 15-25 mph (24-40 km/h); 25+ mph (40+ km/h). The MIC cases were subdivided according to the most severe delta velocity. For instance, if the case consisted of a 12 mph (19 km/h) first impact and a 17 mph (27 km/h) second impact, it was categorized as a 15-25 mph (24-40 km/h) case. For comparison to the SIC, the researchers chose the higher delta velocity, the predominant delta velocity, of the MIC. Figure 3 shows the risk of MAIS3+ injury distribution over the delta velocity ranges for both MICs and SICs for belted drivers.

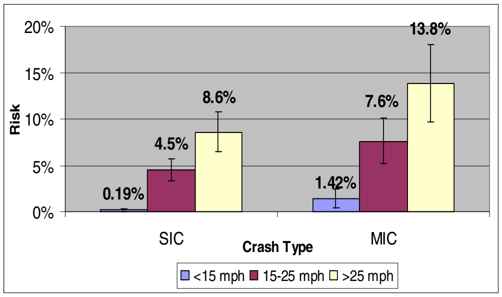

Figure 3. RISK of MAIS3+ Injuries to Belted Drivers by Delta Velocity - NASS/CDS 1998-2002.

In all three delta velocity categories, the risk is greater in MICs than in SICs. The difference in risk of MAIS3+ injury between SICs and MICs is not statistically significant, though for belted drivers the trend shows that MICs typically pose a greater risk for high-severity injuries than SICs.

Impact Speed

The impact speed is a reconstructed value of vehicle speed at the time of collision. The researchers queried the impact speed of SICs and MICs in NASS/CDS 1998-2002 where the impact speed was below 90 mph (145 km/h) to eliminate extremely high and questionable impact speeds.

The average impact speed for SICs was 33 mph (53 km/h) whereas that for the most significant impact in MICs was 44 mph (71 km/h). Note that in this query the researchers only considered MICs for which there were two documented delta velocities, because the confidence and accuracy of the impact speed is greater with two known values for delta velocities.

The impact speed of MICs is generally 10 mph (16 km/h) faster than that of SICs. Although this is based on a limited number of cases, it could imply that multiple impact crashes are higher energy events than single impact crashes.

The researchers also determined the percent frequency of impact speeds where the injury level was MAIS3+. Most high-severity injury multiple impact crashes lie in the 30-40 mph (48-64 km/h) range. The remaining crashes are in the 40+ mph (64+ km/h) range in this MAIS3+ category. The majority of the high-severity injury SICs are in the 40+ mph (64+ km/h) impact speed range. Figure 4 shows the distribution of impact speeds for this MAIS3+ grouping.

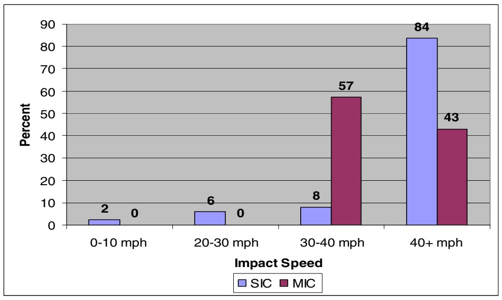

Figure 4. Percent Frequency of Impact Speeds: SIC vs. MICs for MAIS3+ crashes.

The average impact speed was 53 mph (83 km/h) for SICs whereas that for the most significant impact in MICs (with at least two known delta velocities documented) was 46 mph (74 km/h). In this MAIS3+ grouping, the SICs require higher impact speeds than the MICs to result in MAIS3+ injuries. This implies more severe crash characteristics in MICs than SICs, as they are resulting in the same injury severity but at a lesser impact speed.

HARM

The unit cost of crash injuries has been published by NHTSA (DOT HS 809 446). These unit costs can be used to calculate the total annual cost for injuries of all severities that are associated with any category of crashes (Fildes, 1996). The total yearly HARM (a metric for quantifying costs of injury associated with motor vehicle crashes) for all MIC categories is more than $37 billion. See Table 6 for HARM values in all MIC categories. The highest HARM values are in the front-front, front-far, front-near, and near-near categories. Relative to the number of occupants exposed to these crashes, the cost of multiple impact crashes outweighs that of single impact crashes by more than $3,200 per occupant exposed every year.

