Updated Estimates of Potential Traffic Fatality Reductions With Automatic Collision Notification

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ABSTRACT

This paper updates the earlier work done by Wu, Craig, et al. (2013) that explored the effects of earlier emergency medical services (EMS) through Automatic Collision Notification (ACN) on passenger/driver survivability using Fatality Analysis Reporting System (FARS) 2005-09. In this continuing study the earlier results are updated using recent FARS 2009-2012 data, while additional factors together with ACN are also considered: such as EMS arrival, time to hospital, urban/rural location comparison, occupant age and correlation between EMS factors. Kaplan-Meier estimator is applied to compare the survival rates between two conditions (e.g., earlier versus late EMS notification); Proportional hazard model explores simultaneously multiple risk factors related to traffic mortality. Correlations between notification and EMS arrival are explored and especially in rural area. Based on FARS data from 2009-2012, Kaplan-Meier life curves clearly show the benefits associated with earlier notifications within 1-2 minutes (approximately 1.5-2.0% fatality reduction within a timeframe of 6 hours after crash) and earlier arrivals. The relative hazard ratio associated with collision notification, location and age are obtained from a multiple regression model, and the relatively higher fatality hazard (up to 4% higher) is associated the later notification of more than 2 minutes. This paper obtains the driver/passenger survival probability differences over time under different conditions of collision notifications, EMS arrivals, time to reach a hospital, and crash locations, furthermore, this analysis provides the estimations of lives that could potentially be saved (177 to 244 per year approximately) due to earlier crash notification, or Automatic Collision Notification (ACN).

1. INTRODUCTION

During 2009-2012, the Fatality Analysis Reporting System (FARS) data indicate that the traffic fatalities are approximately 33,000 per year in US (33,883 in 2009, 32,999 in 2010, 32,479 in 2011, and 33,561 in 2012, respectively), and approximately 83%~85% fatalities were from drivers and passengers each year. It has been a challenging effort to reduce the traffic fatalities, especially the target study population of drivers and passengers in light trucks and cars under 10, 000 lbs. by all possible means and new techniques. Automatic Collision Notification (ACN) system is one of such efforts and it has been available from some automobile manufacturers since the late 1990s. One benefit of these ACN systems may enable the injured occupants to inform the emergency response personnel quickly about location of a car crash.

Many prior publications have attempted to document the potential motor vehicle crash-related fatalities that could be reduced given ACN. Wu, Craig, et al. (2013) [1] explored the effects of earlier emergency medical services (EMS) through ACN on passenger/driver survivability. It was found that 154 to 290 additional lives per year (approximately 1.8% fatality reduction) could be saved by earlier collision notification times that could result from the presence of ACN systems in passenger vehicles and light trucks and vans. The earlier study used 2005 through 2009 Fatality Analytical Reporting System (FARS) data. The vehicle fleet, communication technologies, and other factors related to occupant safety may have changed in the past few years, and the potential fatality reduction estimates should be re-computed in the light of this changing vehicle fleet, communication technology, and mainly notification status. This updates estimates for potential annual lives saved by ACN using FARS 2009-2012 data, and additional factors together with ACN are also including urban versus rural crash location and occupant age.

Earlier studies were carried out by various researchers. In one study with a relatively small fleet of vehicles equipped with ACN, Kanianthra et al. [2] documented that EMS providers received notifications within two minutes of the crash in all cases while 20% of non-equipped vehicles took over 5 minutes, their study estimated that 240 to 765 lives could be saved. Using similar survival analysis approach, Clark and Cushing [3] estimated the potential benefits of ACN through analysis of 1997 FARS data. One of their models matching FARS fatalities estimated a total annual reduction of 421 fatalities (1.5%). The European Commission's 'eCall' program [5] published a final report regarding its crash notification related efforts (European Commission, 2009). The estimated motor vehicle crash occupant fatality reduction with ACN in the cited studies ranged widely from 1% to 12%.

Existing research has not yet dealt with the relative comparisons of different conditions statistically with sufficiently larger data sizes and significant P-values, for instance, to compare earlier versus later notification outcomes or earlier versus later arrival outcomes. Some relatively older data (FARS 1997) may not reflect today's EMS call status well [3], and the work done by Toyota [6] have provided clear comparisons of notification and arrival times for scenarios with and without ACN, but also proposed prior assumptions of the possible correlations between EMS notification, timeliness of arrival, and survivability. Correlations among EMS factors were rarely mentioned. While the authors are inspired by the earlier research[2-6], efforts are still needed to understand the following:

- Impact of earlier or automatic collision notification on occupant survivability and the potential for fatality reduction with ACN if introduced across the passenger vehicle fleet;
- Survival rate comparisons of varied EMS arrival times including the impact of earlier EMS arrival on survivability, and the impact of shorter time to reach hospital;
- Comparison of EMS response time and survivability in rural versus urban areas;
- Correlations between EMS factors, such as notification time versus arrival time; and
- The relationship between the traffic fatality hazard with several risk factors, including later notification, rural area, and older age, simultaneously.

Earlier crash notification, with timely EMS and earlier hospitalization, may all play a significant role in mitigating the effects of the injuries suffered in a motor vehicle crash. Research [11] has also indicated that proximity to advanced trauma care (earlier EMS and shorter distance to hospital) may also be a key factor in mitigating injury outcome. Since time is of essence in EMS response to such situations, driver/passenger survival rates can vary significantly between different time conditions (e.g., time elapsed before or after the notification call). This could possibly be exacerbated in the case of single vehicle crashes in the remote rural areas where a lone occupant of a vehicle may have lower likelihood to call and receive emergency services, especially within a short time frame. In this paper, the techniques of 'time-to-event', such as Kaplan-Meier estimator and Cox proportional hazard model, are used to address the time effect. This study explores the relative comparisons between different conditions or groups, such as survival rates with earlier notification versus late notification, and survivability in rural areas versus urban areas.

2. DATA AND STUDY DESIGN

EMS is most helpful to the drivers and passengers of passenger cars and light trucks if received within 6 hours immediately following a crash.[1,2] Data was compiled using the 2009-2012 FARS data, with specific evaluation of the 6-hour post-crash timeframe (EMS notification/arrival within 6 hours after crashes; data with missing notification/arrival information was excluded). Data cleaning efforts (defining times of notification, arrival, death, and missing data, et. al) were made in FARS data verification, and all key time variable coding were defined by the authors of NHTSA. For each crash coded in FARS, the following times are recorded: *crash*, EMS *notification*, EMS *arrival at scene of crash*, EMS *arrival at hospital*, and *time of death* (in the event of a fatality, see Figure 1 for definitions of time events and time intervals).

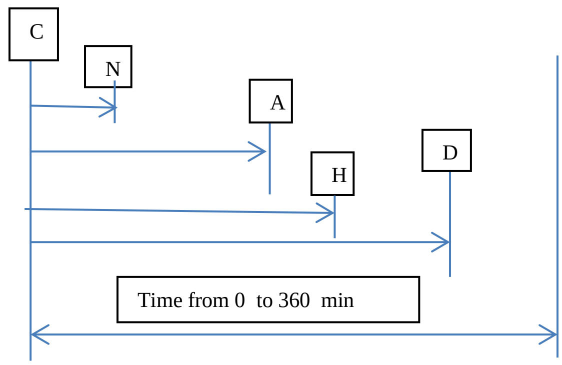

Figure 1: Crash time events and time elapsed between crash (C), notification (N), arrival (A), Hospital (H), and death (D).

These time-date values were used to generate the time intervals needed for the time-to-event or survival analysis. Note that only crashes with available notification and arrival times within six hour window after crashes were used. See Figure 2 for the data flow chart for this study: there were 88,703 fatalities and 29,916 incapacitating injuries under considerations (drivers and passengers in cars or light trucks), 68,043 of them died within 6 hours, and 33,125 fatalities were associated with known notification and arrival times (approximately 48.7% of the 68,043 fatalities within 6 hours, see Figure 3), and 9,873 of 33,125 people died instantly for whom ACN is of no help (crash to death time = 0), and the remaining 23,252 fatal cases are the research sample. They are matched with 24,812 cases of 'Incapacitating Injuries' within the same time frame of six hours as described as Table 2.

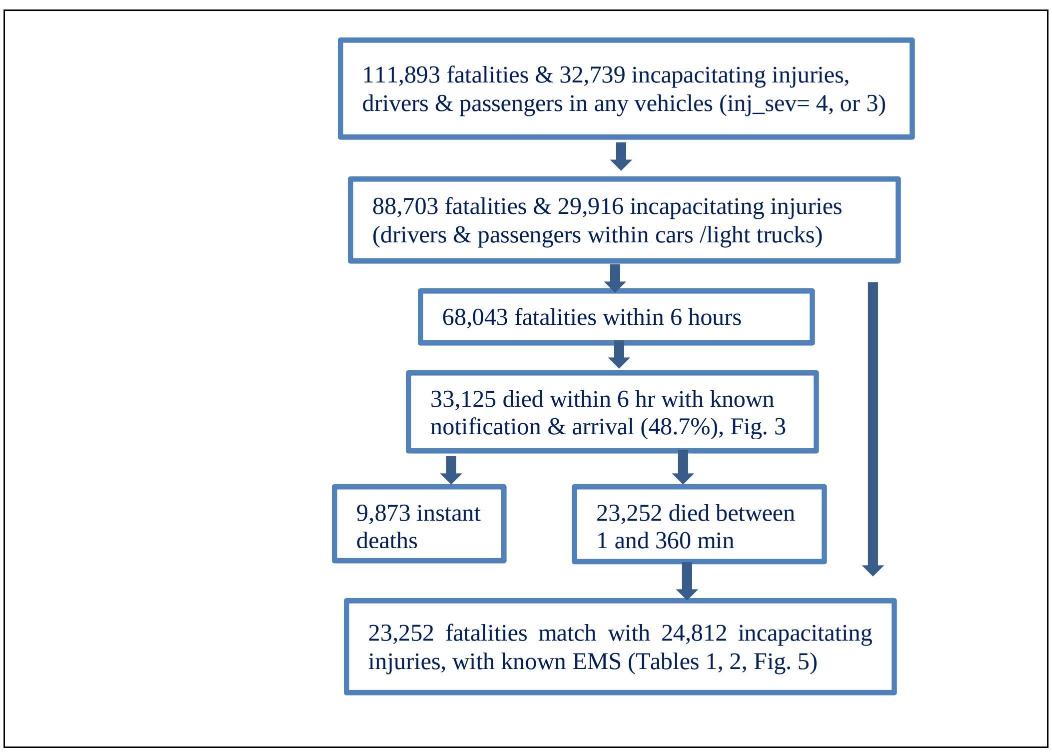

Figure 2: FARS 2009-2012 Population Study Sample

Table 1 shows the statistical descriptive summary for 23,252 fatalities that occurred from 1-360 minutes post-crash who were also associated with known notification and arrival time within six hours (overall, rural, and urban data). The definitions of rural and urban areas are from US Census Bureau.

Table 1: Overall, Rural and Urban EMS Response Times (minutes) Since Crash (FARS 2009-2012)

Overall 23,252 Fatalities Within 6 Hours with Known Notification/Arrival info		
Time	**Mean (min)**	**Std dev (min)**
Call	6.24	17.33
Arrival	16.74	20.29
Death	66.21	67.99
Rural 14,294 fatalities within 6 hours (61.5% of 23,252 fatalities)		
Call	7.25	19.16
Arrival	19.64	22.25
Death	66.46	67.05
Urban 8,924 fatalities within 6 hours (38.4% of 23,252)		
Call	4.61	13.74
Arrival	12.10	15.63
Death	65.74	69.41

FARS database used the key injury variable of '*inj_SEV*' to indicate injury severity as follows: 0 = No Injury; 1 = Possible Injury; 2 = Non-Incapacitating Evident Injury; 3 = Incapacitating Injury; 4 = Fatal Injury; 5 = Injured, Severity Unknown; 6 = Died Prior to Crash; and 9 = Unknown. In this study, two groups of 'Incapacitating Injury, 3' and 'Fatal Injury, 4' are focused, since these two groups need EMS help immediately, and is compared with 'Fatal Injury' group within same time window, for example, within 6 hours after crashes.

Figure 3 shows the fatalities over time (inj_sev=4). This fatality curve, or survival probability curve over time, S(t), indicates that approximately *86.6%* of fatalities occurring within 6 hours occurred within 100 minutes of the crash (including 9,873 instant deaths at time = 0). More details of this life curve will be discussed later using Kaplan-Meier Estimator [7]. Additionally, 20,083 died within 40 minutes since crashes (approximately 61% of all fatalities within 6 hours).

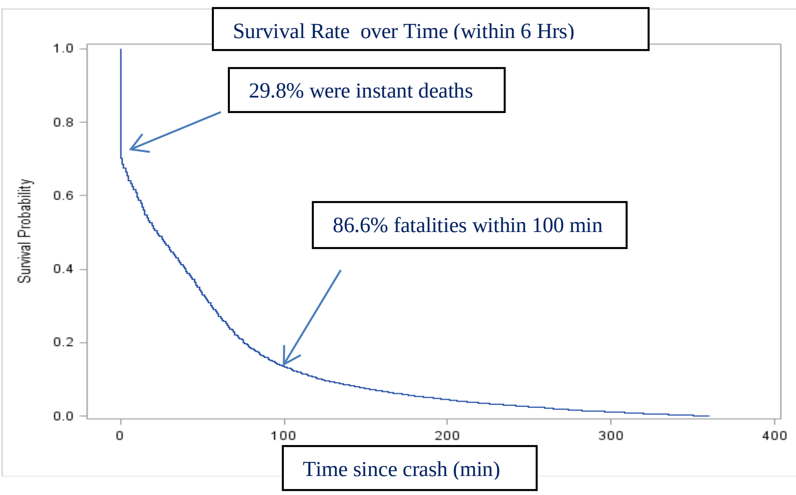

Figure 3: Survival rate, S(t), versus 'crash to death time' of fatalities within 6 hours (33,125 with known notification /arrival times, data from Figure 2).

For the purpose of analyzing the survival rate or proportion, the data set in this study includes the crashes that resulted in at least one fatality, and should not be generalized to the whole crash population. The values of 'inj_SEV=3, 4' are used as the study population, since these two categories need EMS help most while instant fatalities are excluded. There were 24,812 'Incapacitating Injury' cases (inj_Sev=3) that were matched with 23,252 fatalities (inj_SEV=4, within 6 hours after crashes and with known EMS information) in this *cohort study*, or follow-up study [9] as described by Table 2, which compares the subsequent occurrence of traffic injury severities between two groups whose EMS status differs. Fatality rate of 'earlier group' is R_e = A/(A+B), and R_L = C/(C+D) for 'later group', and the fatality relative risk (RR) is (R_L /R_e). The survival rate S(t) = (100% - Fatality Rate) over time, t.

Table 2: Cohort Study of Notification versus Traffic Severity within 6 Hours After Crash (inj_Sev = 3, 4)

Notification	**Fatal, Inj_Sev=4**	**Inj_Sev= 3**	**Total**
Earlier	A	B	A+B
Later	C	D	C+D
Total	23,252	24,812	48,604

3. SURVIVAL RATES WITH DIFFERENT EMS STATUSES

Various factors or EMS statuses may affect traffic fatalities: such as notification time, time of EMS arrival at the crash scene or time of EMS arrival at hospital. Furthermore, EMS services (notification, EMS arrival, et. al., as Table 1) in rural versus urban areas are also rather different. Time plays a very crucial role in life saving. All these issues will be explored in this section.

One of the most useful tools to compare the survival probability over time, S(t) (e.g. Figure 3), for each minute after crash, is a non-parametric method proposed by Kaplan and Meier that is used widely for medical research and reliability engineering [1 7]. The Kaplan-Meier estimator, or life curve, at any time is described by the following formula:

$$\hat{S}(t) = \prod_{t_i <= t} (1 - \frac{d_i}{n_i}) = \prod_{t_i <= t} (\frac{s_i}{n_i}) \tag{1}$$

where 'd_i' is 'deceased' subjects or fatalities, and 's_i' is the 'survivor' subjects or alive ('censored') drivers/passengers, and 'n_i' is total subject number (total persons in study). There were 360 equal intervals, with the length of one minute each since crash (i=1 to 360) if the survivability within 6 hours was focused in this analysis. The sign of 'ΠA_i' stands for the product of "$A_1A_2A_3$" if i=1 to 3.

In order to compare the traffic fatality relative risk or differences between different blocks or groups (such as earlier calls versus late calls), the Log-Rank test, compares the Kaplan-Meir life curves and obtains the statistical significance with p-value. The SAS Proc LifeTest is used for the calculation, and Kaplan-Meier estimator is also termed as 'Product-Limit Survival Estimates'. [7, 8]

3.1 Effect of Earlier Notification

In order to study the survival rates within 6 hours (study or research time) immediately following a crash, Table 3 is used to show the correlation between survival status and notification time, when all data (inj_sev = 3,4) are divided into a few groups based on notification time**.**

Table 3: Notification Time (min) versus Survival Status Within 6 Hours After Crash

Notification, N (minute)	Dead	Alive	Total	Alive % S(t)
N<=1 min	8772	9635	18,408	52.35
1<N <=2	2817	3137	5,954	52.69
2<N<=3	2266	2210	4,476	49.37
3<N<=5	3062	2928	5,990	48.88
5<N<=8	2339	2372	4,711	50.35
8<N<=15	2223	2453	4,676	52.46
15< N<=360	1773	2077	3,850	53.95
Total	23,252	24,812	48,064	51.62

Table 3 indicates that approximately 51% injury and fatality cases (24,362 out of 48,065) occurred within notification time <=1, 2 minutes (top two rows), and occupants also need EMS helps more than any other moments during these crucial two minutes. However, many risk factors, such as notification time, EMS arrival and EMS quality, crash severity, health condition and age, may all contribute to occupant survival status. Particularly, the earlier notification within 1-2 minutes would significantly improve survival rates compared with later notifications of ‘3-15 minutes’. Although Table 3 also shows that the survival rate is relatively high (53.95%) for the smaller group of ’15 <N<=360 minutes’, this smaller group might be associated with less severity crashes, better health conditions or other factors. This smaller group survived earlier crash time window and also happened to notify later than others, and more investigations may be needed for this survival status variation. Again Figure 3, together with Table 3, indicates the majority of fatalities happened very early and 86.6% fatalities occurred during 0-100 minutes, and 61% fatalities within early 40 minutes.

Based on the same format of Table 2 Cohort design, 24,812 ‘Incapacitating Injury’ cases were matched, within same time frame of 6 hours with 23,252 fatalities, and the total sample was then statistically ‘randomized’ (each case had the same probability) and ‘blocked’ (divided into two groups based on EMS notification time). The people with survival times longer than 6 hours were regarded as ‘censored’ data or alive within the current study time.

The status of ‘alive’ or ‘censored’ is also relative and changing over time (Table 4 or Figure 4). The total study sample can be divided into two blocks or groups: the *preferred* or *earlier* group is ‘Call <=1 min after crash and call time before death time’; the rest belong to a second, *un-preferred* group, for the purpose of understanding the effect of earlier notification on fatalities. The survival rate difference between the two groups with earlier (<=1 min) or late (>1 min) notifications is then compared using two Kaplan-Meier life curves and Log-Rank test. Table 4 displays the survival rates of the two groups within the study time (6 hours post-crash). The p-value from Log-Rank test is under 0.0001 (p-value<0.0001).

Table 4: Survivors and Fatalities within 6 Hours After Crash
(Notifications <=1 versus >1 min, inj_sev=3, 4, FARS 2009-12)

Notification, (min)	Dead	Alive	Total	Alive % S(t)
<=1 min	8,772	9,635	18,407	52.34
>1 min	14,480	15,177	29,657	51.18
Total	23,252	24,812	48,064	51.62

Interpretation of Table 4:
The earlier notified group (<=1 min) had a cumulative survival rate (alive/total) of 52.34%, which is 1.16% higher than the late notified group (>1 min, 51.18%) within 6 hours after crashes. Hence, if the late group had made the EMS calls within 1 minute like the earlier group did, then the possible additional lives saved from this late group would be approximately 1.16% x (29,657) =344, this reduction of 344 deaths represents 1.48% of original death numbers of 23,252 within a time frame of 6 hours after crash during four years between 2009-2012, or 86 fatality reductions per year (the earlier study using 2005-2009 had a fatality reduction of 1.84% [1]). Furthermore, data with known notification and arrival times within 6 hour window is only 48.7% of the sample population (Table 1 and Figure 2). If we assume all sample populations (with or without info of notification/arrival, all sample populations are 1/0.487=2.05 times of the sample with known notification/arrival info) would share similar trends, then additional lives potentially saved could have been 177 (2.05 times of 86) per year from 2009-2012. The fatality relative risk of later group versus earlier group is 1.024, or later group has 2.4% higher relative risk of death with a significant P-value under 5%.

Again, Table 3 indicates that earlier notification within 1-2 minutes is very helpful to life saving, and EMS notification cut-off time of ‘1 minute’, or ‘2 minutes’ may lead to slightly different estimations of lives saved, which is discussed as Table 5 (Figure 4), where notification time is divided as two groups of ‘notification <=2 min and call time before death time’ (*preferred* or *earlier* group), or otherwise. The notification group with ‘N <=2 min and call time before death time’ would have larger sample size compared with the group of ‘N<=1 min.’ earlier as Table 4, If notification <=2 min., there were 84 cases that were with notification time and death time being 2 minutes, and that were not treated as the preferred group but otherwise. The similar analysis of Kaplan-Meier life curves, comparing the survival rates of earlier group versus later group, was performed for two notification time divisions, as Table 4 or Table 5. It can be seen, from Table 5, that the preferred earlier notified group had a cumulative survival rate of 52.61%, which is approximately 2% higher than the late notified group (50.62%). Figure 4 came from the two survival probability curves over time of two different notification times (Table 5), the earlier notification groups is assumed as ‘notification <=2 min and call time prior to death’; if ‘notification <=2 min’ instead, the cumulative survival rate difference for earlier and later groups would be slightly smaller (1.63%).

Table 5: Survivors and Fatalities Within 6 Hours After Crash (Notification<=2 or otherwise, inj_sev=3, 4 with FARS 2009-12**)**

Notification, (min)	Dead	Alive	Total	Alive % S(t)
<=2 min (preferred)	11,505	12,772	24,277	52.61
>2 min (non-preferred)	11,747	12,040	23,787	50.62
Total	23,252	24,812	48,064	51.62

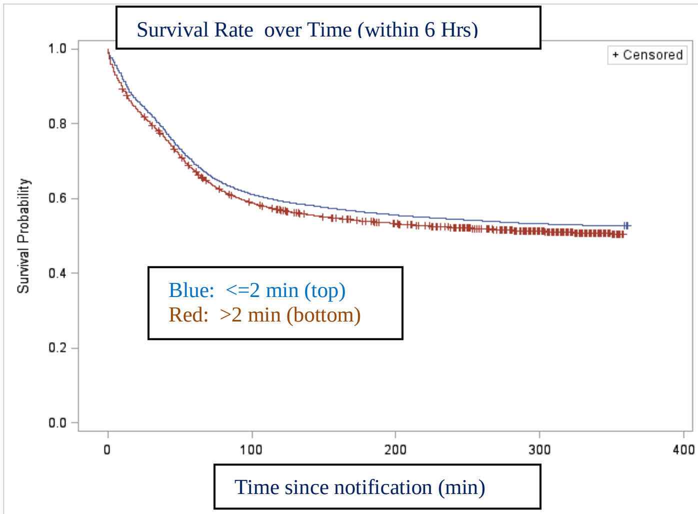

Figure 4: Notifications versus Survival Rate within 6 Hours after Crash (Notifications <=2 versus >2 min, inj_sev=3, 4)

Interpretation of Table 5 and Figure 4:
As seen in Table 5 and Figure 4, the preferred earlier notification group (<=2 min) had a cumulative survival rate (alive/total) of 52.61%, approximately 2% higher than the later notification group (>2 min) within 6 hours after crashes (P-value =0.0034). If the later notification group had made the EMS calls within 2 minutes as the earlier group, then the possible additional lives saved would be approximately 2% x (23,787) = 476 (approximately 2% reduction of original fatalities of 23,252) during 2009-12, or 119 fatality reductions per year. If all data with or without notification/arrival info are under consideration (the total population sample size is 1/0.487=2.05 times of the smaller sample with notification/arrival info), the additional lives saved due to earlier notification could be 244 annually during 2009-2012. The fatality relative risk of later group versus earlier group is 1.04, or later group has 4% higher fatality risk significantly.

Here are some discussions about the earlier notification effect and the analysis method:

- If the EMS cut-off time is longer than 6 hours in this study, the study population will be slightly larger than the population shown in Tables 4, 5. Although most people died within the first few hours as seen in Figures 3, 4, the proper EMS cutoff time depends on when the life curve becomes stabilized or flat after a crash.
- This method derived the fatality reductions or lives potentially saved due to ACN from crossing comparing the survival probabilities of two paired life curves at a specific time of 6 hours (360 minutes), and this comparison can also be made at any specific times chosen by researchers, 4, 5, or 6 hours, after a crash within the timeframe. Comparing survival rate difference of two paired groups at a specific time is a common approach used in clinical trials and public health research.
- The cut-off time of notifications <=1 or <=2 minutes also plays a role in determining the additional lives saved due to earlier notification (ACN), and Table 3 /Figure 4 show the notification within 1-2 minutes are most helpful.

3.2 Effect of Earlier EMS Arrival

Similarly, it is known that earlier EMS arrival may significantly improve occupant treatment and crash survivability, based on real-world data. The field-data also indicated that earlier notifications would not always guarantee either earlier arrivals or better survival chances, although there was a strong correlation between the EMS notification and EMS arrival (details to be discussed by using correlation coefficient). The EMS arrival was hence studied separately as one important variable for survival rate comparison.

Table 6 shows the correlation between the EMS arrival and survival status, and again Figure 3 life curve may be used together with Table 6: majority injuries and fatalities happened very early after crash (approximately 64% within 15 minutes after crashes as Table 6, top three rows). If EMS arrival is <= 5 minutes, the survival rate is 54.36%, which is 2.74% higher than the overall survival rate (51.62%). The smaller groups with '30< Arrival <=360 minutes', with approximately 11.7% of total occupants (bottom two rows), had a relatively high survival rate of 56% approximately, possibly due to less crash severity, better health conditions, or other unknown factors that are not explored in this study.

Table 6: Arrival Time versus Survival Status within 6 Hours After Crash

Arrival, A (min.)	dead	alive	Total	Alive % S(t)
A<=5	3063	3648	6,711	54.36
5<A<=10	6982	7180	14,162	50.70
10<A<=15	5074	4960	10,034	49.43
15<A<=30	5662	5878	11,540	50.94
30<A<=45	1467	1865	3,332	55.97
45<A<=360	1004	1281	2,285	56.06
Total	23,252	24,812	48,064	51.62

3.3 Effect of Earlier Arrival at Hospital

Similarly, an earlier arrival time to a hospital may significantly improve occupant medical treatment and crash survivability. Table 8 provides the correlation between the 'time-to-hospital' and 'survival status'. The survival rate with hospital arrival time (56.41%, Table 8) is approximately 5% higher than the overall survival rate, 51.62% (with and without hospital arrival information, as Table 3 or Table 6). Approximately 40% of occupants in this study, although with known notification and EMS arrival times within six hours, had no documented hospital arrival time. Table 8 does show the importance of reaching a hospital after crash overall, compared with Tables 3, 6.

Table 8: Time to Hospital versus Survival Status Within 6 Hours After Crash

Time to Hospital, H	Dead	alive	Total	Alive % S(t)
H<=15	115	152	267	56.93
15<H <=30	2087	2407	4494	53.56
30<H<=45	3551	4432	7983	55.52
45<H<=60	2972	3821	6793	56.25
60<H<=90	2761	3815	6576	58.01
91 to 360	1039	1584	2623	60.39
Total	12,525	16,211	28,736	56.41

4. CORRELATIONS AND RURAL-URBAN COMPARISON

The statistical results yielded from Kaplan-Meier life curves and 2x2 correlation tables, are very useful when examining one single factor a time. However, many factors, such as time of notification, time of arrival, injury severities, person's age, rural/urban areas, etc., may contribute to the fatality status simultaneously. Hence, the focus here is on the correlation between various EMS factors.

4.1 Correlation between EMS Factors

Correlations between the factors are commonplace, and earlier notification would normally result in earlier EMS arrival (correlation coefficient of 0.69 from overall rural and urban data of Table 9), and following Table 9 indicates, with several notification time groups, the correlation between notification and arrival.

Table 9: Correlation between notification (N) & arrival (A) including urban/rural crashes, inj_sev = 3, 4 (Correlation Coefficient = **0.69**)

A / N	A<=5 min	6-10 min	11-15 min	16-30 min	31-45 min	46-360 min	Total
N<=1	**5424**	**7493**	**3193**	1991	222	84	18,407
1<N <=2	**840**	**2688**	**1387**	906	111	22	5,954
2<N<=3	306	1801	1341	878	109	41	4,476
3<N<=5	140	1641	2062	1845	249	53	5,990
5<N<=8	1	505	1508	2252	353	92	4,711
8<N<=15	0	30	543	2912	968	223	4,676
15 -360	0	4	0	756	1320	1770	3,850
Total	6711	14,162	10,034	11,540	3,332	2,285	48,064

Table 9 (or Figure 5) indicates that the earlier notifications (within 2 minutes) would normally result in EMS arrivals within 15 minutes for 21,025 people (bold number), or 44% of all 48,064 cases.

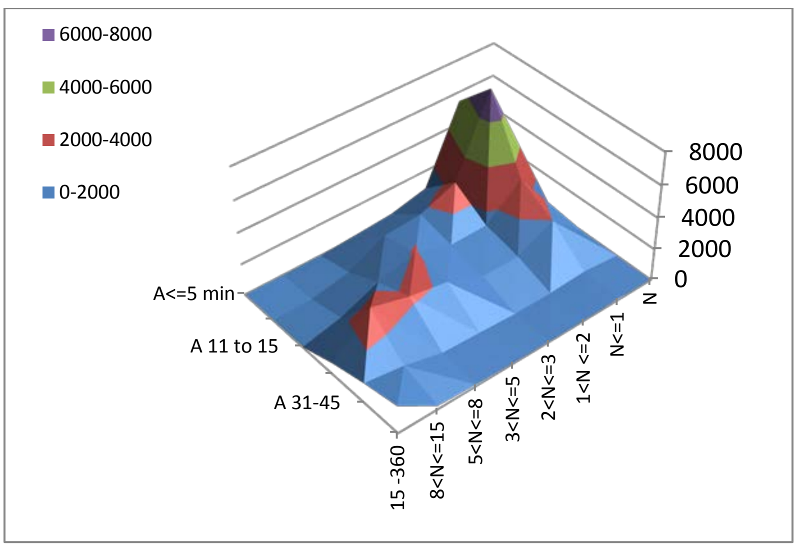

Figure 5: Correlation between notification (N) and arrival (A), and inj_sev=3,4

Urban areas, where over 61% of fatalities occurred, may differ in EMS responses, as shown in Table 1 (the average notification time is 7.25 minutes, and 4.61 minutes for rural and urban, respectively). The correlation between notification and arrival in rural area is different as following Table 10.

Table 10: Correlation between notification (N) and arrival (A) for rural cases (n=29,560)
(Correlation Coefficient = **0.67**)

A / N	**A<=5 min**	**6-10 min**	**11-15 min**	16-30 min	31-45 min	46-360 min	Total
N<=1	**2015**	**3831**	**2283**	1641	204	72	10046
1<N <=2	**311**	**1200**	**977**	756	103	32	3379
2<N<=3	112	823	908	717	99	36	2695
3<N<=5	60	796	1332	1481	211	49	3929
5<N<=8	1	197	815	1758	317	89	3177
8<N<=15	0	12	270	2057	791	199	3329
16 -360	0	1	0	457	1075	1472	3005
Total	2499	6860	6585	8867	2800	1939	**29560**

Table 10 indicates that earlier notification times (within 2 minutes) would result in 10,617 EMS arrivals within 15 minutes, or approximately 36% of all rural cases of 29,560 (bold, top 2 rows and left three columns). Table 11, using urban area data, indicates that similar earlier notification times (N<=2 minutes) would result in 10,384 EMS arrivals within 15 minutes (approximately 56% of all 18,445 urban cases). Hence, the rate difference of EMS arrivals within 15 minutes is 20% between urban and rural areas from Table 10 and Table 11. The correlation coefficient is 0.70 in urban area and stronger than 0.67 of rural area, and the EMS arrivals in urban area are much quicker than the rural areas.

Table 11: Correlation between notification (N) and arrival (A) for urban cases (n=18,445)
(Correlation Coefficient = **0.70)**

A / N	**A<=5 min**	**6-10 min**	**11-15 min**	16-30 min	31-45 min	46-360 min	Total
N<=1	**3403**	**3652**	**908**	345	16	12	8336
1<N <=2	**527**	**1484**	**410**	147	8	0	2576
2<N<=3	194	978	430	161	10	5	1778
3<N<=5	80	840	724	362	38	4	2048
5<N<=8	0	306	691	490	35	3	1525
8<N<=15	0	18	273	853	175	24	1343
15 -360	0	3	0	295	245	296	839
Total	4204	7281	3436	2653	527	344	**18445**

4.2 Multiple Relative Hazard Model

The goal of this aspect of the paper is to explore the relative comparison of passenger vehicle occupant survival rates with one risk factor alone or with several risk factors simultaneously. Cox [8] (1972) proposed a model to consider multiple risk factors simultaneously. The hazard function, *h(t)*, was introduced. Note, the hazard and survival probability functions, S(t) such as Figure 3, are closely related to each other, described by " *h(t) = - S'(t) / S(t)* ", where S'(t) is the derivative of S(t) [1 8]. It can be seen that *h(t)* provides the relative change rate of S(t) over time, and *h(t)* reaches a higher positive value when S(t) dropped rapidly during 0-100 minutes after crashes (Fig. 3 and Fig. 4), and *h(t)* remains zero approximately when S(t) changes little beyond 100 minutes after crashes. Cox proposed that the hazard function can be further expressed in Equation (2), known as the Cox Proportional Hazard Model.[8] This model is to establish a relationship between the hazard function with multiple risk factors simultaneously, while the previously discussed Kaplan-Meier curves, S(t), explore a single risk factor only.[7]

In the current study using same data and notification definitions as Table 5 or Figure 4, the Proportional Hazard Model is used to study the effects of EMS notification together with the effects of occupant age and crash location on crash survivability. It may be impossible to include all risk factors in the current study. SAS Proc *PHREG* is used for calculation.[8 10]

$$h(t) = h_0 \exp(\beta_1 Age + \beta_2 Call + \beta_3 Location) \qquad (2)$$

The model included three factors treated as binary variables: age (over 60 or younger), notification time (later than 2 minutes or earlier notification) and crash location (rural versus urban). The results indicate that age and location are not significant risk factor with P-values of 0.13 and 0.27, respectively. Similar to prior findings in this paper, later crash notification (>2 min) could carry a 4% relatively higher fatality hazard than earlier group of 'notification within 2 minutes and call time prior to death time' (Hazard Ratio=1.04, p-value=0.0028). The arrival variable was not used in the above modeling to avoid the collinearity issue, since it is strongly correlated with notification. Many other risk factors, such as crash severity, occupant health condition, EMS arrival and service quality, et. al., may all contribute to the survival status and hazard ratio. Future investigations are needed to explore these issues, as this study focuses mainly on the time-related issue and notification. Of special interest is that the EMS arrival time in rural area (19.64 minutes, Table 1) is approximately 7.5 minutes later than urban area (12.10 minutes), and the correlation coefficient in rural area (0.67) is also weaker than urban area (0.70), however, the mean time to death for both urban and rural areas remain approximately the same (66 minutes), and more investigations would be necessary to explore this rural/urban difference and hazard patterns.

5. CONCLUSIONS

EMS data is closely associated with time, and 'time to event' data analysis, or survival analysis, is a suitable approach than some other statistical approaches. While FARS 2009-2012 data had limited information about EMS notification, EMS arrival and time to reach a hospital, the data did suggest certain meaningful patterns and facts:

- Earlier crash notification associated with Automatic Crash Notification (ACN) systems could save approximately 177 to 244 motor vehicle occupant lives per year (approximately 1.5% - 2% fatality reduction) when a time window of six hours after crash is considered, and the research population is targeted at 'Incapacitating Injury' and 'Fatal Injury' only. Meanwhile, many other confounding factors may also contribute to occupant survival probabilities.
- Effective ACN and earlier EMS arrival significantly improve crash survivability, and earlier notification (<=1 or 2 minutes) would generally result in the sooner EMS arrival within 5-15 minutes. Kaplan-Meier curves clearly demonstrate the survival differences of two paired groups whose EMS status differs, for example, the benefits associated with earlier notifications within 1-2 minutes (approximately 1.5- 2% fatality reduction within a timeframe of 6 hours after crash). The fatality reductions or lives potentially saved due to ACN are estimated from cross comparing the survival probabilities of two paired life curves at one specific time after crash.
- We did not discover a significant difference in survivability between age groups, and between urban and rural areas overall. However, the results indicate that there is a strong need to improve the EMS arrivals in rural area where the rate of EMS arrival within 15 minutes is 20% lower than the similar rate in urban area, the correlation coefficient between the notification and arrival is 0.70 in urban area, and 0.67 in rural area. Approximately 61% of fatalities happened in rural areas. Earlier EMS arrival within 5-15 minutes would be desired in both rural and urban areas.
- Correlations among various factors, such as notification time, time of EMS arival, time to hospital, and survival status are commonplace. Most injuries and fatalities occurred within a short time window of 1-100 minutes after crash (86.6% fatalities occurred out of all fatalities within six hours). Earlier notification time within 1-2 minutes would significantly improve survival probability, although many other confounding risk factors may contribute to the occupant survival status. EMS arrival time is very desired as soon as possible (best within 5 minutes), reaching a hospital within 15 minutes is desired, although hospital time data are rather limited in this study, the occupants with hospital arrival have significantly higher survival rates than the other occupants.

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AIR BAG RELATED INJURIES IN NHTSA'S CRASH DATABASES

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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) has been monitoring and gathering information on air bag related injuries and fatalities in its data collection programs since air bags were introduced. As frontal air bag technology has progressed from barrier certified (a.k.a. first generation) to sled certified (a.k.a redesigned) and to advanced certified air bag systems, there has been a drastic reduction in the number of injuries and fatalities attributed to these air bags. More recently developed air bags designed to protect occupants in side impacts and rollovers also do not appear to pose a serious threat. The purpose of this paper is to describe the evolution of air bag injuries in all types of air bags collected in NHTSA's in-depth investigation and crash report based programs. Additionally, the paper discusses future plans for collection of air bag and injury information as NHTSA's data collection programs are redesigned in the Data Modernization Project.

INTRODUCTION

Investigation-based programs are the only source of detailed information required to research the injury outcomes related to air bag deployments. NHTSA currently operates three investigation-based data collection programs with detailed air bag information; the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS), Special Crash Investigations (SCI) and the Crash Injury Research and Engineering Network (CIREN). Data from each of the programs has been critical in NHTSA's evaluation of air bag performance. These data collection programs have somewhat different focuses, but also complement one another in different ways.

NASS-CDS is a nationally representative sample of towed light vehicle crashes with an emphasis on the crashworthiness of the vehicle. The case selection algorithm is designed to give fatal and severe injury crashes a higher probability of selection. Data is collected at 24 sites across the country with a yearly average of 4,500 cases per year since 1999. NASS-CDS data can be viewed clinically at http://www.nhtsa.gov/NASS. The yearly SAS data sets are available for statistical use at ftp://ftp.nhtsa.dot.gov/NASS/.

SCI is a collection of approximately 125-150 targeted investigations each year that are utilized by NHTSA and the automotive safety community to understand the real-world performance of existing and emerging advanced safety systems. Both the SCI case viewers and Technical Reports can be accessed at http://www.nhtsa.gov/SCI.

CIREN is a hospital-based study operating at six centers across the country, collecting approximately 300 cases per year. The CIREN process combines prospective data collection with professional multidisciplinary analysis of medical and engineering evidence to determine injury causation in every crash investigation conducted. CIREN data is available at http://www.nhtsa.gov/CIREN.

Although the programs have different overall objectives they are all modeled on the same data collection practices, procedures, and data structures. This consistency allows for researchers to quantify the relationship between vehicle damage and the occupant injuries in the real-world crash environment across multiple programs. Investigations conducted in NHTSA's NASS-CDS, SCI and CIREN include:

- A vehicle inspection is conducted that involves detailed documentation including crush deformation, occupant compartment intrusion, occupant contacts, assessment of the safety systems, and photography.
- Additionally, the vehicle inspection includes an image of the Event Data Recorder (EDR) data when available.
- Medical records for injured occupants are evaluated, allowing trained injury coders to assign Abbreviated Injury Scale (AIS) codes and make a determination on the specific

vehicle component that was contacted to produce the injury.

The analysis in this paper is focused on the injury outcomes of the various air bag systems in real world crashes. This was especially important for looking at the injury outcomes that may be related to the advanced air bag occupant protection rulemaking.

BACKGROUND

NHTSA has been collecting in-depth data utilized to study the effects of occupant protection devices since 1972. While the focus of the specific investigations has changed over the years the primary goal has remained to provide researchers the information necessary to protect occupants in crashes with little or no unintended consequences.

The air bag has been utilized as a supplemental form of occupant protection restraint since 1974. Air bag systems have evolved through the years, primarily to mitigate unintended injury consequences to occupants positioned too close to the air bag at the time of deployment. NHTSA initiated interim and long-term regulatory actions to reduce and eventually eliminate the adverse effect of frontal air bags for infants, children, and other high-risk occupants while retaining the benefits of air bags for most people.

These regulatory actions aimed at air bag systems were made based in part on the data collected from NHTSA's in-depth data collection programs. The data was also utilized to help evaluate the effectiveness of the regulatory actions in real-world crashes [1]. The details on the unintended injury consequences are documented in previous ESV papers [2].

NHTSA's interim action was to modify the occupant protection Federal Motor Vehicle Safety Standard No. 208 (FMVSS No. 208) to introduce a sled test option in lieu of the existing unbelted barrier crash test certification requirement on March 19, 1997. The sled test allowed air bags to be designed to deploy less forcefully. While some researchers felt this was sufficient, the real-world in-depth data was still reporting unintended consequences. While significantly less than first generation air bags, the undesirable outcome still existed in the sled certified air bags.

In 2000, NHTSA issued another upgrade to FMVSS No. 208 to fulfill its long-term effort to counter the adverse effects of frontal air bags. In this advanced air bag rule, significant changes were specified in the frontal occupant protection requirements for light passenger vehicles. These changes included adding requirements for protecting small adult female occupants, adding requirements to minimize the risk of deploying air bags to out-of-position (OOP) children and small adult occupants, increasing the requirements for belted occupants, and reducing the test speed for the unbelted 50th percentile male occupants. Manufacturers began phasing in the sale of vehicles meeting the advanced air bag requirements beginning with model year 2003 vehicles. All vehicles sold after August 31, 2006 must certify meeting the advanced air bag requirements. Details on the real-world results are included in a previous ESV paper [3].

As of the writing of this paper NHTSA's crash data systems have not identified or reported any fatality related to the air bag deployment involving a vehicle certified to the advanced air bag requirements.

METHODS

The data used in this analysis were NASS-CDS, SCI, and CIREN cases from crash years 2000-2013 in which a 1990-2013 model year vehicle had a deployed air bag in an occupied seat. The air bags deployment location was not limited to upper instrument panel or steering wheel air bags which were most common. Any deployed air bag location was considered including air bags that deploy from the seat back, roof side rail, door, and mid or lower instrument panel. Especially in more recent model year vehicles, there could be more than one deployed air bag per occupied seating location.

Injuries in NHTSA's in-depth investigation programs are assigned by trained injury coders based upon the Abbreviated Injury Scale (AIS) developed by the Association for the Advancement of Automotive Medicine (AAAM). Crashes prior to 2010 were coded using AIS90 Update 98. Cases with a crash date 2010 and newer used AIS2005 Update 2008.

NASS-CDS

NASS-CDS was the primary data analyzed for this paper due to the sheer volume of cases and nationally representative design of the program. In NASS-CDS (2000-2013 in which a 1990-2013 model year vehicle had a deployed air bag in an occupied seat) a total 42,691 deployed air bags fit the criteria as shown in Figure 1. Applying the NASS-CDS weights, these represent over 12.5 million deployed air bags as shown in Figure 2.