Table 6.
HARM by MIC Category

Sequence	HARM	Sequence	HARM
FF	$ 4.0	NF	$ 1.2
FN	$ 3.1	NN	$ 3.0
FFar	$ 3.4	NFar	$ 1.6
FR	$ 1.0	NR	$0.22
FarF	$ 1.3	RF	$ 1.1
FarN	$ 1.4	RN	$0.08
FarFar	$ 1.6	RFar	$0.34
FarR	$0.26	RR	$0.10

CLINICAL CASE REVIEWS

Injuries resulting from SICs and MICs are documented and readily available in the NASS/CDS data. For MICs, however, the data is not clear as to *when* during the multiple impact collision each of the injuries was sustained.

Perhaps all of the significant injuries were sustained during the initial impact, therefore implying the subsequent impacts were minor. Or the reverse could be true. Either way, the NASS/CDS database is not constructed in such a way that one can query *when* (during which impact) the injuries occurred.

For this reason, the researchers conducted a clinical review of numerous multiple impact crashes to determine *when* the injuries occurred. The goal was to better decipher the problems inherent in multiple impact crashes. See “Characteristics and Crash Factors Producing High-Severity Injuries in Multiple Impact Crashes”, reference [1], for detailed information regarding these clinical reviews.

The team reviewed a group of 50 NASS/CDS cases and 13 Crash Injury Research and Engineering Network (CIREN) cases in detail. Cases were selected for review if the vehicle did not rollover, if the driver was belted and not ejected, and if the two most significant events were either of a frontal or near-side nature. The crash may have contained impacts to other sides of the vehicle, but the team required that the two most significant impacts involve the front or near-side (in any combination thereof). This limitation served to narrow the research scope.

The crashes were broken down into two phases: most significant impact and other significant impact. This assignment enabled the reviewers to look at only the two highest injury-causing impacts, as there were more than two impacts in some crashes.

In addition, the researchers characterized and referred to the two impacts under review as the first and second significant impacts. This is different than the most significant impact and the other significant impact in that either could have been the first or second impact.

After reviewing the documented injuries, vehicle inspection data, vehicle inspection photographs, and scene diagrams, the researchers determined the injury mechanism. Subsequently, they determined the timing of injury, that is, during which significant impact the injury was sustained.

The clinical reviews revealed five properties of multiple impact crashes.

- A crash with multiple impacts may result in injuries due to more than one impact.
- Injuries sustained during the first impact can be exacerbated during subsequent impacts.
- After the first impact, an occupant is likely moved out of position prior to the subsequent impact(s).
- The vehicle’s crumple zones, intended for occupant protection, are exhausted during the first impact and are therefore unavailable for subsequent impacts.
- Occupant protection devices, such as airbags, may be depleted after the initial impact, and therefore are unavailable for subsequent impacts.

CONSEQUENTIAL VERSUS INCIDENTAL MICs

The clinical case reviews led the researchers to expand the definition of multiple impact crashes. In some instances, the data showed that the first impact either caused injury or in some way influenced the injury incurred during the second impact. In other cases, the researchers found that only one of the significant impacts had any noteworthy bearing on the injury outcome. Perhaps the first impact caused the injury, but the second impact was a minor side slap that did not influence the injury outcome in any way. Clearly these examples are both multiple impact crashes, but now the question arises: Do both impacts influence the injury outcome?

The researchers conducted a review of more than 100 additional NASS/CDS multiple impact crashes from 1998 through 2002. The purpose was to find a way to further define or classify the multiple impact crashes. The researchers subdivided the MIC crashes into two classifications based on the characteristics of the crashes themselves: incidental and consequential multiple impact crashes.

An incidental MIC (IMIC) is defined as a single collision sequence in which the subject vehicle incurs more than one impact but only one of those impacts is influential in the injury outcome. Following is an example of an IMIC.

A vehicle incurs a front-near impact with respective delta velocities of 15 mph (24 km/h) and 5 mph (8 km/h). The frontal collision deploys the airbag and forces the belted driver toward the front of the vehicle. The driver sustains bilateral tibia and fibula fractures and left radius/ulna fractures as a result of the frontal impact. The occupant is no longer in a pre crash position. The near-side impact is to the left rear fender at a 5 mph (8 km/h) delta velocity. No injuries are incurred during the second collision. This example shows that although the collision had multiple impacts, the injury outcome was dependent upon only one of the impacts.

A consequential MIC (CMIC) is defined as a single collision sequence in which the subject vehicle incurs more than one impact and where at least two of those impacts influenced the injury outcome. The impacts may influence the injuries in a number of different ways. An example of a CMIC follows.

A collision involves an 18-year-old female driver. She is belted and the driver's frontal airbag deploys during the first of three impacts. The first impact is a frontal impact at 30 mph (48 km/h) stretching across the front of the vehicle. This is followed by a minor impact to the left rear fender. The final impact is a frontal, 15 mph (24 km/h) delta velocity impact to a pole. The injuries sustained in the collision include four AIS1 abrasions; five AIS2 lacerations; contusions; concussions or fractures; and one AIS3 orbit fracture.

This collision is classified as a CMIC because of the high delta velocities and the injuries sustained. The nose and orbit fracture were likely sustained during the third impact. At that point the airbag had already been deployed and deflated as it was exhausted during the first impact. Had the airbag been available during the first *and* the third impacts, the injuries would have likely been mitigated.

Two predictors of consequential multiple impact crashes were uncovered in the case reviews. If the crash had either of the following characteristics, it could be considered a CMIC:

- At least two delta velocities are >15 mph (24 km/h)
- The second impact is more severe than the first

The following charts (Figures 5-8) show the risk of an MAIS3+ injury for a belted driver in CMICs and IMICs. They are separated by first impact direction. Near-near collisions pose the highest risk to this population. This is different from MICs in general where near-rear MICs pose the highest risk.

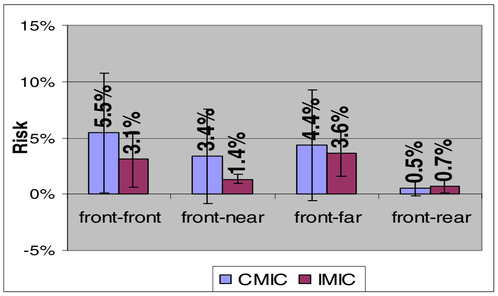

Figure 5. Risk of MAIS3+ Injury to Belted Driver in CMIC and IMIC – Front Impact First.

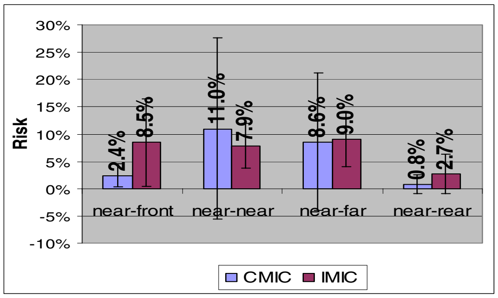

Figure 6. Risk of MAIS3+ Injury to Belted Driver in CMIC and IMIC – Near Impact First.

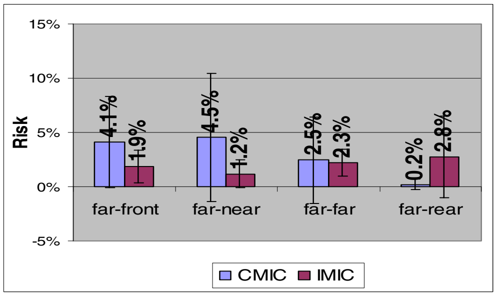

Figure 7. Risk of MAIS3+ Injury to Belted Driver in CMIC and IMIC – Far Impact First.