Figure 1
Deployed Air Bags
In Occupied Seats
(Unweighted)

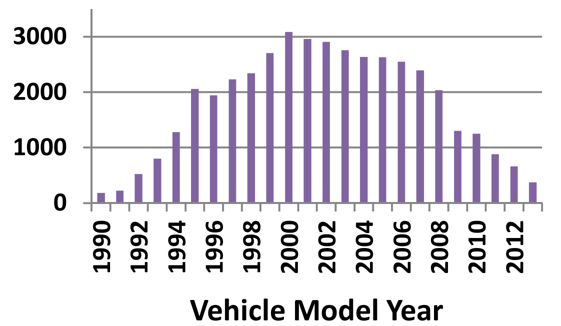
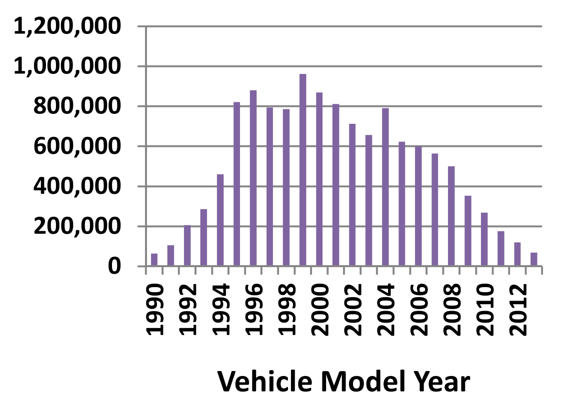
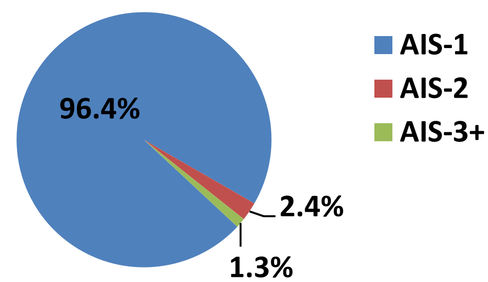


Figure 2
Deployed Air Bags
In Occupied Seats
(Weighted)



From the 42,691 deployed air bags in an occupied seat there were 16,776 instances where an air bag was identified as the source of an injury. These cases represent 4.4 million injuries nationwide during the 14-year period (2000-2013 in which a 1990-2013 model year vehicle had a deployed air bag in an occupied seat) using the weighted data. Though this may seem like a high number of injuries on the surface, Figure 3 shows over 96% of air bag injuries were minor (AIS-1) in severity and likely prevented more severe consequences in most instances. The analysis included all air bag associated injury sources which are listed in Appendix A. It should be noted that NASS and SCI refer to these as injury sources, while CIREN refers to them as involved physical component (IPC).

Figure 3
Air Bag Injury Source
AIS injury severity



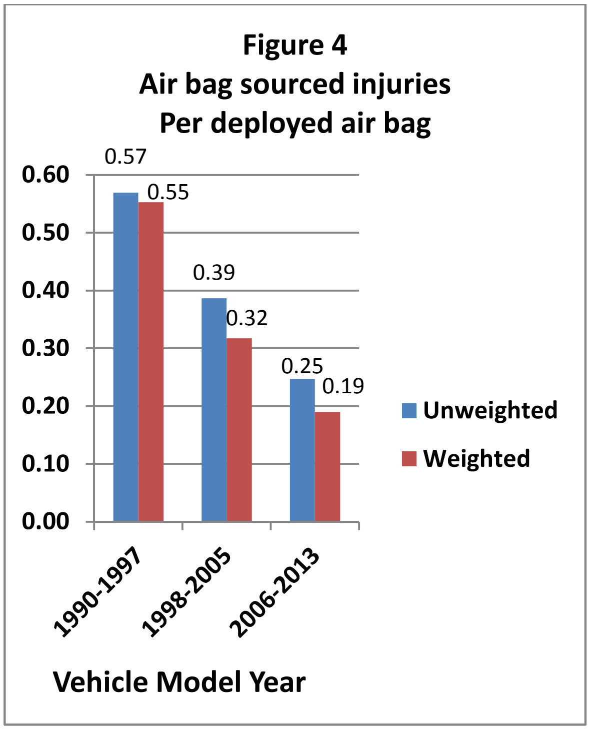
As the figures 1 and 2 show, the number of injuries attributed to air bags in NASS-CDS has decreased drastically as frontal air bag technology has progressed from first generation, to redesigned, and currently to advanced air bags systems.

Air bags designed to protect occupants in side impacts and rollovers also do not appear to pose a serious threat.

Although there is significant model year overlap in air bag generations due to phase-in periods the Figures 4 and 5 break down vehicle model years into 8-year ranges:

1990-1997 (first generation)
1998-2005 (redesigned)
2006-2013 (advanced)

Figure 4 shows the decrease in the number of total injuries sourced to the air bag in an injury per deployed air bag ratio. The unweighted raw counts as well as weighted values are included.



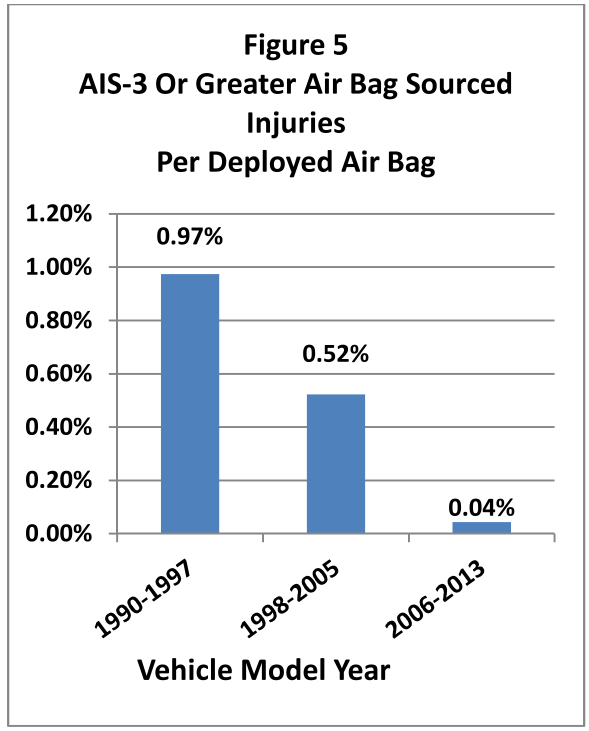


Figure 4 details vehicles from 1990-1997 averaging just over one coded injury for every two air bags deployed in an occupied seat. More recent air bags from 2006-2013 model year vehicles average less than half as many injuries. The severity of injuries in more recent air bags has also been greatly reduced. Figure 5 shows the decrease in AIS-3 (serious) or greater injuries where air bags were the injury source.

AIS-3+ injuries sourced to the air bag decreased from one in every 101 (.97%) deployed bags in first generation air bags to one in every 2,288 (.04%) deployed air bags in model years 2006-2013, a significant reduction.

Only five AIS-3+ injuries sourced to the air bag have been identified in NASS-CDS in the 2006 and newer model year vehicles . The data are summarized in Table 1. The cases reveal the five injuries involved extremity fractures and there were no indications of air bag malfunction.

Table 1
NASS-CDS cases with AIS-3+ Injury
2006-2013 Model Year Vehicle

Case Number	Vehicle	Occupant	Air Bag Location	Injury Code	Injury Source
2007-48-131	2006 Toyota Camry	71-year-old Female Restrained Passenger	Top Instrument Panel	7528043 Radius fracture open/displaced/comminuted	Air bag (Certain)
2009-04-011	2008 Volkswagen Jetta	26-year-old Female Restrained Driver	Steering Wheel	7528043 Radius fracture open/displaced/comminuted	Air bag compartment cover (Probable)
2008-75-116	2006 Toyota RAV4	90-year-old Female	Top Instrument Panel	7528043 Radius fracture	Air bag (Certain)

		Restrained Passenger		open/displaced/comminuted	
2008-75-116	2006 Toyota RAV4	90-year-old Female Restrained Passenger	Top Instrument Panel	7532043 Ulna fracture open/displaced/comminuted	Air bag (Certain)
2012-49-031	2009 Lexus ES	96-year-old Female Restrained Driver	Lower Instrument Panel	8541723 Tibia fracture, proximal, complete articular	Air bag compartment cover (Probable)

SCI

SCI has actively sought out injuries and fatalities associated with air bags since their introduction into the fleet. It is important to remember that SCI cases are not nationally representative and the case selection criteria is very different from NASS-CDS. Table 2 shows the number of AIS-3+ injuries associated with air bags for SCI cases with a crash date 2000-2013. Similar to the NASS-CDS results, the number of AIS-3+ injuries has decreased dramatically in 2006-2013 model year vehicles and no fatalities have been confirmed due to air bag injury sources. Table 3 is a listing of the three AIS-3+ injuries in SCI. There were no indications of air bag malfunction in the cases.

Table 2
SCI Air bag sourced AIS-3+ Injuries

Model Year Vehicle	AIS-3+ Injuries
1990-1997	328
1998-2005	91
2006-2013	3

Table 3
SCI cases with AIS-3+ Injury
2006-2013 Model Year Vehicle

Case Number	Vehicle	Occupant	Air Bag Location	Injury Code	Injury Source
DS13002	2012 Hyundai Sante Fe	42-year-old Female Restrained Passenger	Roof Side Rail	6402003 Cord contusion, cervical spine, NFS	Air bag Indirect (Probable)
DS07009	2006 Cadillac SRX	81-year-old Male Unrestrained Driver	Steering Wheel	4502524 Rib cage fracture open/displaced/comminuted with hemo-/pneumothorax	Air bag (Possible)
IN11016	2011 Buick Lucerne	78-year-old Female Restrained Driver	Roof Side Rail	6502283 Cervical Spine fracture odontoid (dens)	Air bag (Possible)

CIREN

CIREN has six AIS-3+ injuries with an involved physical component (IPC) associated with an air bag in 2006-2013 model year vehicles. CIREN's ability to identify more air bag injuries than the other in-depth programs is likely due to the programs emphasis on newer model year vehicles, increased medical documentation detail and scrutiny, and biomechanics evaluation. It is important to note that CIREN cases are not nationally representative and the case selection criteria is different from NASS-CDS. Table 4 shows the number of AIS-3+ injuries associated with air bags for CIREN cases with a crash date 2000-2013. Similar to the NASS-CDS and SCI results, the number of AIS-3+ injuries has decreased dramatically in 2006-2013 model year vehicles and no fatalities have been noted due to air bag IPC's. The six AIS-3+ injuries in SCI are shown in Table 5. There were no indications of air bag malfunction in the cases.

Table 4
CIREN Air bag sourced AIS-3+ Injuries

Model Year Vehicle	AIS-3+ Injuries
1990-1997	250
1998-2005	196
2006-2013	6

Table 5
CIREN cases with AIS-3+ Injury
2006-2013 Model Year Vehicle

Case Number	Vehicle	Occupant	Air Bag Location	Injury Code	Involved Physical Component
857095509	2007 Hyundai Accent	77-year-old Male Restrained Driver	Steering Wheel	4502303 Rib cage fracture >3 ribs on one side and <=3 ribs on the other side, stable chest or NFS	Air bag (Possible)
857095509	2007 Hyundai Accent	77-year-old Male Restrained Driver	Steering Wheel	7526043 Humerus fracture open/displaced/comminuted	Air bag (Probable)
842012167	2006 Chrysler PT Cruiser	63-year-old Female Restrained Driver	Steering Wheel	6502223 Cervical Spine fracture facet	Air bag (Probable)
842012167	2006 Chrysler PT Cruiser	63-year-old Female Restrained Driver	Steering Wheel	7532043 Ulna fracture open/displaced/comminuted	Air bag (Probable)
842012167	2006 Chrysler PT Cruiser	63-year-old Female Restrained Driver	Steering Wheel	7528043 Radius fracture open/displaced/comminuted	Air bag (Probable)
100108251	2006 Mercedes E-Class	55-year-old Female Restrained Driver	Roof Side Rail	1406063 Cerebrum contusion single small	Air bag (Probable)

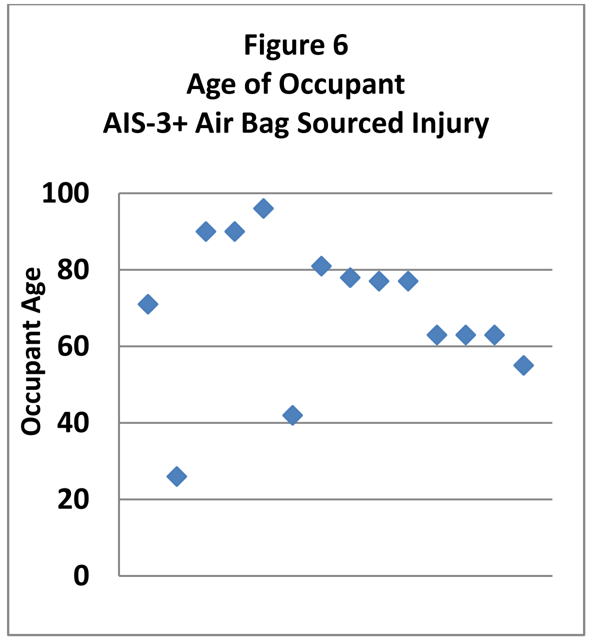
DISCUSSION

The first generation of frontal air bags saved the lives of thousands of drivers and right-front passengers. However, the first generation air bags harmed occupants positioned close to the air bag at the time of deployment, especially small statured females, infants and children. Air bag effectiveness analysis performed by NHTSA's Office of Regulatory Analysis and Evaluation (ORAE) using Fatality Analysis Reporting System (FARS) and SCI data have shown that as the fleet has moved from first generation to redesigned air bags, the fatality risk was reduced for children and the life-saving benefits of first-generation air bags was preserved for adults [4]. NASS-CDS data in Figures 4 and 5 show the high number of AIS-3+ injuries from air bags decreased over the progression of air bags.

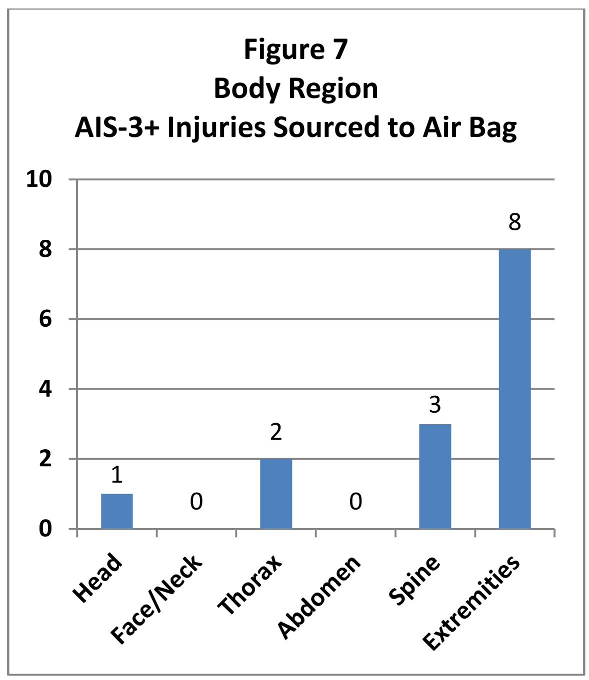
The 2013 ORAE analysis using FARS and R.L. Polk National Vehicle Population Profile (NVPP) data concluded that the progression from redesigned frontal air bags to certified advanced systems showed no statistical significant difference in fatality rate [1]. Recent papers using FARS data through calendar year 2011 show statistically significant fatality reductions for all four types of curtain and side air bags in near-side impacts for drivers and right-front passengers of cars and LTVs [5].

Along with the fatality rate improvement as the fleet has moved from first generation to redesigned and finally to advanced air bags, the reduction in the number of AIS-3+ injuries sourced to the air bag in vehicle model years 2006-2013 has been substantial. These types of injuries have been significantly reduced with only fourteen AIS-3+ air bag injuries identified in all three of NHTSA's investigation-based programs. These cases were reviewed individually and revealed some common characteristics.

Older occupants were over-represented in the fourteen cases with AIS-3+ injuries sourced to the air bag in vehicle model years 2006-2013 as shown in Figure 6. The average age in the fourteen cases was over 69 years old. NHTSA's 5-year Traffic Safety Plan for Older People discusses the increased risk that older occupants face, primarily due to increased frailty, and potential measures that could attempt to address injury risks for older occupants [6].



The AIS body regions involved for the AIS-3+ injuries are shown in Figure 7.



Half the AIS-3+ air bag injuries involved serious lower arm fractures to the radius or ulna. These injuries were identified with high confidence levels for the injury source/involved physical component. Primarily because of the physical evidence available. Identifying the air bag as the injury source to the other body regions are much more difficult, and often have a confidence level of only "possible." A common situation is chest injuries to a driver in a severe frontal collision. The driver typically has interaction first with the seat belt, then loads through the air bag into the steering wheel. Determining which of the three components is the source of the specific injury is very challenging and ultimately relies on many factors including: crash scenario, exterior vehicle damage pattern, interior intrusion, occupant contact, interior component deformation, and injury patterns.

Future Data Collection

NHTSA currently collects data that can be used to evaluate injury sources in three crash investigation-based programs, NASS-CDS, SCI, and CIREN. In Fiscal Year 2012, Congress appropriated funds for NHTSA to modernize NASS. The formal project, known as the Data Modernization Project, was launched in January 2012. The goal of Data Modernization is to ensure that the agency is collecting quality data to keep pace with emerging technologies and policy needs, which will help affirm NHTSA's position as the leader in motor vehicle crash data collection and analysis. The multi-year project is set for implementation beginning in January 2016.

The replacement to NASS-CDS has been named the Crash Investigation Sampling System (CISS). New nationally representative data collection sites have been selected using a sample design approach similar to NASS-CDS. The new sites were chosen using the most recent census and vehicle registration data and hope to better reflect the nation's overall crash picture and improve upon the availability of newer model vehicles and severe crashes at the data collection sites.

NHTSA believes that collection of detailed injury data including medical record collection, AIS code assignment, contacted components, and injury causation must be a point of emphasis in CISS, as well as in the other field investigation-based data collection programs. Current plans include adopting the latest version of the Abbreviated Injury Scale (AIS 2015) and using the U.S. Army Research Laboratory (ARL) Visual Anatomical Injury Descriptor (VisualAID) software to enhance injury coding in all the NHTSA programs.

CONCLUSION

Unintended fatalities and serious injuries were a problem in barrier certified (a.k.a. first generation) air bags and to a lesser extent in sled certified (a.k.a. redesigned) air bags. No fatalities in a 2006-2013 model year vehicle have been reported in NHTSA's investigation-based data collection programs with an air bag attributed as injury source/involved physical component vehicle. The prevalence of AIS-3+ injuries has also been drastically reduced with the introduction of vehicles into the fleet that meet the advanced occupant protection rulemaking. NHTSA's future data collection efforts will continue to monitor for these types of injuries.

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APPENDIX A

Air bag injury sources 2002-forward

Air bag
Air bag and eyewear
Air bag and jewelry
Air bag and object held
Air bag and object in mouth
Air bag compartment cover
Air bag compartment cover and eyewear
Air bag compartment cover and jewelry
Air bag compartment cover and object held
Air bag compartment cover and object in mouth

NOTE: Beginning in 2002 air bag injuries were linked to a specific air bag

Air bag injury sources 2000-2001

Air bag-driver side
Air bag-driver side and eyewear
Air bag-driver side and jewelry
Air bag-driver side and object held
Air bag-driver side and object in mouth
Air bag compartment cover-driver side
Air bag compartment cover-driver side and eyewear
Air bag compartment cover-driver side and jewelry
Air bag compartment cover-driver side and object held
Air bag compartment cover-driver side and object in mouth
Air bag-passenger side
Air bag-passenger side and eyewear
Air bag-passenger side and jewelry
Air bag-passenger side and object held
Air bag-passenger side and object in mouth
Air bag compartment cover-passenger side
Air bag compartment cover-passenger side and eyewear
Air bag compartment cover-passenger side and jewelry
Air bag compartment cover-passenger side and object held
Air bag compartment cover-passenger side and object in mouth
Other air bag (specify)
Other air bag compartment cover (specify)

A CONCEPT FOR NATURALISTIC DATA COLLECTION FOR VULNERABLE ROAD USERS USING A SMARTPHONE-BASED PLATFORM

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ABSTRACT

This paper presents a smartphone-based platform for large-scale, low-cost, long-term naturalistic data collection aimed at vulnerable road users (VRUs). The approach taken is to collect naturalistic movement data from VRUs based on information from the embedded sensors in high-end smartphones. The Smartphone application, *LogYard*, developed in the current study, allows the recording of high quality data (tri-axial acceleration and rotation at 100 Hz plus GPS position and velocity each second). This way, large data quantities from ATV drivers' movements during daily use in different use cases, can be transferred from a large number of users and accumulated in a cloud-based server for off-line analysis.

Apart from the description on how data is recorded and managed in the smartphone-based platform, also a procedure on how to include participants to studies and how private integrity issues and informed consent can be handled from a distance is presented. By means of the presented smartphone based platform, large number of participants taking part in several parallel on-going studies can be easily administered. This makes the platform a powerful tool to use in large-scale, low-cost, long-term studies providing data from large groups of study participants.

The information made available this way can be used to develop automatic crash notification (ACN) systems directed to VRUs based on identifying movements outside what is "normal" for bicyclists, mopedists, motorcyclists and ATV users.

INTRODUCTION

Almost half of the over 1.2 million deaths in road traffic accidents worldwide each year strike vulnerable road users (VRUs) (WHO, 2009), i.e. pedestrians, bicyclists, moped drivers, and motorcyclists. The typical accident scenario that comes in mind is that the VRU collide with a car. Contrary to such preconceptions, statistics show e.g. that 8 out of 10 bicycle accidents are single vehicle accidents, and that these are often due to bad maintenance or slippery road conditions (Niska and Eriksson, 2013). Single bicycle accidents produce about ¾ of the severe injuries (Niska and Eriksson, 2013) and single accidents account for almost half of the fatalities for motorcyclists (Strandroth and Persson, 2005). An accident with a two-wheel vehicle may, even at fairly low velocities, lead to the driver getting unconscious or in other ways incapable of calling for help, and the accident may stay unnoticed for a long time if happening on small roads or during low traffic.