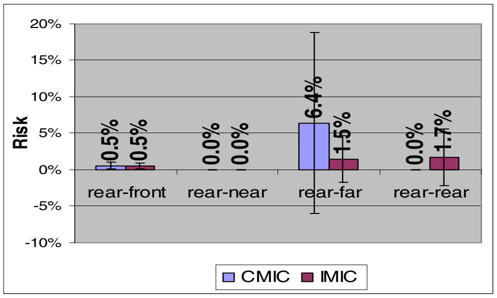

Figure 8. Risk of MAIS3+ Injury to Belted Driver in CMIC and IMIC – Rear Impact First.

Table 7 lists the risk of MAIS3+ injuries per CMIC and IMIC categories in addition to the frequency of MAIS3+ injuries associated with those risks and collision sequences.

Table 7.
Risk and Frequency of MAIS3+ Injuries in CMIC/IMIC Categories

	CMIC	# of Injuries	IMIC	# of Injuries
FF	5.5%	2611	3.1%	3786
FN	3.4%	439	1.4%	2356
Ffar	4.4%	587	3.6%	4607
FR	0.5%	150	0.7%	689
NF	2.4%	742	8.5%	4086
NN	11.0%	225	7.9%	6693
Nfar	8.6%	554	9.0%	2247
NR	0.8%	39	2.7%	175
FarF	4.1%	1348	1.9%	1417
FarN	4.5%	771	1.2%	943
FarFar	2.5%	460	2.3%	2389
FarR	0.2%	5.7	2.8%	152
RF	0.5%	467	0.5%	904
RN	0.0%	0	0.0%	0
Rfar	6.4%	53.1	1.5%	53.0
RR	0.0%	0	1.7%	51

CMICs emerged as the foremost component of multiple impact crashes, and therefore should be underscored and considered for further study. Where the IMICs could be classified as a single impact crash due to the insignificance of one of the impacts, CMICs are viewed as more noteworthy because they comprised the very safety problems inherent to multiple impact crashes.

FINDINGS AND CONCLUSION

The researchers defined and characterized multiple impact crashes, establishing a number of important findings:

- Multiple impact crashes make up 42 percent of all tow-away crashes that occurred on U.S. roadways in 1998 through 2002.
- The average yearly HARM value associated with MICs is $37 billion, which averaged over 42 percent of the total HARM per year for SICs and MICs combined.
- The majority of impact speeds of MICs are 10 mph (16 km/h) higher than those for SICs. Impact speeds for MICs resulting in MAIS3+ injuries are lower than that for SICs suggesting that delta velocities do not distinguish a high-severity/high-injury MIC from those of low severity.
- Front-front MICs occur most often with belted drivers, followed by near-near and front-near crashes. The most harmful category is front-front MICs.

The researchers divided MICs into two categories: incidental (IMIC) and consequential (CMIC):

- An IMIC is a single collision sequence in which the subject vehicle incurs more than one impact but only one of those impacts is influential in the injury outcome.
- A CMIC is a single collision sequence in which the subject vehicle incurs more than one impact and where at least two of those impacts influence the injury outcome.
- A crash is likely considered a CMIC if two delta velocities are 15 mph (24km/h) or greater or if the second impact is a higher severity than the first impact.
- Near-near CMICs pose the highest risk of MAIS3+ injury to belted drivers at 11 percent.

This research addressed the phenomena of multiple impact crashes and how their characteristics relate to high-severity injury outcomes. The researchers showed that in general, the risk of injury associated with MICs is higher than that of SICs. The study presents MICs as an occupant safety problem worthy of additional consideration by industry, regulators, and clinicians.

More specifically, the research shows that belted drivers, the population for whom the most occupant protection is designed, are at a greater risk in these MICs than those in SICs. The greater risk, coupled with the fact that $37 billion (in HARM) is associated each year with MICs, is enough to justify further research and countermeasures development for occupant protection in multiple impact crashes.

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