There is obviously a lot to gain if road users could be equipped with a system or function that not only can detect an accident or emergency situation but also can inform about this by sending an automatic alarm in case the driver is incapable of calling for help. Such an Automatic Crash Notification (ACN) system was first developed for cars by General Motors and installed in their luxury models under the brand name OnStar. Today, OnStar, or similar systems, is installed in millions of vehicles from different manufacturers. These systems automatically send an alarm to a call center in case of a crash triggering the airbag to be deployed. Further development of ACN systems was initiated by US researchers in the late 90s (Champion, et al., 2003), showing that it is possible to use the information available from vehicle sensors such as accelerometers to not only detect crashes but also estimate the severity of the crash and predict how the impact may have affected the passenger(s). In the European Union an ACN initiative is expected to be introduced in 2018; this service shall work in all member countries and is referred to as *eCall*. Although the *eCall* initiative is first and foremost aimed at automobiles, an adaptation of the system targeting also motorcycles is in progress.

In line with the *eCall* concept for cars, also riders of bicycles, mopeds, motorcycles or all-terrain vehicles (ATVs) can be equipped with sensors that are connected to e.g. a smartphone application (the embedded sensors in the smartphone may be good enough) that triggers an alarm when sudden changes in position or velocity outside what is considered normal for the specific type of vehicle is detected. Although this approach is similar to the *eCall* initiative, it differs significantly as the sensors preferably should be worn by the driver, as it is more relevant to trace what happens to the driver than the vehicle. This approach is further pronounced when considering the opportunity to use GPS information to find not only the site of the accident, but also the exact position of the driver who may be far separated from the vehicle after an accident.

The *Postcrash* group at SAFER foster a general interest in ACN systems and how these can be used to improve the rescueing activities after an accident. Since VRUs is an important group to target in order to reduce road traffic injuries it is highly relevant to extend the current ACN initiatives now starting to be commonly available in automobiles also to other categories of road users.

In order to test the feasibility of an ACN system for VRUs, we performed a pilot study to test the hypothesis that the built-in/embedded sensors of a high-end smartphone can be used to detect a bicycle accident. We found that the smartphone sensors (accelerometers, gyroscopes, and GPS system) can provide information about the movements during bicycling and that a smartphone app can use this information to evaluate falls or crash events in real time (Candefjord, et al., 2014). The study, demonstrated a smartphone app (“jalp!”, available from GooglePlay) for detecting bicycle accidents on the Android platform using a Google Nexus 4 smartphone. Although a number of simulated crash situations were used during the development, the main approach was to collect motion data from bicycle use in different situations (on different surfaces, with different bicycles and persons, different placements of the smartphone, on rural roads and in city environments, seated and standing position, etc.). This information was then used to develop an algorithm capable of distinguishing crashes from normal cycling (Candefjord, et al., 2014).

We are now taking this smartphone based ACN concept further by adapating the algorithm for other VRUs. The next in line is ATVs. ATVs have become popular and are commonly used as a light-weight tractor and transportation means in agriculture, forestry, and leisure activities on- and off-road. Unfortunately, the use is associated with a high prevalence of accidents and serious injuries (even fatal). This can be explained by the driver being unprotected, ATVs being heavy (which becomes dangerous if overturning), and, despite the four wheels, having poor driving properties in regular traffic.

As ATV use is more diverse than bicycling we need to learn more about what signifies normal ATV use. In line with the approach taken in the development of the bicycle app described above, extensive data collection can provide a base for what can be considered safe. Movements beyond normal use will then indicate potentially riskful situations that can be used to warn the ATV driver but also send an alarm if an integrated automatic evaluation of all available sensor signals indicate an accident. However, such large-scale collection of naturalistic data to provide a pool of, in this case, “normal ATV use” is generally considered both time consuming and expensive due to the extra mobile equipment needed to follow the driver/vehicle over time. As we use smartphones to detect accidents by means of the developed app for bicycle use, there is just some additional software needed to also record the high-quality accelerometer and gyroscope signals as well as the GPS-information. We have developed the smartphone app “LogYard” (available from Google Play and App Store) that takes the sensor signals from the embedded sensors at 100 Hz, and GPS information every second, and store them for later upload to a cloud-based server.

The aim of this paper is to present a smartphone based platform for low-cost collection of large-scale naturalistic movement data and ways to do this while adhering to established integrity levels for the participating VRUs.

METHODS

Methodological issues relating to large-scale collection of naturalistic movement data from VRUs concerns individual recordings of VRUs activities, ways of contributing additional metadata, and anonymity/privacy.

Recordings of activities

Individual recordings of movement data is performed by means of the developed smartphone app “LogYard” available from Google Play (Android) and App Store (iOS). The study participant simply starts the recording of data from the embedded sensors (accelerometers, gyroscopes, GPS) of the smartphone by pressing “start” on the app. The recording goes on until it is stopped by activating the “stop” button shown on the smartphone screen during recording.

Ways to contribute metadata

Additional information about the recording can be provided by keying in short text messages during the ride, or afterwards to each file containing the recorded information when presented to the user in upload mode. By means of this function, metadata about the recording (road conditions, special events, etc) can be added and made available to the analyst in the analysis. The upload functionality also provide the user with options about which files (i.e. recordings) that should be uploaded and which should be deleted and not made available to the analysis.

Participants’ anonymity

The recording of driver movements or behaviour during regular use of any vehicle in order to improve safety might at first be considered unproblematic. However, the experiences from introducing systems that enable postcrash analysis in cars tells us that many car customers are reluctant to such initiatives as it can provide data that may be incriminating to the driver. The use of GPS-information can also be considered sensitive and highly intrusive. Thus, high volume recording of VRUs’ movements must comply to *good research practice* and be able to adhere to different levels of anonymity/privacy according to the purpose of the study and the participants’ interest.

Three anonymity/privacy levels can easily be discerned:

i) No need for anonymity/privacy: This is trivial in the sense that no measures needs to be taken to govern the privacy or anonymity of the participants taking part in the study. However, the validity of data collected under these circumstances may be questioned as participants may choose to leave out information or avoid activities when not acting under the cover of anonymity.

ii) Complete anonymity/privacy: Although there are many applications where anonymously provided data can be of interest, the design of systems that can ensure complete anonymity based on data provided by smartphones is beyond the scope of this presentation. Even though measures are taken to secure anonymity, we have learned that virtually no system can stand hostile attacks from a resourceful intruder.

iii) High demands on anonymity/privacy: In the research community, good research practice has established a high level of anonymity that, for all intents and purposes, come close to complete anonymity. This level of anonymity allows research personnel to handle sensitive information from individuals by using individual codes and the link between the code and the actual person (the key) is kept hidden and only available to the person being responsible for the study and act under vow of silence/confidentiality. This means that it is only in exceptional cases where it is in all concerned parties’ interest to connect specific data to the actual person, that the key information is used. In a clinical study, for instance, it might be that the analysis has identified a serious condition that needs to be treated.

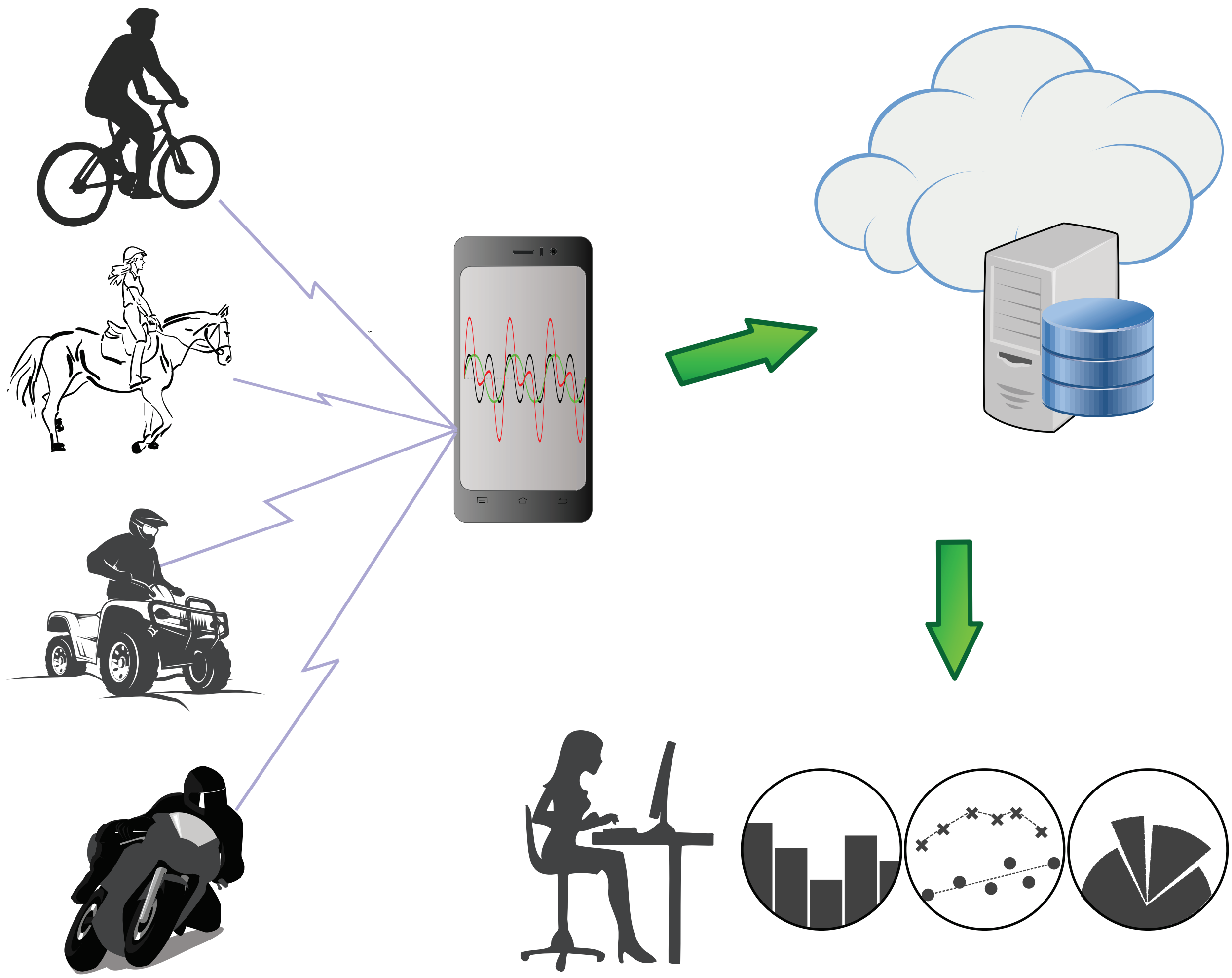

Figure 1: Participants taking part in a study can record movement data (from the smartphone embedded tri-axial accelerometer, gyroscopes and GPS –system) during their everyday transportation/spare time activities (left). The participants upload their activity files of choice to the "cloud". Researchers and other stakeholders associated to a specific study can easily access all the study data and download it for analysis but cannot connect a participants' data to the actual person. Data upload/download is secured via an encrypted file transfer protocol (FTP).

RESULTS

The suggested smartphone based-platform for large-scale recording of VRUs movement data is presented in Figure 1. All information collected from the users can be uploaded to a cloud-based server. The data integrity is provided by means of an individual key that is sent out to each study participant which establish the link to the cloud-based server where the information is organized according to study and participant.

Procedure to establish an "Informed consent" in high-volume data collection

The procedure to establish an individual "informed consent" from a distance to many participants is shown in Figure 2. The start is always to find and send out information to potential participants. This can be done by sending out flyers or posting invitations on the web. Interested and eligible persons are included in the study after signing the "informed consent" document where the study is described and the study candidate is informed about that the participation in the study is voluntary and the particiapant's right to at any time leave the study without being asked to explain why.

If the informed consent form is not signed in paper, an email response from the study candidate on the outgoing message providing the necessary information from the study coordinator/principal investigator stating that a response saying "I have read the information and confirm participation in the study" is considered as a signed informed consent. The study candidate thereby becomes a study participant. The principal investigator can then send out the study code that the participant should enter in the LogYard app which then is linked to the specific study in future uploads of LogYard data to the cloud-based server while keeping the participant anonymous to the research staff.

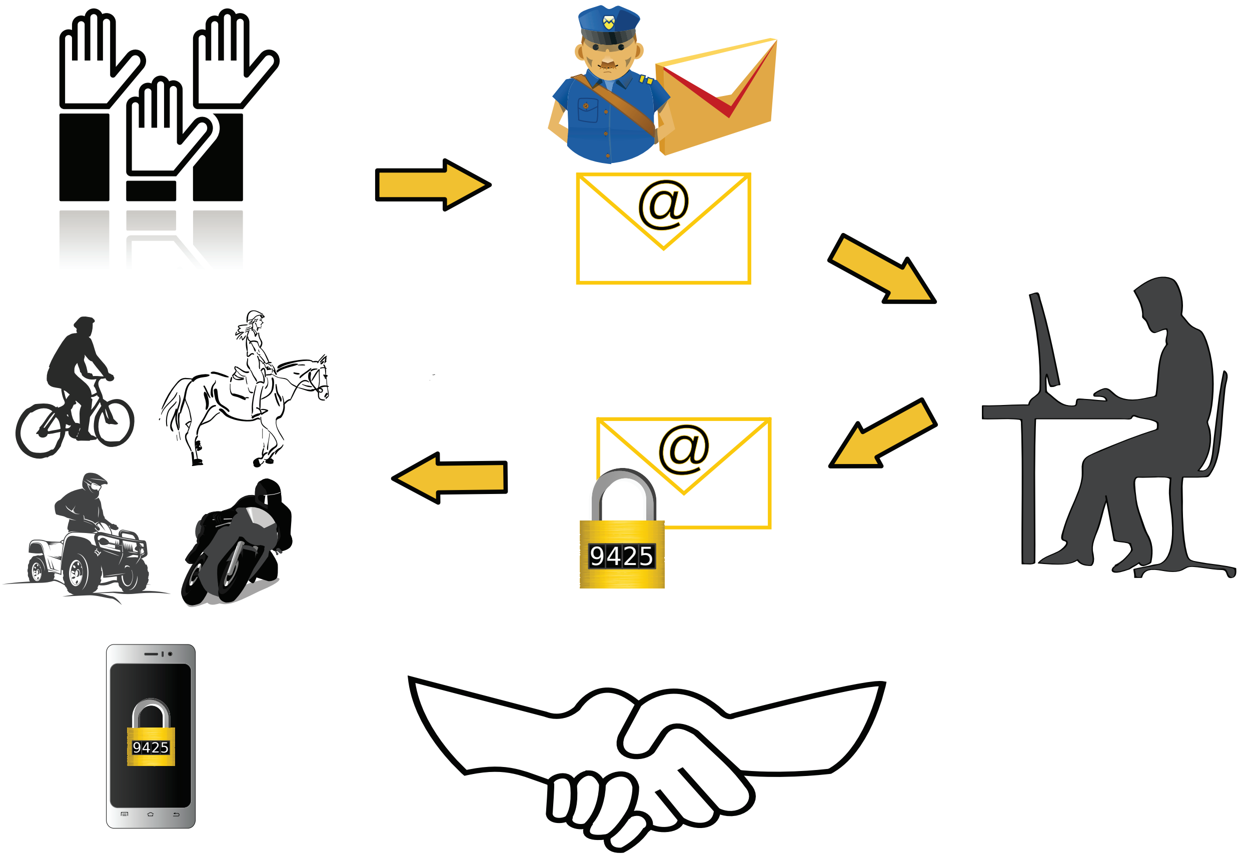

Figure 2: Each participant's privacy is assured according to the procedure shown in the figure. Those that have gotten information about the study and are interested to take part (raised hands) send the signed informed consent form by regular mail (or a corresponding confirmation by email) confirming the will to participate in the study. The principal investigator/person responsible for the study returns the unique study code to the participant. When this code is entered in the smartphone app the link to the cloud-based server is established and the participant can then record and upload data to the study server (as shown in Figure 1). Only the principal investigator knows and has access to the "key" connecting the subject study code to the participating person.

CONCLUSIONS

The infra-structure for large scale, long-term, low-cost smartphone based naturalistic data collection developed in this study can provide large quantities of high quality data from different VRUs use cases and studies. We believe that this information can be used not only to learn about everyday use but also potentially dangerous situations. This information can be used to increase awareness of safer driving behavior based on movement data and the accompanying comments, but also allow automatic crash notification systems for vulnerable road users, similar to the eCall initiative for cars, to be developed.

ACKNOWLEDGEMENT

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IDENTIFYING AND PROVING AUTOMOTIVE ALGORITHM DEFECTS AND AFFECTING RECALLS

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ABSTRACT

The societal cost in lives lost and injuries sustained from electronic defects, such as occupant size algorithm misclassification and ignition switch failure, was studied. In addition, the societal cost of ineffective production restraint systems in frontal and angled-frontal crashes was evaluated. Fatalities due to electronic defects were compared to the total fatalities from frontal and angled-frontal crashes.

Accident statistics show that, from 2001 to 2013, there were only 50 electronic algorithm defect deaths annually compared to 10,676 deaths annually from frontal and angled-frontal crashes involving vehicles that met the Federal Motor Vehicle Safety Standard (FMVSS) 208 test requirements. Our research indicates that many more deaths would have been prevented in a single year than electronic defects caused in 20 years if certain features of passive restraint systems proposed in the 1970's had been implemented. The same trend applies to injury mitigation.

The research question explored here is: Should "WE" prioritize identifying and repairing:

- algorithm defects that cause only 50 of the 10,676 fatalities annually, or
- ineffective production restraints systems in vehicles compliant with FMVSS 208 test requirements that cause 10,626 of the 10,676 fatalities annually.

Since NHTSA cannot specify design requirements, a simple solution is to substitute for the right and left angled barrier test a compartment angled at 20º to the right and then 20º degrees to the left on a sled simulating a 30 mph crash.

BACKGROUND

Since the first Drive-by-Wire (DBW) systems, independent engineers, manufacturers, and government have been aware of algorithm defects in production vehicles. Unintended acceleration, occupant size algorithm misclassification, and ignition switch failures are newly-reported, not newly-identified defects. To affect a recall, complaints and accidents must occur. Then, the NHTSA directs research and testing to identify and prove a defect. Litigation often accelerates the research and testing phase of the recall process. However, crashworthiness testing does not prove causation. Electronic defects are proven by downloading and anaylyzing control module stored functional data for a specific crash; this stored data does prove causation. The population of affected vehicles are identified. The cost of the defect is assessed in terms of lives lost and injuries mitigated. Technical service bulletins are issued. Recalls are implemented. Today's media informs the public.

Automotive DBW systems interconnect at least 40 microprocessors, their algorithms, hundreds of sensors and millions of lines of software code. Industry has developed DBW systems to improve engine fuel efficiency and responsiveness, reduce emissions, enhance occupant comfort, improve injury protection, and streamline repair and service diagnostics. In spite of rigorous testing, the DBW system is so complicated that it still has previously-identified, but unfixed bugs. Those bugs are generally discovered in litigation and lead to millions of recalled vehicles to mitigate potential deaths and injuries.

In 2014, millions of vehicles were recalled for unintended acceleration, ignition switch engine cut off, and/or failed airbag inflator housings. Congressional oversight investigations urged NHTSA to penalize manufacturers for delaying notification of such defects for up to 10 years. Press coverage highlighted the potential for death and injury.

in this paper, the annual fatalities and injuries caused by automotive electronic defects are compared with the thousands of deaths that occur annually in vehicles that meet all applicable FMVSS test requirements due to ineffective restraint systems. An example of the cost in lives is presented here.

METHODS

Accidents Statistics Data

In 2013, the Fatality Analysis Reporting System (FARS) identified 27,051 vehicle fatalities categorized as frontal, side, rear and rollover. Of those, there were 10,676 fatalities in non-rollover frontal impacts and angled-frontal impacts between 11 o'clock and 1 o'clock. That amounts to an average of 29 deaths per day in the United States [1]. These deaths are valued at $9.1 billion in accordance with Department of Transportation Policy Guidance, amount to a societal loss of $96 billion in monetary terms , not moral terms.

An estimate of the distribution at 11 o'clock, 11:30 , 12 o'clock, 12:30 and 1 o'clock of the 10, 676 fatalities from frontal and angled-frontal crashes[2] is shown in Table 1:

Table 1.
Estimated Frontal Fatalities by Clock Position

Clock Position	Angle	Total Fatalities
11:00	-30º	843
11:30	-15 º	Estimated 2,745
12:00	0 º	Estimated 3,850
12:30	15 º	Estimated 2,560
1:00	30 º	679

It is important to note the large number of deaths attributed to angled impacts at 11:30 and 12:30 where the restraints are ineffective. In developing airbags for NHTSA in the 1970s, Minicars determined that the left and right frontal 30º angled barrier impacts corresponded to ±10º of real world angled impacts because corner friction between the vehicle and the barrier limits the equivalent real-world angle. In other words, compliance with the regulatory test only requires occupant protection in frontal and ±10º angled real-world impacts. Current supplemental airbags are sized to protect occupant head and neck from contact with interior components. The deployment algorithms preclude activation in angled impacts relying on the belts to limit motion. Therefore, occupants of real-world angled impacts greater than ±10º are virtually unprotected and account for the large number of fatalities at 11:30 and 12:30 clock positions. Apparently, NHTSA has not recognized this discrepancy in protection, where the industry can be in full compliance with the test requirements, but only protect less than half of the frontal fatality population.

Algorithm Misclassification An investigation of an essentially frontal crash in a 2008 sedan produced physical evidence of a defective occupant size algorithm misclassification defect. The Crash Data Retreival (CDR) record confirmed the driver airbag deployment and right front passenger airbag deployment suppression. A download of the stored data in the passive occupant detection system control module was conducted. The stored data showed that a 170-lb belted right front seat passenger, who lifted off the seat, was misclassified as a small adult 1.5 seconds prior to impact, resulting in suppressed passenger airbag deployment.

An Office of Defect Investigation (ODI) petition called for a response from the manufacturer, whose analysis refuted the defect claim. The manufacturer:

1. did not deny that the algorithm resulted in occupant size misclassification, and
2. claimed the right front passenger was out-of-position.

Ignition Switch Defect Studies show that, over the 10-year period from 2003 to 2013, the ignition switch defect accounts for the 338 fatalities of the 3,806 claims. Based on the probable resolution of many of these claims, the annual cost of this defect is unlikely to exceed 20 fatalities and 100 serious injuries annually.

Safety Belts and Airbag Defects In the 1960s, there were no safety belts in cars and the concept of passive protection by automatically deploying airbag was born. In 1973, GM produced about 10,000 Cadillacs and Oldsmobiles with driver and passenger airbag protection.

In the context of the 1974 amendment to FMVSS 208, occupant protection is specified in Paragraph S4.1 Frontal Barrier Crash. "When the vehicle impacts a fixed collision barrier perpendicularly or at any angle up to and including 30º in either direction from the perpendicular, under the applicable conditions of S6, while moving longitudinally forward at any speed up to and including 30 mph with test device at each designated testing position, it shall meet the injury criteria of S5."[3] A review of the latest post 2006 version of FMVSS 208 confirms this test procedure.

In spite of the amendment by 1981, the automotive industry drove the design of 3-point safety belts and associated supplemental airbags to perform in frontal and angle barrier impacts at the equivalent of ±10º of impact angle. This design strategy rendered occupants in crashes involving impact angles greater than 10º or 15º vulnerable to deaths and injuries. The annual cost of those impacts is in the range of 5,000 fatalities.

In the example frontal crash of the 2008 sedan presented above, the manufacturer claimed that there existed no proof that passenger airbag deployment would have mitigated the occupant's injuries. The manufacturer made the following statement:

> *"The Petitioner's suggestion that the occupant would have benefited from passenger airbag deployment is not supported in the Petition and is pure speculation. The Petitioner has not supplied – and the manufacturer is not aware of – any evidence or argument that supports the conclusion that a passenger-side airbag should deploy in the conditions recorded by the vehicle's AOS, or that the full deployment of the passenger-side airbag would have mitigated – and not exacerbated – the injuries allegedly sustained by the occupant during the accident.[4]*

The implication of this statement is that safety belts do not keep the occupant in close proximity to the seat and, if the passenger's airbag had deployed, it would not have mitigated the passenger's injuries as it did for the driver. In fact, the manufacturer claimed that deployment could exacerbate occupant injury.

An analysis of airbag effectiveness is tied to the frontal impact regulatory requirement test. The airbag is optimized to minimize head injury criteria in frontal ±10º impacts and sized accordingly. However, the slack in the safety belts is sufficient to put the occupant somewhat out-of-position, where the size of the airbag is insufficient to protect the occupant's head. This analysis suggests that fatalities and injuries are the result of ineffective safety belts and/or airbags.

As early as 1972, the NHTSA sponsored the 1975 Minicars Research Safety Vehicle (RSV) project aimed at airbag development to protect occupants from interior impact at up to 30º at 30 mph [5-6]. Minicars found that a large-diameter chambered airbag had a significant effect on mitigating fatality and injury without requiring a revised test standard. The requirements for the airbags included frontal protection at 50 mph and protection from 11 to 1 o'clock at 30 mph. The RSV driver dual airbag was incorporated into the steering wheel on a stroking steering column with a foam knee restraint. The inner bag deployed first and vented into an approximately 30-inch outer diameter bag tethered to each other. The passenger airbag was chambered to fill in the bottom half and vent into a multichambered head impact bag. This design provided 50 mph occupant protection without safety belts at up to 30º off-axis (at 30 mph). Projected to the 1985 vehicle population, this design results in a 75% reduction in frontal fatalities.

The frontal crashworthiness compliance test and its vehicle rating system is based on a barrier crash at ±10° of 12 o'clock. The vehicle rating system assigns 3 of 5 possible stars if dummy injury measures meet the injury criteria and up to 5 stars if the injury measures are 50% of the injury criteria. This is a powerful incentive for manufacturers to optimize safety belt and airbag design for the test at minimum size, cost and weight.

Since NHTSA can only require performance criteria, an equivalent simple solution is to substitute for the right and left angled barrier test a compartment angled at **20**º to the right and then **20**º degrees to the left on a sled simulating a 30 mph crash**.** A further modification within NHTSA's authority is to substitute a low durometer neck for the Hybrid III production neck to more appropriately represent current population of occupants. An experiment demonstrated the effect. Two identical sled tests of a restrained Hybrid III dummy, one with a production and the other a low durometer neck were tested a 15 mph. The low durometer neck allowed the head of the dummy to be extended forward approximately 4" further than the production neck as shown in Figure 1.

Figure 1. Production vs. Low Durometer Neck

RESULTS

The occupant size algorithm misclassification and the ignition switch defects account for only about 50 fatalities annually. In contrast, restraint systems that meet the regulatory requirements account for nearly 30 times the annual fatalities caused by electronic defects. The narrowly-defined FMVSS 208 requirements only protects occupants in direct frontal crashes. A variety of variables, each of which can account for several hundreds of fatalities in the real-world, are not adequately addressed in the existing standard. For example:

- the impact angle is greater than ±10º,
- occupants are frequently out-of-position,
- the dummy does not represent the current population,
- 30% of occupants do not wear their safety belts, and
- the DBW system fails.

CONCLUSION

Clearly, automotive safety efforts should prioritize reducing the 10,626 of 10,676 annual fatalities by improving safety belts for those occupants who wear them and expanding airbag passive protection for those who do not wear safety belts, instead of focusing on algorithm defects that cause only 50 of 10,676 fatalities annually.

Since FMVSS 208 is a performance, not design requirement, the most effective means of reducing fatalities and injuries is to substitute for the right and left angled barrier test a compartment angled at 20º to the right and then 20º degrees to the left on a sled simulating a 30 mph crash. A further modification would be to substitute a low durometer neck for the Hybrid III production dummy neck.

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EDR DATA COLLECTION IN NHTSA'S CRASH DATABASES

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Paper Number 15-0260

ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) has been gathering Event Data Recorder (EDR) information in its data collection programs since the late 1990s. The various EDR data elements collected in NHTSA's crash databases provide insight into the vehicles' safety systems and actions leading up to a crash. This EDR data will be a key source as focus on crash avoidance countermeasures increase and crashworthiness countermeasures are optimized in the automotive safety community. The purpose of this paper is to describe the evolution of EDR data collection in NHTSA's in-depth crash investigation programs leading up to the implementation of the Code of Federal Regulation (CFR) 49 Part 563. Additionally, the paper will discuss the techniques used to collect EDR data, and detail future plans for their coding in NHTSA's crash databases.

INTRODUCTION

NHTSA is currently imaging EDR data using a commercially available tool in its three field investigation-based data collection programs: the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS), Special Crash Investigations (SCI) and the Crash Injury Research and Engineering Network (CIREN).

NASS-CDS is a nationally representative sample of towed light vehicle crashes with an emphasis on the crashworthiness of the vehicle. The case selection algorithm is gives fatal and severe injury crashes a higher probability of selection than less severe crashes. Data is collected at 24 sites across the country with an annual average of 4,500 cases per year since 1999.

SCI is a collection of approximately 125-150 targeted investigations annually that are utilized by NHTSA and the automotive safety community to understand the real-world performance of existing and emerging advanced safety systems.

CIREN is a hospital-based study operating out of six centers across the country, collecting approximately 300 cases per year. The CIREN process combines prospective data collection with professional multidisciplinary analysis of medical and engineering evidence to determine injury causation in every crash investigation conducted.

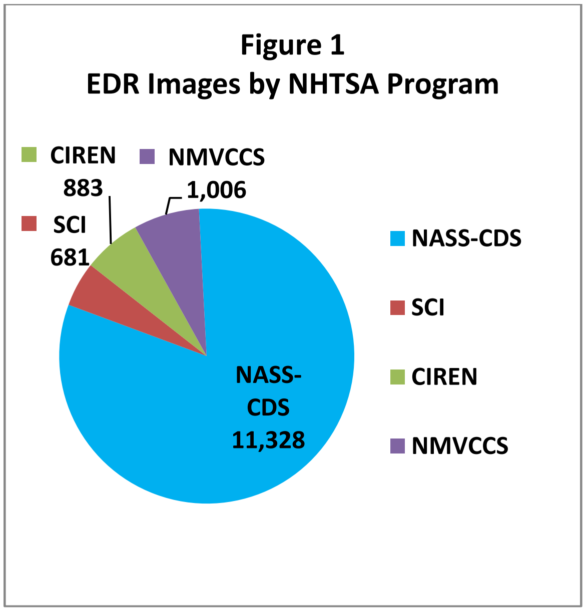
EDR data was also collected by NHTSA in a special study using the NASS infrastructure from 2005-2007, the National Motor Vehicle Crash Causation Survey (NMVCCS). NMVCCS was a nationally representative survey of light vehicle crashes that used Emergency Medical Services (EMS) notifications as the primary case initiation criterion. Researchers conducted on-scene field investigations on nearly 7,000 crashes during the project, focusing on the pre-crash phase of the crash.

While the three active data collection programs NASS-CDS, SCI, and CIREN have distinct overall objectives they do share four key data collection areas:

- Examining the crash scene
- Interviewing involved occupants
- Reviewing occupant medical records
- Conducting detailed inspections of crash-involved vehicles

The vehicle inspection involves the documentation and photography of crush deformation, occupant compartment intrusion, occupant contacts, and assessment of the safety systems in the vehicle. Additionally, the vehicle inspections include an attempt to image the EDR if the vehicle is so equipped and supported by the commercially available Crash Data Retrieval (CDR) tool.

As of January 8, 2015 the four investigation-based programs have imaged 13,898 EDRs since 1999. Figure 1 outlines the breakdown of EDRs imaged by each of the NHTSA programs.



BACKGROUND

NHTSA began collection of very rudimentary EDR data in the 1970s. General Motors (GM) introduced the first regular production driver/passenger air bag systems as an option in selected 1974-76 production vehicles. They incorporated electromechanical g-level sensors, a diagnostic circuit that continually monitored the readiness of the air bag control circuits, and an instrument panel Readiness and Warning lamp that illuminated if a malfunction was detected. The data recording feature used fuses to indicate when a deployment command was given and stored the approximate time the vehicle had been operated with the warning lamp illuminated. This information was extracted by the SCI investigators with a GM proprietary tool.

In 1990, GM introduced a more complex air bag control module called the Diagnostic and Energy Reserve Module (DERM). The DERM was introduced with the added capability to record closure times for the multiple electromechanical switches for crash sensing, arming, and discriminating sensors as well as any fault codes present at the time of deployment. Beginning with the 1994 model year, GM introduced a single solid state analog accelerometer and a computer algorithm integrated in a Sensing & Diagnostic Module (SDM). The SDM also computed and stored the change in longitudinal vehicle velocity (deltaV) during the impact to provide an estimate of crash severity. This feature allowed GM engineers to obtain restraint system performance data when a vehicle was involved in a deployment event or experienced an impact-related change in longitudinal velocity, but did not command deployment (i.e. a near-deployment event). The SDM also added the capability to record the status of the driver's seat belt switch (buckled or unbuckled) for deployment and near-deployment events.

In certain GM vehicles beginning in the 1999 model year, the capability was added to record vehicle systems status information for a few seconds prior to an impact. Vehicle speed, engine RPM, throttle position, and brake switch on/off status are recorded for the five seconds preceding a deployment or near-deployment event.

At that time, the information in GM DERMs and SDMs could only be extracted by the manufacturer using a proprietary tool. Therefore, only a limited number of images were obtained by GM at the request of NHTSA to support air bag and EDR research from 1990 to 1999.

In 1999, NHTSA launched a research project with Ford on the real-world crash experience of advanced featured air bags equipped in 2000 Taurus/Sable fleet. For this research, Ford supplied the SCI teams a rudimentary EDR tool for extracting the basic air bag deployment data from the Restraint Control Module (RCM). The RCM also computed and stored a short duration (~80ms) of the change in longitudinal and lateral vehicle velocity during the impact sequence to provide an estimate of crash severity. This feature allowed Ford engineers to obtain restraint system performance data to help "tune" the deployment algorithms.

Beginning in 1999, the various NHTSA field data collection teams were equipped with a commercially available tool called the Crash Data Retrieval (CDR) system, produced by Vetronix Corporation to collect EDR data. Late in 2003, Vetronix, which was the only commercially available supplier of the CDR retrieval tool, was purchased by Robert Bosch GmbH. In the early years, only some GM vehicles were supported by the CDR hardware and software, but in 2003 and 2007, respectively, select Ford and Chrysler vehicles were added to the list of supported models. From 1999-2007, the number of models supported by the CDR tool continued to increase for these three major U.S. manufacturers. Therefore, by the beginning of 2008, roughly half of the vehicles sold in North America since model year 2004 were supported by the CDR system [1].

Based on the outputs from the early EDRs, the subsequent commercially available tool, and NHTSA's recognition of the safety benefits to the driving public, a team of experts was formally organized to research the efficacy, collection, storage and imaging of the data. The Summary of Findings by the NHTSA EDR Working Group [2] was published in 2001 and included a recommended set of standardized results.

The final rule addressing EDRs, CFR 49 Part 563 was issued on August 6, 2006 [3] and on January 14, 2008 the response to petitions for reconsideration followed [4]. The regulation does not mandate that EDRs be installed in vehicles, but among other items, it specifies that if a vehicle is equipped with an EDR, the following conditions apply:

1. The EDR must capture crash data in a uniform format (detailed in Part 563)
2. There must be a standardized notification statement in the vehicle owner's manual
3. There must be a commercially available tool to access the data

CFR 49 Part 563 also defines an EDR as a device or function in a vehicle that records dynamic time-series data just prior to an event (speed versus time or delta V versus time) and the data is intended for retrieval after a crash event. It is important to note that EDR data does not include audio or video. If a vehicle is equipped with an EDR that records data, the following items are required:

- Delta V Longitudinal
- Max Delta V Longitudinal
- Time, Max Delta V
- Speed, vehicle indicated
- Engine throttle %
- Service brake on /off
- Ignition cycle, crash
- Ignition cycle, download
- Safety belt status, driver
- Frontal air bag warning lamp on/off
- Frontal air bag time to deploy – driver air bag
- Frontal air bag time to deploy – passenger air bag
- Multi-event – number of events
- Time from event 1 to 2
- Complete file recorded yes/no

The rule also specifies the interval/time and the sample rate for each element. There are also similar format requirements for additional data elements if they are recorded.

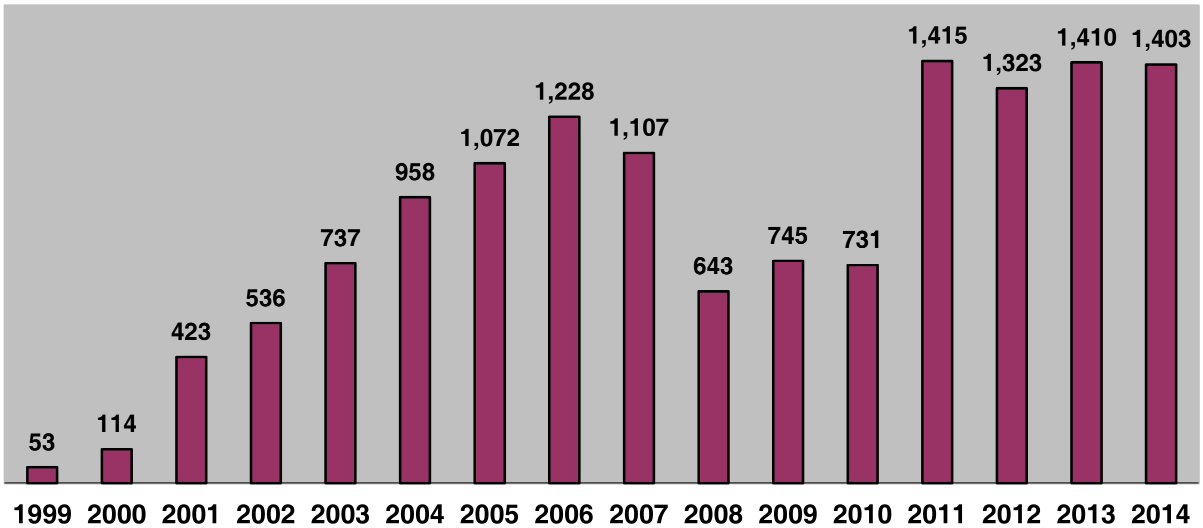
The regulation, which applied to vehicles manufactured after September 1, 2012, had a positive effect on the number of manufacturers standardizing their data and being supported by the Bosch CDR data retrieval tool. Several major Japanese and European manufacturers partnered with Bosch to make their EDR data retrievable using the CDR tool. By October 2014 the following manufacturers have some or all of their models supported:

- General Motors
- Ford
- Chrysler/Fiat
- Toyota
- Honda
- Mazda
- Nissan
- Volvo
- BMW
- Daimler
- Volkswagen
- Suzuki

The current Bosch CDR system (Version 14.1) costs about $11,400 and includes approximately seventy (70) different cables and connectors and a one-year subscription to the software. The software must be upgraded yearly at a cost of $900 per user. In addition to the equipment and software, extensive training for the field personnel is required for both the imaging and interpreting of the data.

Some manufacturers, Hyundai/Kia and Subaru for example, chose not to partner with Bosch and developed their own commercially available tool for EDR data collection in their vehicles. A few other manufacturers have elected to forego the recording of EDR data so they are not subject to Part 563. Although NHTSA has purchased some of the manufacturers proprietary EDR kits to image high interest cases, at the present time it is not cost effective to equip every field investigation team with those tools.

Figure 2
Number of EDRs Imaged Yearly



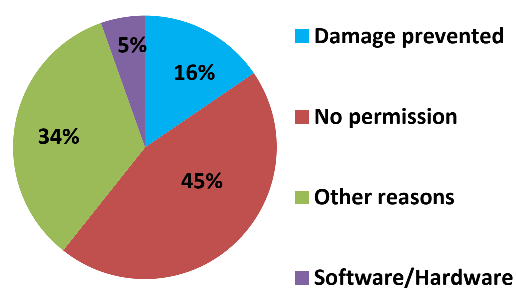
HISTORICAL EDR DATA COLLECTION

Figure 2 shows the number of EDR's imaged yearly as of January 8, 2015, in the four NHTSA investigation-based programs (NASS-CDS, SCI, CIREN, and NMVCCS). In total they have imaged 13,898 EDRs since 1999.

As the number of vehicles supported by the CDR software has increased in the fleet, the number of EDRs imaged by the programs has generally increased yearly. However, the graph shown in Figure 2 has several fluctuations that require explanation. Aside from the general upward trend, a spike occurred from 2005-2007 due to the addition of the NMVCCS special study which was conducted during the time period. The sharp decrease from 2008-2010 was due to significant cuts that were made to the NASS system, eliminating the NMVCCS program and forcing significant cutbacks to the infrastructure. In an effort to reduce costs, NASS field offices were reduced in staff and EDR equipment was reduced to one complete CDR kit per field office.

Realizing the importance of EDR acquisitions as the effective date of CFR 49 Part 563 approached, late in 2010 NHTSA conducted a simple analysis to determine reasons NASS-CDS Technicians were unable to image the EDR data when the vehicle was supported by the CDR tool. Figure 3 depicts the reasons why the EDR data in supported vehicles could not be obtained in 2009-2010 NASS-CDS cases.

Figure 3
Reasons EDR Not Obtained in Supported Vehicles NASS-CDS 2009-2010



Among the reasons the EDR data could not be obtained, the largest percentage (45%) were because the vehicle owner denied permission to image the data. This included both outright owner refusals to the NASS-CDS Technician, and also the owner not wanting any additional damage to the vehicle to obtain the data. In cases where the On Board Diagnostic (OBD) plug was damaged, or there was no power to the vehicle, the Technician would need to go direct to the module. This would include disassembling the vehicle's console or cutting the carpet to gain direct access to the EDR module. As Figure 3 indicates, damage prevented the Technician from obtaining the data in 16% of the cases. Vehicle damage included situations where the electrical system was compromised and the Technician could not access necessary connections and/or damage prevented access to the module.

"Other" reasons accounted for 34% of vehicles where the EDR data could not be obtained. These "other" reasons included:

- The Technician was allowed an exterior inspection only (evidentiary reasons) or the vehicle was locked and no keys were available
- The Technician only obtained photographs of the damaged vehicle
- The EDR was removed prior to the NASS-CDS vehicle inspection (usually by law enforcement)

A combination of software and hardware issues were cited as the reason the remaining 5% of supported vehicle downloads were unsuccessful. Software issues generally occurred when the Technician's CDR tool could not successfully communicate with the EDR module. Hardware issues were related to plugs, connectors, and laptop problems.

As mentioned earlier, owner permission was not limited to refusals to the NASS-CDS Technician to image the EDR data. "Refusal" also included a large percentage of owners who would not permit any additional damage to the vehicle in the process of imaging the EDR data. There are three basic ways to image an EDR:

- Through the On-Board Diagnostics (OBD) port
- Direct to the EDR module
- Removing the module and imaging later on a bench top

To successfully obtain an image of the EDR through the OBD port, generally the electrical system cannot be compromised and the OBD connection plug (usually located beneath steering wheel under instrument panel) port cannot be damaged. NASS-CDS cases are intentionally sampled at a higher rate for towed vehicles with severe damage and injuries. Therefore, the electrical system will sometimes be damaged either during the crash or during post-crash extrication activities.

Going direct to module is possible when the electrical system is compromised, however, this process involves:

- Determining module location
- Removing consoles, instrument panel parts, or seats
- Cutting the carpet

This process can be complicated by crash damage and in situations where power seats are obstructing access to the module and the vehicle has no power. Oftentimes, owners will not allow the additional damage to their vehicle that is required to access the EDR.

The final way to access the EDR data is to remove the module from the vehicle and image the data later at another location. This method is not permitted because strict NASS-CDS policies are in place forbidding retention of any vehicle component.

After NHTSA reviewed the results of the analysis it was apparent the number of EDR images in the programs could increase significantly if retrieval techniques could be employed that would:

- Cause no further damage to the vehicle
- Allow the EDR to be imaged when no keys are available
- Increase successful attempts on severely damage vehicles

A natural increase in the number of cases with EDR data would also be expected due to the greater penetration of EDRs into the fleet.

One advanced EDR imaging technique, commonly referred to as the Fuse Block Method (FBM), involves supplying power to the EDR through the vehicles fuse panel and imaging the data through the OBD port. Although not always successful, this method eliminates the need to dismantle consoles, disassemble vehicle components, and cut carpets. In addition, when vehicle keys are not available, powering the EDR through the fuse block allows for OBD download.

In December 2010 NHTSA conducted EDR update training and provided the necessary additional equipment for all field personnel to begin using the FBM when other data imaging techniques failed. The agency also instituted tighter quality control measures within the NASS software and placed additional emphasis on successful EDR retrieval. The field personnel began using the new method of collection in 2011 and improved EDR acquisition results followed.

CURRENT EDR DATA COLLECTION

The 2012-2013 NASS-CDS revealed that about 45% of the over 7,000 vehicles inspected were supported by the Bosch CDR retrieval tool. With CFR 49 Part 563 in place and the increased number of manufacturers supported by the commercially available tool, that percentage will likely continue to grow as EDRs become more widespread in the fleet.

The renewed emphasis on EDR data acquisition and implementation of the FBM had a major effect on the number of EDRs imaged by the NASS Technicians. Figure 4 shows the success rate roughly doubling the three years after the FBM EDR training compared to the two years prior. The two most recent years of data shows the NASS-CDS Technicians successfully imaged the EDR, when the vehicle was supported, 74% of the time.

Figure 4
NASS-CDS
Successful EDR Image %
(When vehicle supported)

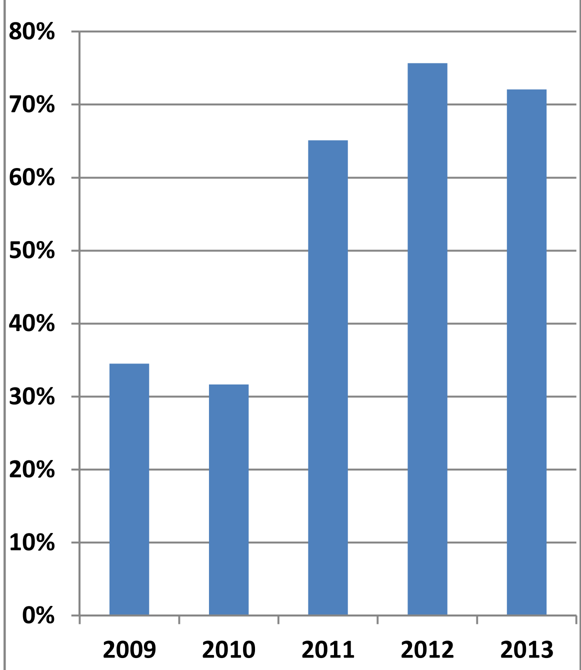
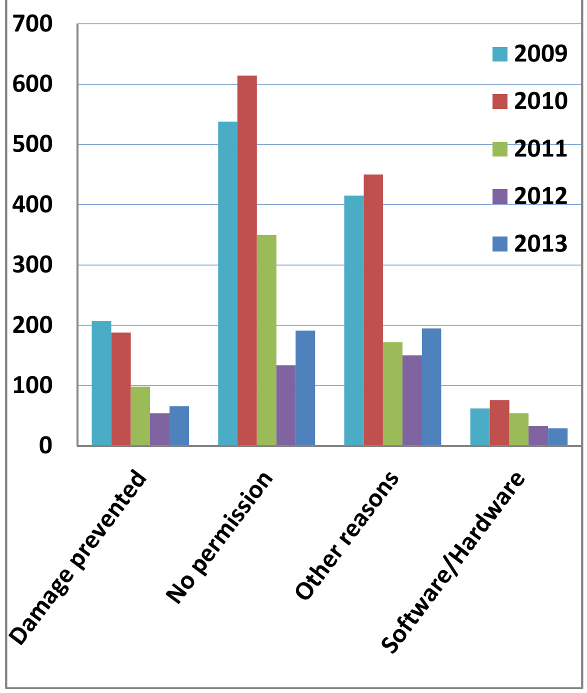


Figure 5 shows that after the training in late 2010 there was a decrease in unsuccessful EDR data retrieval. The figure also shows the associated reasons for lack of success by year. As discussed earlier, the FBM dramatically decreased the number of times damage prevented the EDR imaging, that permission was denied, and/or there were other reasons cited as the reason the EDR could not be imaged.

Figure 5
Reasons for Unsuccessful EDR image
(When vehicle supported)



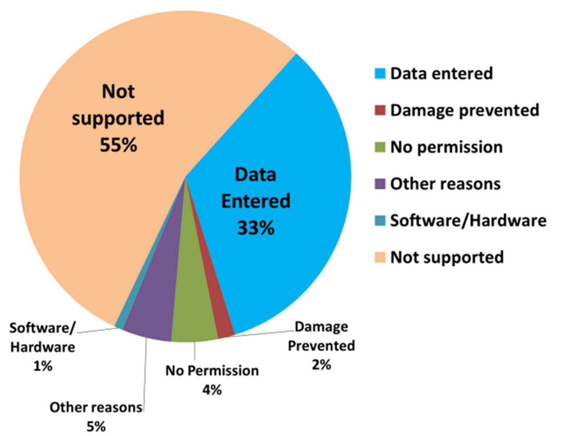
In the current NASS-CDS system EDR data is available to the public in two formats. An Acrobat .pdf of the CDR file is available for each vehicle with a successful image. The reports can be found at ftp://ftp.nhtsa.dot.gov/NASS/EDR_Reports/. Secondly, the coded EDR data is available for clinical review within each individual NASS-CDS case. The case viewer for 2004-2013 data year NASS cases is located at http://www-nass.nhtsa.dot.gov/nass/cds. 1999-2003 NASS-CDS cases are available at http://www-nass.nhtsa.dot.gov/BIN/NASSCaseList.exe/SETFILTER?CASETYPE=PUBLIC.

Query tools are also provided in the NASS-CDS case viewers to narrow areas of focus down to specific makes, models, delta V ranges, injuries, and deformation types, among many other filter criteria.

Figure 6 shows the final overall percentages of EDR acquisition in inspected NASS-CDS vehicles from

2012-2013. One third of inspected vehicles have imaged EDR data, 55% are not supported by the CDR tool, and the remainder are split among the various unsuccessful reasons. Those 55% that were not supported requires clarification. Although all light vehicles equipped with EDRs sold in the United States after September 1, 2012 are required to meet CFR 49 Part 563, and almost 2,500 year/make/models are supported in version 14.1 of the Bosch CDR software released in October of 2014 [5], one must keep in mind that NASS-CDS is not limited to late model year vehicles. Since it serves as a multi-purpose nationally representative database, a large percentage of the sample are older model year vehicles.

Figure 6
NASS-CDS EDR Data
2012-2013



SCI cases are another valuable source of EDR data available to the public, and the cases can be viewed at http://www.nhtsa.gov/SCI. In addition to the data available in a NASS case, the SCI cases also feature a technical report which includes a detailed discussion of the EDR findings. The SCI investigators have attended EDR interpretation courses and are experts in advanced imaging techniques. In 2012-2013, the SCI investigators successfully imaged the EDR when the vehicle was supported 80% of the time.

FUTURE EDR DATA COLLECTION

NASS was initially designed in the 1970s, and the system needed to be updated to meet the data needs of the transportation community that have increased and significantly changed over the last three decades. In Fiscal Year 2012, Congress appropriated funds for NHTSA to modernize NASS. The formal project, known as Data Modernization, was launched in January 2012. The goal of Data Modernization is to affirm NHTSA's position as the leader in motor vehicle crash data collection and analysis, by collecting quality data to keep pace with emerging technologies and policy needs. The multi-year project is set for implementation to begin in January 2016.

Congress was specific in their request to modernize NASS and NHTSA is looking to improve upon the following practices:

- Increase the sample size
- Expand the scope of its data collection to possibly include large trucks, motorcycles, and pedestrians
- Assess the need for more data from the pre-crash, crash, and post-crash phases of the crash sequence
- Review the crash data elements to be collected
- Solicit input from interested parties including suppliers, automakers, safety advocates, research organizations, and the medical community

The replacement to NASS-CDS has been named the Crash Investigation Sampling System (CISS). New nationally representative data collection sites have been selected using a sample design approach similar to NASS-CDS. The new sites were chosen using the most recent census and vehicle registration data and the goal is to better reflect the nation's overall crash picture and increase the availability of newer model vehicles and severe crashes at the data collection sites.

NHTSA believes that EDR data collection will continue to be a point of emphasis in CISS, as well as in the other field investigation-based data collection programs. Crash Technicians collecting data at the CISS sites will be trained on the various EDR imaging techniques and be equipped with the most current versions of the CDR software and connection cables.

Public access of EDR data in CISS will be an improvement from previous program. Current plans call for the original imaged .cdr file to be made available along with coded EDR data entered in the case viewers. Data from the Table 1 and Table 2 of CFR 49 Part 563 will also be available in SAS files and other analysis formats to enhance end user accessibility.

CONCLUSION

EDRs will likely continue to be a important source of information as focus on crash avoidance countermeasures increase and crashworthiness countermeasures are optimized in the automotive safety community. Over the past 16 years, investigation-based data collection programs sponsored by NHTSA have accumulated one of the most extensive libraries of real-world crash EDR data in the world. Largely due to the implementation of CFR 49 Part 563, the vehicles in the fleet equipped with EDRs, and correspondingly the number of EDRs imaged by NHTSA, will increase even more rapidly in upcoming years.

Through the years EDR imaging acquisition rates in NHTSA's investigation-based programs have continually improved because of up-to-date equipment, the training of advanced imaging techniques, and the emphasis by the Agency to make the successful retrieval of EDR data a priority. The data collection programs are at the point now if the field personnel conduct an inspection of a vehicle equipped with an EDR, there is a high likelihood the data will be successfully imaged.

NHTSA's Data Modernization project should have a positive effect on EDR data collection, particularly in CISS which is set to begin in 2016. Plans are to equip each of the Crash Technicians with the CDR tool to image EDRs. The EDR data will be more accessible for end users through additional file formats, and the new data collection locations are projected to have increased percentages of EDR-equipped vehicles selected in the sample.

References

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[3] National Highway Traffic Safety Administration. 2006. Federal Register Citation 71 FR 50998, Code of Federal Register 49 Part 563.

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REAL-WORLD ANALYSIS OF FATAL REAR-END CRASHES

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ABSTRACT

In March 2011, the National Highway Traffic Safety Administration (NHTSA) published its Vehicle Safety Rulemaking and Research Priority Plan 2011 – 2013, which described the projects that are the agency's priority in the rulemaking and research areas in those calendar years. Programs that are priorities or will take significant agency resources included the development of performance criteria and objective tests to support the identification of effective advanced safety technologies that provide a warning of an impending forward collision and/or automatically brake the vehicle.

In support of the Forward Collision Avoidance and Mitigation project listed in the priority plan, an analysis of real-world crash data was conducted to determine the scope of the crash problem and examine the factors that contribute to rear-end crashes in light vehicles. A review of the 2003 – 2012 National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) was conducted for rear-end crashes involving a fatal occupant.

For each crash identified, a review of the accompanying investigation was conducted using a methodology similar to that described by Bean, et al. [2009]. The authors were then able to identify crash characteristics associated with occupants sustaining fatal injuries in rear-end crashes. For each case, primary and secondary factors were assigned as crash attributes which contributed to the fatal injuries to an involved occupant. This review suggests that fatal rear-end crashes are generally attributed to excessive speed at the time of impact. In order to address these crashes with a forward collision avoidance system, a crash alert warning must be timely and any automatic emergency braking must be aggressive to significantly reduce the impact speed to mitigate the severity or prevent the crash from occurring.

INTRODUCTION

According to NHTSA's Traffic Safety Facts 2012, fatal crashes increased by 3.1 percent from 2011 to 2012, and the fatality rate rose to 1.13 fatalities per 100 million vehicle miles of travel in 2012. The injury rate increased by 6.7 percent from 2011 to 2012, to 80 persons injured per 100 million vehicle miles of travel in 2012. However, the occupant fatality rate (including motorcyclists) per 100,000 population, which declined by 22.7 percent from 1975 to 1992, decreased by 31.1 percent from 1992 to 2012, and the occupant injury rate (including motorcyclists) per 100,000 population, which declined by 13.6 percent from 1988 to 1992, decreased by 37.8 percent from 1992 to 2012. Of the more than 5.6 million police-reported motor vehicle crashes that occurred in the United States in 2012, 29 percent of those crashes (1.63 million) resulted in an injury, and less than 1 percent (30,800) resulted in a death [NHTSA, 2014].

Rear-end type crashes (i.e., front of a motor vehicle striking the rear of another vehicle) are the most frequent first harmful event and account for approximately 33 percent of all crashes including collisions with a motor vehicle in transport, fixed object, non-fixed object and non-collisions such as rollovers. Specifically where the first harmful event was a rear-end crash there were 1,827 fatal, 518,000 injury and 1,327,000 property damage only crashes in 2012 [NHTSA, 2014].

Prior studies have focused on quantifying the size and the identification of trends in rear-ends crashes through the use of descriptive statistics. One study used NHTSA's 1992 – 1996 National Automotive Sampling System-General Estimates System (NASS-GES), which is a weighted sample database of police reported crashes, to identify the relative frequency of 10 major rear-end pre-crash scenarios [Najm, 1998]. Using the coded data, these scenarios identified the pre-crash dynamic state of the involved vehicles by roadway curvature. The rear-end crash data were sorted by injury severity, roadway surface condition and posted speed. The intent of the study was to define the crash problem from a dynamic crash scenario level for safety benefits estimation.

A follow up study analyzed the same NASS-GES years of data, and provided a statistical description of the scenarios discussed in the previous paper [Wiacek, 1999]. The statistics presented encompassed driver characteristics of the following vehicle, including avoidance maneuver attempted before impact, crash contributing factors, driver age, and gender; vehicle body types involved in these rear-end pre-crash scenarios; and initial travel speeds of the following vehicle under various posted speed limits. The results of the study were intended to be useful for estimating the safety benefits of rear-end crash avoidance technologies for crash number reduction and severity mitigation.

These studies have been used to assess the benefits of rear-end crash avoidance technologies, from field operational tests and also as the basis for evaluating these systems in a test environment. An independent evaluation of an Automotive Collision Avoidance System (ACAS) was conducted with vehicles equipped with forward collision warning and adaptive cruise control [Najm, 2006]. The goals of the independent evaluation were to characterize ACAS performance and capability; achieve a detailed understanding of ACAS safety benefits; and assess driver acceptance of ACAS. Utilizing data from the field tests and the crash scenarios defined above, the study estimated that ACAS, as an integrated system of forward collision warning and adaptive cruise control functions, has the potential to prevent about 6 to 15 percent of all rear-end crashes depending on the source of crash data used for safety benefits estimation.

A more recent study that used the NASS-GES data identified and described a new typology of pre-crash scenarios for crash avoidance research [Najm, 2007]. This new typology consists of pre-crash scenarios that depict vehicle movements and dynamics as well as the critical event occurring immediately prior to crashes involving at least one light vehicle. Specifically, the study identified the 37 most frequent crash scenarios; many of these crash types involved rear-end collision scenarios. Of the 37 groupings used to describe the overall distribution of pre-crash scenario types, the Lead-Vehicle-Stopped, Lead-Vehicle-Decelerating, and Lead-Vehicle-Moving-at-Lower-Constant-Speed crashes represented in the 2004 GES data were found to be the 2nd, 4th, and 12th most common crash scenarios overall, respectively, and were the top three rear-end pre-crash scenarios.

The prior studies have been instrumental in developing test procedures to evaluate the forward collision warning systems installed on late-model passenger vehicles. The test maneuvers described were designed to emulate the top three most common rear-end pre-crash scenarios reported in the 2004 NASS-GES data base. The test procedures continue to be the basis for evaluating advanced rear-end crash avoidance technologies, including those that automatically apply the foundation brakes to decelerate the vehicle to avoid or mitigate the severity of a potential crash.

The findings of the studies discussed primarily relied on NASS-GES police accident report based on coded data for high-level understanding of the frequency of rear-end crash specific characteristics. However, a detailed clinical analysis of the rear-end crash environment and injury causation using the NASS-CDS investigation data will help to provide a more thorough understanding and guide system performance to prevent or mitigate the severity of fatal crashes. This crash database is a nationally representative sample of tow-away crashes that occur on U.S. roads. Every year, detailed information on vehicle damage, injury, and injury mechanism is collected on about 4,500 of these light passenger motor vehicle crashes. The data consists of over 600 variables that describe crash events, damage to vehicle, crash forces involved, injuries to the victim and injury causation mechanisms for frontal, side, rear, and rollovers crashes. The work presented in this paper represents one of the steps necessary to better understand the rear-end crash problem.

METHODOLOGY

Using a technique similar to Bean, et al. [2009], a detailed review of real-world rear-end crashes was conducted where an occupant sustained fatal injuries in an involved vehicle. The review focused on coded and non-coded data (photographs, summaries, crash diagrams, etc.), and resulted in the identification of critical factors contributing to the fatal injuries in rear-end crashes. The cases were selected from the NASS-CDS database for the years 2003 to 2012. The following parameters were required for a crash to be included in the data set:

- The crash was fatal (AIS level 6)
- The crash was coded as forward impact into a parked vehicle, rear-end, or forward impact of vehicles going in the same direction on the same trafficway (accident type 11 or 20-43)
- The subject vehicle (SV) was a passenger vehicle (bodytype 1-49)
- The SV general area of damage in the first crash event was frontal (General area of damage=F for accseq=1)
- The pre-impact location of the SV was “stayed in original travel lane” (preiloc=1)
- The SV pre-event movement was “going straight”, “decelerating in traffic lane”, “accelerating in traffic lane”, “starting in traffic lane”, or “passing or overtaking another vehicle” (premove=1,2,3,4, or 6)
- The lead vehicle (LV) preimpact location was “no driver present” or “stayed in original travel lane” (preiloc=0 or 1)
- The LV pre-event movement was “no driver present”, “going straight”, “decelerating in traffic lane”, “accelerating in traffic lane”, “starting in traffic lane”, “stopped in traffic lane”, “passing or overtaking another vehicle”, or “disabled or parked in travel lane” (premove 0-7)
- There were no restrictions on restraint use or travel speed

Thirty eight cases that involved 39 fatalities were identified in the data set that met the above criteria. The cases were then divided amongst the authors, who summarized each case using a standard format. The authors then assessed the primary, secondary, and (if applicable) other factors associated with the fatal injury sustained by the vehicle occupant. A factor, in this context, is an event or condition present at or after the time of impact that probably and logically increased the likelihood that this specific impact would be fatal to an occupant. Factors related to the fatality were deemed primary or secondary, depending on the nature of their causative effects. The distinction between primary and secondary factors is similar to what was described by Rudd, et al. [2009].

The following section provides descriptions of the factors associated with injury causation assigned to the crashes in this data set:

Improperly Restrained Occupant: The occupant’s injuries were directly associated with not utilizing the restraint system (i.e., seat belt) provided in the vehicle and/or the vehicle may not have been equipped with an air bag at the seating position in question. For nearly every occupant that was classified as being improperly restrained, the crash severity was deemed to be survivable.

Medical Condition: The driver of the subject vehicle lost consciousness just prior to the event because of an identified medical problem.

Speed of Striking Vehicle: The velocity of the subject vehicle at the time of impact (i.e., closing speed) was identified to have contributed to a high change in velocity and subsequent fatal injuries for an involved vehicle.

Second Event the Most Harmful Event: The primary source of the occupant’s fatal injury was not directly attributed to the first event which was the rear-end impact. However, the fatal injury was attributed to a more harmful event that occurred directly after the initial rear-end impact.

Multiple Vehicles Involved: For an involved vehicle, the fatal injuries sustained by an occupant were attributed to the nature of the crash involving multiple impacts with multiple vehicles. For example, the subject vehicle was first involved in a minor rear-end crash by impacting a lead vehicle, however, it was subsequently impacted in the rear, which contributed to the fatal injuries.

Post-Crash Fire: The subject vehicle sustained a post-crash fire resulting from the rear-end impact, which caused or contributed to the fatal injuries. Generally, the crash severity as measured by rear-end crush was significant.

Struck Vehicle Comparable Size or Smaller: The NASS-CDS coded mass of the struck vehicle was either similar or less than the striking vehicle in the crash. This factor attempts to identify crashes where mass incompatibility between the striking and struck vehicle contributed to the severity of the crash outcome for the struck vehicle.

Truck-Trailer Underride: The striking subject vehicle experienced severe underride with intrusion extending generally into the greenhouse area of its occupant compartment, leading to fatal injuries. For the cases reviewed in this study, the type of rear-impact guards present on the trailers was unknown, and there was likewise no measure of their performance in the crash. The key is poor structural interaction with the crash partner.

Alcohol Involvement: The driver of an involved striking vehicle was determined to have had high Blood Alcohol Concentrations (BAC). This was only assigned as a factor if it was determined that alcohol consumption contributed to the cause of the crash, such as when the striking vehicle driver was under the influence of alcohol. When the BAC was known, it was well above the 0.08 legal limit.

Given the case-review nature of this work, no statistical analyses have been performed on the data, and no assessment of injury risk can be performed since case weights were not used.

RESULTS

The cases were first grouped by common factors that were assessed to have been relevant to the severity of all the rear-end crashes reviewed. A high-level grouping of the factors for all the cases is presented in Table 1. For all the fatal cases analyzed, the primary factor associated with 27 of the 38 cases reviewed was the Speed of the Striking Vehicle. This was assessed to be the most frequent primary factor in the fatal crash event. For all the crashes, the most frequently occurring secondary factor was Struck Vehicle Comparable Size or Smaller followed by Truck-Trailer Underride. Lastly, alcohol involvement was identified in 14 of the cases.

Table 1.
Summary of Rear-End Crashes by Factor.

Factor	Primary Factor	Secondary Factors	Other Factor	Totals
Improperly Restrained Occupant	4	0	1	5
Medical Condition	1	0	0	1
Speed of Striking Vehicle	27	0	0	27
Second Event the Most Harmful Event	6	0	0	6
Multiple Vehicles Involved	0	0	4	4
Post-Crash Fire	0	0	3	3
Struck Vehicle Comparable Size or Smaller	0	18	0	18
Truck-Trailer Underride	0	13	1	14
Alcohol Involvement	0	3	11	14

What follows is a more detailed analysis of the primary and secondary factors, and the corresponding crash characteristics and associated injury. A summary of the data is presented in Table 2 and a summary of all of the factors associated with each individual case involved in this assessment is provided in the Appendix.

Table 2.
Rear-End Crash Grouped by Common Primary and Secondary Factors.

Primary Factor	Secondary Factor	Cases
Speed of Striking Vehicle	Struck Vehicle Comparable Size or Smaller	14
Speed of Striking Vehicle	Truck-Trailer Underride	13
Second Event the Most Harmful Event	NA	6
Improperly Restrained Occupant	Struck Vehicle Comparable Size or Smaller	4
Medical Condition	NA	1

Fatal Occupant in Lead Vehicle Struck by a Similar or Larger Vehicle

The most frequently occurring primary and secondary factor combination was the Speed of Striking Vehicle and Struck Vehicle Comparable Size or Smaller. This combination accounted for 14 of the cases reviewed. In these cases, the striking vehicle, impacted a vehicle with a similar mass or smaller at a high rate of speed. In this grouping, the fatal occupants were always in the struck vehicle. In these types of crashes the fatally injured occupant in the struck vehicle generally sustained head and/or neck injuries such as a brain stem laceration or cervical spine cord laceration sourced to the head restraint. In all but two crashes, the fatality was in the front seat. In Case Nos. 2006-9-168 and 2007-41-38 the fatal occupant was in the rear. It should be noted that in both of these crashes, the front occupants sustained moderate to minor injuries. The photos in Figure 1 illustrate the severity of the impacts.

Figure1. NASS-CDS Case No. 2006-9-168 Struck Vehicle (left) and Case No. 2007-41-38 Struck Vehicle (right).

For this type of crash, on average, the severity as measured by the NASS-CDS estimated Delta-V for the striking and struck vehicle was 46 km/h and 62 km/h, respectively. On average the striking vehicle was 400 kg heavier than the struck vehicle. The highest mass differential was 1,296 kg. The average maximum measured crush for the struck vehicle was 122 cm. It should also be noted that three cases involved a post-crash fire in the struck vehicle resulting in fatal burns. For the two crashes where the crush was measured, the maximum crush was 121 cm and 123 cm (Case Nos. 2006-2-12 and 2008-79-62).

The injuries for the striking vehicle were generally minor, especially when the occupant(s) were properly restrained and the vehicle was equipped with frontal air bags. Most occupants sustained minor bruising or abrasions. In five crashes there were no reported injuries in the striking vehicle. On average the Delta-V for the striking vehicle was 46 km/h, which is lower than the NHTSA's New Car Assessments Program's frontal crash test speed that results in a 56 km/h Delta-V.

In five cases, alcohol was involved for the driver of the striking vehicle, and it was also reported to be dark out in 11 cases. Lastly, for eight cases, it was reported that the lead vehicle was stopped prior to impact.

An example of this crash type is Case No. 2007-82-15. A 1994 Geo Prism (1,065 kg) was disabled and stopped in the same lane ahead of a 2002 Jeep Liberty (1,912 kg). The front of the Jeep impacted the back of the Geo resulting in 127 cm of crush in the rear (Figure 2.) For both of these vehicles the Delta-V was not computed. However, the maximum frontal crush measured on the Jeep was only 10 cm. The posted speed on the roadway was 97 km/h. The driver of Geo sustained a fatal brain stem laceration sourced to the head restraint, and the front passenger sustained a flailed chest sourced to the seat. The crash occurred at 03:44 with the conditions being coded as dark but lighted and with clear atmospheric conditions. The driver of the striking vehicle had a 0.08 BAC.

Figure 2. NASS-CDS Case No. 2007-82-15 Struck Vehicle (left) and Striking Vehicle (right).

Fatal Occupant in Striking Vehicle Impacting Heavy Vehicle

The second most frequently occurring primary and secondary factor combination was the Speed of Striking Vehicle and Truck-Trailer underride. This combination accounted for 13 of the 38 cases reviewed. In all of these cases, the striking vehicles were traveling at a high rate of speed and impacted the rear of a large truck and/or trailer where the driver of the striking vehicle sustained the fatal injuries. It was generally observed that speed along with insufficient structural interaction between the two vehicles resulted in underride and significant intrusion into the occupant compartment. For these crashes the severity as measured by the change in velocity (Delta-V) was not computed by NASS-CDS due to the crash being out of scope of the computing software. In this type of crash, the striking vehicle's driver sustained fatal injuries that were sourced to the intruding interior components or direct contact with the rear surface of the truck-trailer. Of the cases reviewed, it was found that for five of the 13 crashes the drivers of the striking vehicle had an elevated BAC. Seven cases occurred when it was dark. In eight of the cases, the struck vehicle was coded as stopped. In these cases, there was a significant speed differential between the vehicles at the time of impact.

For example, in Case No. 2003-73-129, a 1989 Chevrolet Cavalier impacted the rear of a 1998 International truck tractor pulling a trailer, which was slowing due to traffic congestion. The time of the crash was reported as 06:44 where it was dark and no adverse atmospheric-related driving conditions. The driver of the Chevrolet sustained a brain stem laceration sourced to direct contact with the rear of the struck vehicle. Figure 3 illustrates the severity of the damage to the striking vehicle.

Figure 3. NASS-CDS Case No. 2003-73-129.

Second Event Was the Most Harmful Event

Six cases were classified with a primary factor of the Second Event was the Most Harmful Event. For these cases the most harmful event that resulted in the fatal injuries was preceded by a minor rear-end impact. In five of the six cases, the most harmful event was a subsequent rollover, and one case resulted in a front-to-front head on impact with another vehicle. Of the five rollover crashes, three occupants were ejected. All but one crash occurred when it was dark out, and in two cases the driver of the striking vehicle had an elevated BAC. None of the struck vehicles was coded as stopped.

For two of the cases (Nos. 2006-81-79 and 2009-72-43), the striking vehicle was attempting to change lanes when it struck the rear of a lead vehicle resulting in a loss of control for an involved vehicle. The loss of control resulted in a rollover and ejection of an occupant causing fatal injuries. In Case No. 2006-81-79, the ejected occupant was the unrestrained driver of the striking vehicle and in Case No. 2009-72-43, the rear seat unrestrained occupant of the struck vehicle was ejected.

For example, in Case No. 2007-50-006, a 2007 Chevrolet Impala was traveling south on a urban roadway. A 2003 Mazda Pickup was traveling south in front of the Chevrolet on same roadway. The front of the Chevrolet contacted the back of the Mazda. The Chevrolet appeared to have lost control, departed the roadway, struck a utility pole, and rolled over. The crash occurred at 16:38. It was daylight but raining. The unrestrained driver of the striking vehicle (Figure 4) sustained a fatal brain stem laceration. It was unknown if the front seat passenger was restrained, but the occupant sustained only minor abrasions. The frontal air bags deployed in the event. No injuries were reported for the driver of the struck vehicle. As Figure 4 shows, there was negligible damage to the Mazda.

Figure 4. NASS-CDS Case No. 2007-50-6 Striking Vehicle (left) and Struck Vehicle (right).

Case No. 2006-49-23, was unique in that the fatal occupant was not involved in the initial rear-end impact. A 1998 Ford Windstar impacted the rear of a 2002 Toyota Corolla. The Ford, after impacting the Toyota, drove off of the roadway to the left and across the median into oncoming traffic. A 2003 Nissan Altima was traveling in the opposite direction. The front of the Ford impacted the front of the Nissan. The driver of the Nissan sustained fatal brain stem injuries (Figure 5). The driver of the Ford also sustained serious head injuries.

Figure 5. NASS-CDS Case No. 2006-48-23 Other Vehicle.

After assessing these cases, it was determined that if not for the rear-end impact, an involved vehicle would not have experienced the second event which resulted in the fatal injuries.

Improperly Restrained Occupant

Of the 38 cases analyzed, four were identified by the primary and secondary factors of Improperly Restrained Occupant and Struck Vehicle Comparable Size or Smaller. In these cases, the fatal occupant was in the striking vehicle. It was assessed that based upon the crash severity as measured by Delta-V and the crush on the striking vehicle, if the occupant was properly restrained with a lap and shoulder belt and the vehicle had frontal air bags the occupant would have likely survived the event. For all the crashes where it was computed, the estimated Delta-V for the striking vehicles was approximately 56 km/h or below. In all cases, the fatal front seat occupant sustained a severe brain stem injury. Three out of the four crashes occurred when it was dark out. Only one crash involved alcohol use for the driver of the striking vehicle.

In Case No. 2003-12-199, the fatal occupant was the front seat passenger and the vehicle was not equipped with a passenger side frontal air bag and the seat belt was not used. The passenger sustained fatal head injuries from contact with the windshield. However, the driver, who was restrained, only sustained minor skin abrasions. In Case No. 2003-49-133, the driver was wearing a seat belt at the time of the crash but the vehicle was not equipped with a frontal air bag. The driver sustained fatal head injuries from contact with the steering wheel.

Case No 2012-11-112, is an example of a multi-vehicle crash where the striking 2003 Dodge Ram impacted a stopped 2001 Hyundai Santa Fe, which then struck a stopped 2000 Freightliner. The crash occurred at 07:55 on a clear day. The severe impact resulted in a Delta-V of 60 km/h for the Dodge and 86 km/h for the Hyundai.

The unrestrained driver of the Dodge sustained brain stem injuries sourced to the steering wheel. The frontal air bags in the vehicle did not deploy. It should be noted that the 60 km/h Delta-V may overestimate the severity of the impact especially after observing the crush in Figure 6. Max crush was measured to be 34 cm but it was not uniform across the bumper.

The injuries for the Hyundai's front occupants were not coded. It is only noted in the case that they were incapacitating injuries. Given the severe nature of this crash for the Hyundai, even though the occupants did not sustain fatal injuries, the crash is consistent with the Fatal Occupant in Lead Vehicle Struck by a Larger Vehicle category discussed above. The severity was also aggravated by the Hyundai impacting the rear of a larger vehicle after being struck by the Dodge. It should be noted that in some multi-vehicle crashes the crash severity is intensified because the struck vehicle is not pushed out of the way but is constrained by a vehicle it impacted. This leads to the vehicle having to absorb more of the crash forces.

Figure 6. NASS-CDS Case No. 2012-11-112 Striking Vehicle (left) and Struck Vehicle (right).

Medical Condition

In one relatively minor crash (Case No. 2009-79-44) an 84-year old unrestrained driver of a striking vehicle sustained fatal cervical spine injuries. However, according to the supplemental information associated with the case, there was a possibility that the driver of the striking vehicle suffered a stroke (cerebrovascular accident with infarct and hemorrhage) that led to the rear-end vehicle crash. There was no evidence of braking at the scene and no avoidance maneuver was attempted by the driver.

DISCUSSION

Fatal Occupant in Lead Vehicle Struck by a Similar or Larger Vehicle

Generally, in this rear-end crash type that resulted in a fatality in the struck vehicle, impact speed and mass were significant contributors to the amount of crush in the subject vehicle. The data showed on average the maximum measured crush for the struck vehicle was 122 cm and one case the vehicle experienced 155 cm of crush (Case No. 2011-49-41).

To understand the severity of these crashes, limited data was reviewed from crash tests that were conducted in accordance to the FMVSS No. 301 "Fuel system integrity" test procedure. NHTSA had conducted a number of crash tests on vehicles manufactured after 2005. The FMVSS No. 301 test specifies that the stationary test vehicle is impacted in the rear by a 1,367 kg deformable barrier, with a 70 percent overlap at, 80 km/h. The test does not specify that the maximum crush is measured post-impact. However, in 38 tests for which the vehicle crush was recorded for research purposes, the maximum crush varied from 11 cm for 2008 Volkswagen Touareg to 84.4 cm for 2013 Toyota Avalon Hybrid. The average maximum crush from all vehicles in the tests was 52.7 cm.

The crush in the rear-end fatal crashes on average is double the amount of maximum crush as measured in the FMVSS No. 301 test condition. It also should be mentioned that in eight of the 15 crashes the lead vehicle was stopped, which is consistent with FMVSS No. 301 test procedure. These crashes are thus exceedingly severe in nature, meaning that for a forward collision avoidance system to be effective, the alert would need to be timed to warn the driver early enough to significantly reduce the travel speed. Similarly, an automatic emergency braking system would need to be aggressive enough to reduce the travel speed to either prevent the crash from occurring or to reduce the impact severity well below the NASS-CDS estimated Delta-V of 62 km/h for the struck vehicle in this analysis.

Fatal Occupant in Striking Vehicle Impacting Heavy Vehicle

Rear-end crashes that involve a light vehicle striking a large tractor-trailer combination vehicle at a high rate of speed are generally characterized by the severity of the upper-body intrusion in the striking vehicle and serious head injury often attributed to direct contact with the struck vehicle. There also is an apparent lack of structural engagement between the two vehicles. It would also appear that in these crashes, if an underride guard was present, it could not withstand the force of the crash, leading to the rear of the heavy vehicle interacting with the A-pillar and upper compartment of the striking vehicle. This crash type has been identified in a prior analysis but not in the context of rear-end crashes (Bean, 2009). This crash type composed almost half of the cases analyzed.

There are a number of considerations to be examined from the perspective of utilizing rear-end crash avoidance technologies and determining the potential benefits. Five of the 13 drivers of the striking vehicle had an elevated BAC, seven cases occurred when it was dark and the struck vehicle was coded as stopped in eight of the cases. For intoxicated drivers, it is unknown how effective a warning may be. However, these systems would need to be robust enough to track a stopped or slowing vehicle in the night at a high rate of speed. In order to have changed the outcome of these particular crashes, automatic emergency braking systems would need to properly identify a stopped large truck sitting higher off the ground with a large rear overhang and underride guard, and have sufficient authority to mitigate or prevent the crash. The system would require enough braking authority to avoid the crash even if the driver is intoxicated; i.e., be able to intervene without driver action or involvement.

Second Event was the Most Harmful Event

These particular crashes were of interest because an initial rear-end impact set off a series of events that resulted in a fatality in an involved vehicle. Generally the rear-end crash was minor but still significant enough for an involved vehicle to lose control, which in turn led to a more harmful event. In five of the six cases, the initial rear-end impact led to a rollover. Whether the fatality was in the struck or striking vehicle was a matter of circumstance at the time of the crash. Of importance was the fact that, if not for the initial minor rear-end impact, the more harmful event would not have occurred. From a benefits standpoint, a rear-end crash avoidance system could be effective in preventing the initial rear-end crash, and thus the more harmful event.

Improperly Restrained Occupant

For all the crashes where it was assessed that the occupant sustained fatal injuries because the occupant was improperly restrained, the crash was likely survivable. In Case Nos. 2003-12-199 and 2003-49-133, because the vehicles were older and not designed to the current FMVSS, the occupants were not afforded the protection from frontal air bags. For occupants not wearing a lap and shoulder belt, it is not known how a rear-end crash avoidance warning and an automatic emergency braking system would have changed the outcome of the crash. A warning would have had to be extremely effective in causing the driver to react to prevent the crash from occurring as would an automatic emergency braking system. Even with an automatic emergency braking system that reduced the speed at impact, an occupant could still sustain serious injuries if not properly restrained. The estimated Delta-V for the striking vehicles was approximately 56 km/h or below for these crashes. For these reasons it is unknown how a crash avoidance system will predictably reduce injury levels unless the crash is avoided entirely.

Medical Condition

Only one case (Case No. 2009-79-44) was identified where a medical condition caused a minor crash where the occupant sustained fatal injuries. This case is noted only because this type of crash, though rare, does occur in the real-world. When assessing potential benefits of rear-end crash avoidance systems, various medical conditions can potentially cause a driver to lose consciousness and cause a crash, in which case a crash avoidance alert may be ineffective. However there may be some benefit for systems with automatic emergency braking that will prevent the crash or reduce the overall severity.

EDR NASS-CDS Analysis

A supplemental analysis of the NASS-CDS data was conducted to better understand the pre-crash dynamic states of the involved vehicles in rear-end crashes. Cases were selected where both the striking and struck vehicles were equipped with an Event Data Recorder (EDR). There were no other constraints placed on the case selection such as belt usage or injury severity. For the fatal cases, there was a very limited amount of EDR data available for the involved vehicles because they were generally not equipped with the device and the analysis had to rely on the coded or computed data from the investigation. This analysis attempts to better understand (1) pre-crash relative speed prior to impact, (2) if the striking vehicle's driver made any avoidance maneuver (such as braking), and (3) if the struck vehicle was stopped or decelerating to a stop prior to impact, and compares the data to how they were coded by the NASS-CDS investigator.

An EDR generally captures approximately five seconds of data prior to algorithm enable (AE) and approximately one hundred milliseconds or more during a crash. AE generally activates at the onset of a crash. An EDR reports AE as T-0 of a crash event and subsequently reports the pre-crash data such as vehicle speed and brake activation status from that reference and generally at one second increments prior to AE. After the crash, the EDR will capture the severity of the event as longitudinal Delta-V in the case of front-to-rear crashes.

The cases were analyzed using a common approach and similar format to the fatal cases. An initial cut of the 2003 through 2012 NASS-CDS data identified 29 cases with paired EDR data for both the striking and struck vehicles. A lot of focus was placed on assessing the EDR data for both vehicles to verify that the data were captured in the relevant crashes. For example, the air bags would likely not deploy in the struck vehicle. In this vehicle, the EDR may have captured data, but because the air bags did not deploy, the data were not locked and could have been overwritten by the time the investigation was conducted. The data captured needed to make sense in the context of the physical evidence from the investigation.

After an assessment of the EDR data, 19 cases were verified to have relevant data for both the struck and striking vehicles. The following is a summary of the results from the analysis:

- Average. Longitudinal Delta-V for striking vehicle was 19 km/h
    - Frontal air bag deployed in 10 crashes for the striking vehicle
- Average: Longitudinal Delta-V for struck vehicle, when known, was 17 km/h
- Average relative speed at T-1 with respect to AE prior to impact was 45 km/h
- In 8 cases the striking driver did not brake prior to impact, or AE
- In 7 cases the striking driver was braking prior to impact (longer than one second prior to AE)
- In 4 cases the striking driver applied the brakes at T-1 but not earlier
- In 1 case the struck lead vehicle was accelerating from a stop
- In 3 cases the struck lead vehicle was decelerating to a stop than impacted
    - NASS-CDS reported 2 cases where the struck vehicle was stopped
    - NASS-CDS reported 1 case where the struck vehicle was decelerating
- In 2 cases the struck lead vehicle was stopped
    - NASS-CDS reported both vehicles as stopped
- In 13 cases lead vehicle was decelerating
    - NASS-CDS reported 7 cases where the lead vehicle was stopped

The EDR vehicle speed and Delta-V data collected from these crashes suggest these were generally low severity events, which were further verified from the coded injury data. Almost all of the crashes occurred at a posted speed of 72 km/h or below. Only one AIS 3 wrist fracture injury was reported. For all other cases, injuries were either coded as unknown (not reported) or no injuries.

Of interest were the cases where the EDR data showed the struck lead vehicle was decelerating to a slower speed or decelerating to a stop at impact and NASS-CDS coded the vehicle as stopped. In a majority of the cases the driver of the striking vehicle did not brake or braked late prior to impact.

This analysis was conducted with the limited EDR data available. This analysis should be revisited when more paired EDR cases are available. Figure 7 plots the severity of the event for the struck vehicle. In 10 of the cases, the EDR did not record Delta-V. This is likely attributed to the way the EDR was designed, waking up from the impact but the crash was not severe enough to record Delta-V or of the type to deploy the frontal air bags since the vehicle was impact in the rear. Only pre-crash information was recorded. From the available data, the most frequent change in velocity range was between 9 km/h and 16 km/h, in four cases.

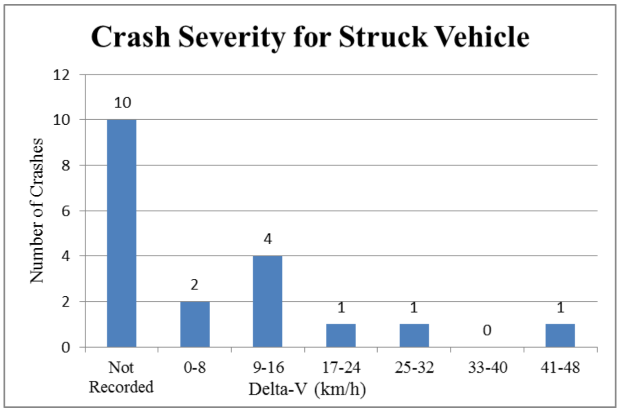

Figure 7. EDR-Captured Crash Severity for Struck Vehicle.

For the striking vehicle, all EDRs recorded a Delta-V (Figure 8). All the vehicles sustained a Delta-V at or below 56 km/h with 15 vehicles experiencing a Delta-V between 9 km/h and 40 km/h. When compared to the NCAP frontal crash Delta-V of 56 km/h, the crashes were of a low to moderate severity impact. This is also consistent with the low level of injuries experienced by the occupants.

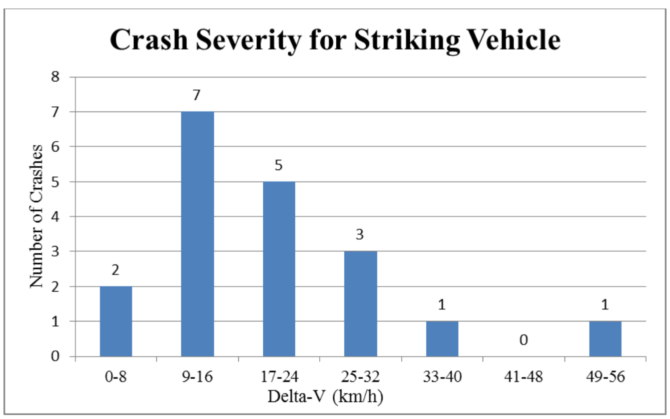

Figure 8. EDR-Captured Crash Severity for Striking Vehicle.

Of importance is the relative impact speed between the striking and struck vehicles (closing speed) when considering test conditions to measure the effectiveness of forward crash avoidance system with automatic emergency braking. The vehicle velocity used in this analysis was the vehicle speed captured by the EDR at T-1 second prior to AE. From Figure 9, all but one of the crashes occurred at closing speeds below 80 km/h. A majority of the crashes occurred with a relative impact speed of between 33 and 56 km/h. Again, this is limited data, but at these speeds, occupants in the vehicles were not injured. In Case No. 2006-12-123 where the relative impact speed was 102 km/h, the EDR captured Delta-V for the striking and struck vehicle were 51 and 48 km/h, respectively. The occupants of both vehicles sustained only minor injuries. To bound this discussion, in the crashes where the primary and secondary factor were the Speed of Striking Vehicle and Struck Vehicle Comparable Size or Smaller, on average the Delta-V resulting in the fatal injuries for the struck vehicle was 62 km/h.

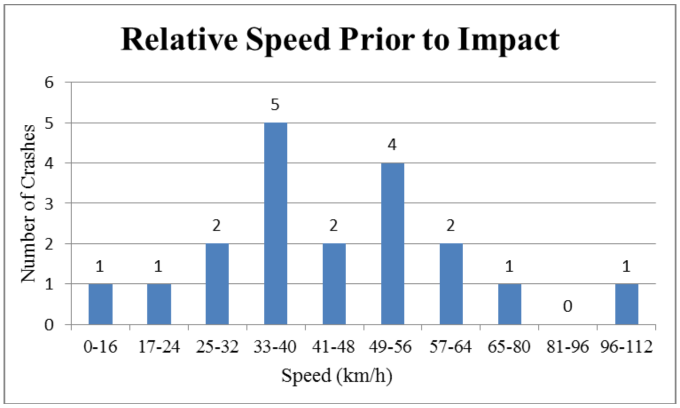

Figure 9. EDR-Captured Relative Speed Prior to Impact.

CONCLUSION

This paper did not focus on crash causation except to note alcohol involvement as a factor and the one case where a medical condition apparently caused the fatal crash. When reviewing these cases, it was initially concluded for every case except for those mentioned above, it appeared driver inattention or distraction was the likely cause of these fatal crashes. Given the frequency it was decided that the factors should focus on vehicle attributes and crash dynamics contributing to the fatal crash. This approach would also compliment the prior studies discussed earlier by providing a more detailed analysis of the fatal real-end crash problem.

This analysis showed, for a properly restrained occupant to sustain fatal injuries in a rear-end impact the striking vehicle must impact the struck vehicle at an excessive relative speed resulting in a high Delta-V. Which vehicle sustains the fatality is generally a factor of size and mass difference between the involved vehicles. The fatality was shown to occur in the striking vehicle when it impacts a large truck. Conversely the fatality is in a smaller struck vehicle when impacted by a larger vehicle at a high rate of speed. In general, for all of the crashes analyzed the fatal occupant sustained fatal head injuries in the smaller vehicle. It should also be noted that minor rear-end crashes can cause a loss of control for an involved vehicle resulting in a second, more harmful event such as a rollover.

The EDR data provided insight into the vehicle dynamics of rear-end crashes. The crashes were generally not severe and involved property damage only. It is recognized that the data analyzed was limited, but this analysis should be expanded as more paired EDR data is available. However, the data does provide some initial baseline conditions for an average rear-end crash and further evidence that the fatal rear-end crashes are extremely aggressive events. The results of this analysis could be used to assess the performance of vehicles equipped with advanced rear-end crash avoidance technologies and estimate the safety benefits in the real-world.

Lastly, what the analysis identified was fatal rear-end crashes are generally attributed to excessive speed at the time of impact. In order to address these crashes in the real-world, a forward collision avoidance system must provide a timely alert and automatic emergency braking must be aggressive to significantly reduce the impact speed to mitigate the severity or prevent the crash from occurring.

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Appendix

NASS-CDS Case No.	Primary Factor	Secondary Factor	Other Factor(s)
2003-49-133	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	Alcohol Involved Truck-Trailer Underride
2003-12-199	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	
2012-11-112	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	Multiple Vehicles Involved
2012-49-36	Improperly Restrained Occupant	Struck Vehicle Comparble Size or Smaller	
2009-79-44	Medical Condition		
2006-49-123	Second Event the Most Harmful Event (Rollover)	Alcohol Involvement	
2007-50-6	Second Event the Most Harmful Event (Rollover)	Alcohol Involvement	
2006-49-23	Second Event the Most Harmful Event (Head on impact)		
2009-4-166	Second Event the Most Harmful Event (Rollover)		
2009-72-43	Second Event the Most Harmful Event (Rollover)		
2006-81-79	Second Event the Most Harmful Event (Rollover)	Alcohol Involvement	
2003-74-130	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2006-49-120	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2006-50-105	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2011-49-41	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Muliple Vehicles Involved Alcohol Involved
2012-9-72	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Alcohol Involvement
2010-82-137	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Multiple Vehicle Involved
2006-2-12	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Post Crash Fire
2006-3-49	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Post Crash Fire
2008-79-62	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	Muliple Vehicles Involved Post Crash Fire
2006-9-168	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2005-50-116	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2007-41-38	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2007-82-15	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2010-79-89	Speed of Striking Vehicle	Struck Vehicle Comparble Size or Smaller	
2003-73-129	Speed of Striking Vehicle	Truck-Trailer Underride	
2005-72-129	Speed of Striking Vehicle	Truck-Trailer Underride	
2005-81-48	Speed of Striking Vehicle	Truck-Trailer Underride	
2005-9-189	Speed of Striking Vehicle	Truck-Trailer Underride	
2006-48-161	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2007-50-108	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2007-73-37	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2009-49-178	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2009-73-144	Speed of Striking Vehicle	Truck-Trailer Underride	
2009-9-99	Speed of Striking Vehicle	Truck-Trailer Underride	
2010-11-240	Speed of Striking Vehicle	Truck-Trailer Underride	Alcohol Involved
2012-49-160	Speed of Striking Vehicle	Truck-Trailer Underride	
2011-73-83	Speed of Striking Vehicle	Truck-Trailer Underride	Improperly Restrained Occupant

IMPROVING THE SWISS NATIONAL ACCIDENT STATISTICS BY PROVIDING AIS DATA TO CLASSIFY INJURY SEVERITY

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ABSTRACT

To provide more detailed data on the injury severity of persons involved in a traffic accident, Switzerland has implemented various measures. The key component was the establishment of AIS coded injury severity data. Linking the national hospital statistics to the national traffic accident statistics allowed identifying persons that were injured in a police recorded traffic accident. Using information on the diagnosis given in the hospital statistics (ICD code) the corresponding AIS code was derived. An ICD-to-AIS translator was developed, mapping the medical information to corresponding AIS codes. Since not all ICD codes correspond to a unique AIS code the translator made use of additional medical information in order to map as many cases as possible. Applying the translator to the data sets of 2011 and 2012, a MAIS could be derived for approximately 95% of all cases. Using the newly implemented procedures, it is now possible to report the share of MAIS3+ injuries sustained on Swiss roads.

INTRODUCTION

Information on the severity of injuries sustained in traffic accidents is a key factor for policy making. To develop strategies for road safety such basic data is required. While the number of traffic fatalities is usually very reliable, information on the number of surviving casualties and the severity of their injuries is of a lesser quality. To date, many countries rely on police-recorded data on the injury severity. In Switzerland and various other countries the police coarsely classifies injury severity as “not injured”, “minor injuries”, “severe injuries”, “died on the spot”, “died within 30 days” or “unknown”, respectively. The definitions when an injury is to be regarded as minor or severe are often not very precise and /or the application of the definitions is not particularly strict. In Switzerland, a person was by definition regarded as severely injured when he/she sustained an impairment that prohibits normal activity at home for at least 24h, for example, due to a stay in hospital. Practically every person that was admitted to hospital was thus regarded as severely injured independent of the duration of hospitalization which could range from a day to several weeks. Analysis of the data showed that injuries classified as severe include fairly simple fractures as well as life-threatening brain injury. With politics currently shifting their focus from road fatalities to addressing severely injured persons, more detailed information on injury severity is needed to be able to appropriately analyze this group.
To improve the data basis, the use of the Abbreviated Injury Scale (AIS) is recommended [1, 2] where "serious" injuries are generally regarded as injuries with a maximum AIS of 3 or greater (MAIS3+). Currently there is no general agreement on how such AIS data should be derived. Depending on the national data available, different approaches are pursued.
This study presents the different measures that Switzerland has implemented to improve injury severity data. The key component of this approach is the establishment of AIS coded data based on hospital statistics. The strategy how to derive AIS data along with first results is presented.

METHODS

To improve the Swiss national accident statistics, data acquisition was addressed on two levels. Generally the police will continue to record injury severity when reporting a traffic accident. Gathering all relevant information needed to investigate an accident is a responsibility of public administration. However, to improve data collection a slightly altered scheme was introduced. Furthermore, these efforts were complemented by retrospectively deriving AIS data based on the hospital statistics. An algorithm mapping ICD to AIS codes was developed and implemented.

Improved police reports

The classification of the injury severity that was used in the national police reports until the end of 2014 was coarse. It allowed differentiating the injury outcome of a person as "not injured", "minor injuries", "severe injuries", "died on the spot", "died within 30 days" or "unknown", respectively. Given the prerequisite that injury severity data must be reported by the police, complex medical schemes are not applicable. Furthermore, practical aspects must be considered in order not to increase the administrative work load of police officers too much. Therefore it was decided to change the currently used classification scheme in police reports such that a further category was introduced. The classification "severe injuries" was replaced by the two categories "life-threatening injuries" and "serious injuries". Similarly to countries like, for instance, Norway, life-threatening injuries should be recorded separately from all other injuries requiring medical treatment in a hospital (i.e. "serious injuries"). All other categories remain unchanged. Detailed guidelines were provided to the police, and the new national reporting system became effective on 1 Jan 2015. Based on this concept the current scheme of police reporting was slightly changed with the benefit of identifying life-threatening injuries.

ICD-AIS-Mapping

Every in-patient in a Swiss hospital is registered and the medical data related to this stay in hospital is recorded in the national hospital statistics. For each patient, the relevant data includes the main diagnosis and up to eight further diagnoses. All diagnoses are coded using ICD-10-GM, i.e. the German version of the International Statistical Classification of Diseases and Related Health Problems issued in 2008. It was decided to use the ICD codes as a basis to derive AIS codes for each person injured in a traffic accident. An ICD-to-AIS translator was therefore developed and applied to the data sample to generate a better assessment of the injury severity. Figure 1 illustrates the decision tree model that forms the basis for the translator.

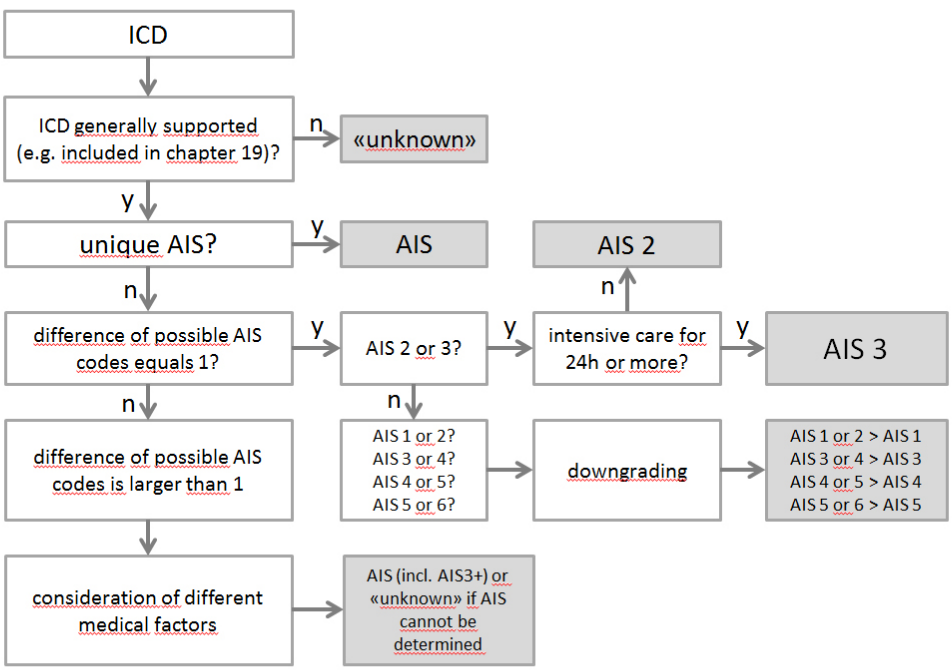

Figure1. Simplified schematic of the decision tree model used to derive AIS codes based on ICD.

Only ICD codes of chapter 19 (injuries) were considered. The translator automatically derives AIS codes for given ICD codes and then determines the patient's maximum AIS (MAIS) and the body region(s) that correspond to the MAIS. Since not all ICD codes correspond to a unique AIS code, a decision scheme also considering further medical information was developed and implemented. The most important of these additional parameters was the information whether a patient required intensive care and the duration (in hours) which a patient spent in an intensive care unit. Generally, a conservative approach was implemented; in cases where one ICD code corresponded to two possible AIS codes differing only by 1, the lower AIS code was chosen, i.e. the true injury severity was at least the chosen AIS code.

ICD chapter 19 consists of 2026 diagnoses of which 1204 were regarded relevant in the context of traffic accidents. Of these 1204 entries only 480 correspond to a unique AIS code. 215 diagnoses can be transferred to a set of AIS codes of the same severity (e.g. an ICD describing a fracture can correspond to several entries in the AIS dictionary all having the same code). Consequently these 215 diagnoses result in the same AIS. For a further 229 ICD codes several options of AIS coding exist where the difference of these AIS codes is only 1. Using a conservative approach, the lower of two possible codes was chosen. The remaining 280 ICD codes can be mapped to AIS codes of different severity. The ICD code for concussion, for instance, can correspond to AIS codes ranging from 1 to 5 depending on the duration of unconsciousness, whereas this duration is mostly unknown in the available medical data set.

Based on (a) the official handbook for hospitals how to record data for the national hospital statistics, (b) the results of a first correlation between injury severity and the length-of-stay in hospital [3] and (c) considering the characteristics of the Swiss health system it was assumed that a more severe injury most likely results in a longer stay in intensive care. Hence, cases in which an ICD code can correspond to a range of AIS codes and in which the patient did stay in intensive care for more than 24h, the AIS is most likely AIS3 or more. These cases were therefore translated into a code called AIS3+, i.e. the AIS is expected to be at least AIS3. If the duration on an intensive care unit was below 24h, the AIS code was downgraded. The introduction of the code "3+" also reflects the fact that there is a particular political interest in identifying the number of MAIS3+ victims.

Data sources

The Swiss national hospital statistics and the national traffic accident database were used. While the accident data base is continuously updated, unfortunately the hospital statistics linked to the accident data can only be provided annually and – due to administrative processes – it is only available with a delay of two years, i.e. in 2014 the hospital data of 2012 were made available. To improve injury severity data for road traffic accidents, it is necessary to match both available databases. The accident data formed the basis of this approach such that the hospital statistics was checked whether it included a person registered in the accident statistics. As there is no unique identifier that allows matching personal data, different criteria (such as age and postal code) were used to link the two data sets. Matching of the data was performed by the Swiss Federal Statistical Office. For this study the data sets of 2011 and 2012 were made available.

RESULTS

The national traffic accident statistics for 2011 and 2012 include a total of 113’240 and 112’598 cases, respectively. In the corresponding hospital statistics 4’277 and 4’123 cases, respectively, were identified that could be matched with traffic accident data (Table 1), i.e. these persons received treatment as in-patients in a hospital after being injured in a road traffic accident. As can be seen from Table 1, the police-reported injury severity does not match well with the cases identified in the hospital statistics. There are, for example, some cases in which the police records indicated that a person was not injured, although the person was actually treated as in-patient in hospital.

Table1.
Number of cases available in the accident and hospital statistics.

	2011		2012	
Injury severity according to police reported accident data	**Number of cases in traffic accident data base**	**Number of these cases identified in hospital data (ICD available)**	**Number of cases in traffic accident data base**	**Number of these cases identified in hospital data (ICD available)**
not injured	83’510	321	83‘647	301
minor injuries	18’805	1’898	18‘016	1‘780
severe injuries	4’437	2’022	4‘202	1‘998
died on the spot	195	0	217	4
died within 30 days	125	35	122	33
unknown	6’168	1	6‘394	7
total	**113’240**	**4’277**	**112‘598**	**4‘123**

The ICD-to-AIS translator was applied to determine the MAIS code for all cases identified in the hospital statistics. Table 2 summarizes the results, i.e. it shows the distribution of AIS code for cases which could be considered by the ICD-to-AIS translator. The score 3+ indicates cases in which the MAIS could not be established clearly, but the medical data suggests that the injury severity was at least MAIS 3. Using the translator it was possible to assign a MAIS code to approximately 95% of the cases for which ICD codes were available; for the remaining cases no MAIS was derived.

Table2.
MAIS codes that were derived based on ICD data.

	2011	2012
MAIS	**Number of cases**	**Number of cases**
0	14 (0.3%)	19 (0.5%)
1	610 (15.0%)	587 (15.0%)
2	2’523 (61.9%)	2’355 (60.1%)
3	362 (8.9%)	349 (8.9%)
3+	521 (12.8%)	563 (14.4%)
4	5 (0.1%)	8 (0.2%)
5	19 (0.5%)	20 (0.5%)
6	1 (0.0%)	0 (0%)
unknown	22 (0.5%)	18 (0.5%)
total	**4’077 (100%)**	**3’919 (100%)**

As shown in Table 2, the distribution of MAIS codes is very similar for both years investigated here. Approximately 76% of the persons injured in traffic accidents sustained an MAIS1 or MAIS2 injury while approximately 23% sustained in MAIS3+ injury.

The potential of the improved injury severity data is illustrated in the following example. In Table 3 the injury severity for different kinds of two-wheelers is compared (inclusion criteria: injured person was driver, ICD diagnosis was available). The example demonstrates that more detailed information is now available thanks to AIS-based injury severity data. It can be observed that the number of injured e-bikers increased between 2011 and 2012, but the MAIS distribution of injured e-bike users seems very similar to injured cyclists. Also the MAIS distribution for motorbike users is similar to the bicyclists and e-bikers, but there are clearly more cases with MAIS 4 and MAIS 5 injuries.

This data can now be used as a basis for a more detailed analysis of the injury outcome and thus provides a better foundation for policy making. In addition the newly established data provides details such as injured body regions. Depending on the research question, it can, for example, be analyzed which body region is responsible for the corresponding MAIS. While it seems not particularly helpful to present a summary table simply counting all injured body regions, it can be interesting to define specific research questions and investigate possible correlations between injury severity and injured body regions. With more data becoming available in future, such an analysis seems highly promising with respect to investigating a possible shift in injury outcome due to various measures to reduce the accident or injury risk, respectively.

Table3.
Example: MAIS data for different kind of two-wheelers.

MAIS	bicycle				e-bike				motorbike			
	2011		2012		2011		2012		2011		2012	
	n	%	n	%	n	%	n	%	n	%	n	%
0	1	0.2	1	0.2	0	0.0	0	0.0	3	0.3	0	0.0
1	47	7.5	33	5.1	3	5.1	4	5.4	102	8.9	113	10.3
2	435	69.2	428	66.5	43	72.9	50	67.6	722	62.9	664	60.6
3	58	9.2	66	10.2	4	6.8	7	9.5	147	12.8	134	12.2
3+	85	13.5	111	17.2	9	15.3	12	16.2	149	13.0	171	15.6
4	1	0.2	2	0.3	0	0.0	0	0.0	2	0.2	2	0.2
5	0	0.0	2	0.3	0	0.0	0	0.0	13	1.1	10	0.9
6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
unknown	2	0.3	1	0.2	0	0.0	1	1.4	10	0.9	1	0.1
total	**629**	**100.0**	**644**	**100.0**	**59**	**100.0**	**74**	**100.0**	**1148**	**100.0**	**1095**	**100.0**

DISCUSSION

To obtain more information on the injury severity of persons injured in traffic accidents, the Swiss national accident statistics were improved by establishing MAIS data. Today Switzerland is thus one of the few European countries providing AIS-based information on the injury severity of road traffic victims. This represents a significant improvement as such data allows a more detailed analysis of the outcome of traffic accidents.

The ICD-to-AIS translator that was developed for this purpose worked well. Besides ICD codes, also information such as the duration of intensive care was used to map the codes. Eventually the algorithm allowed assigning a MAIS code to approximately 95% of all cases. Limitations of this process include the fact that hospital statistics cover in-patients only. Currently this limitation seems acceptable as the focus is on MAIS3+ injuries which generally require treatment at a hospital. For research purposes it would, however, be interesting to add AIS based information for other patients. Mapping data from a national accident insurance database could be one option to obtain this additional data.
Furthermore it must be noted that not all ICD codes can be uniquely mapped to AIS codes. This requires implementation of certain strategies in the ICD-to-AIS translator. Of course, general strategies such as downgrading a code introduce a bias towards a more conservative estimation. Applying such rules consistently also ensures comparability of data from different years.
The introduction of MAIS3+ as a further category could be regarded as a further limitation. However, given the general interest in MAIS3+ injuries, this procedure resolved the problem of not being able to assign a unique AIS code in some cases without having to make use of further assumptions in the medical data.

A more general problem is the fact that the hospital data is currently only available with a time delay of two years. Procedures should be improved such that the medical information becomes available more rapidly. On the other hand, this highlights the necessity to also improve the police-recorded injury severity data since this data is continuously available. The introduction of a further category "life-threatening injury", which became effective in 2015, is considered to represent an important step in this context. Future analysis will investigate how well this category matches with AIS-based data and to which extent the police-recorded data correlates to ICD-derived AIS data.

In addition to the injury severity, the MAIS derived from ICD codes also offers the possibility to locate the body regions that were injured. This represents an interesting information which was not available in the past. Depending on the research questions, additional information with respect to changes in injury patterns can thus be retrieved.

In summary, it was shown that the implementation of an ICD-to-AIS translator allows generating injury severity data with a high relevance for policy making and research. Switzerland has established a national scheme to derive detailed injury severity data and has thus set a well-founded basis for future accident statistics.

CONCLUSIONS

ICD-to-AIS mapping was introduced on a national level which improves the available information on injury severity significantly. Injury severity data is essential to evaluate the performance of measures to improve traffic safety. Estimates of the potential benefit of safety technologies or any other preventive measure can thus be improved.

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