CLARIFICATION OF PRIORITY FACTORS FOR REDUCING TRAFFIC ACCIDENT FATALITIES IN THE U.S. AND BENEFIT ESTIMATION OF AEB SYSTEM FOR ONCOMING VEHICLES

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ABSTRACT

Until recently, most joint initiatives between the government and industry in the U.S. to help reduce traffic accident fatalities have focused on enhancing passive safety, such as through the safety assessment ratings of the New Car Assessment Program (NCAP) and the like. In addition, active safety technologies, such as automated emergency braking (AEB) and lane departure warning (LDW) systems, have also started to become more widespread. This paper describes a study that estimated the safety performance of recent vehicle models by analyzing U.S. traffic accident databases. This data was then used to estimate the benefit of the safety systems in these vehicles and to guide the development of the next-generation of safety technology. The fatality rate of each collision mode in recent vehicles was compared by analyzing data from the Fatality Analysis Reporting System (FARS), and the key contributing factors of fatal collisions were analyzed and prioritized using data from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS). The estimated fatality rate reduction in all collision modes was identified by analyzing FARS data. A relatively large reduction in fatalities caused by side collisions and accidents not involving a collision (mainly rollovers) was found. The collision mode with the highest fatality rate for recent vehicles was frontal vehicle-to-vehicle (VTV) collisions. The most significant contributing factors in fatal frontal VTV head-on collisions were the advanced age of the driver, intrusion of the steering post into the cabin, high delta-V, and high occupant weight. The last three factors are particularly seen in high kinetic energy collisions. Although LDW systems are expected to help reduce frontal VTV head-on collisions, many collisions occur while the vehicle is negotiating a curve (not yet evaluated in NCAP tests) or while the other vehicle is traveling in the opposite direction in the same lane as the driver's vehicle. The benefit of LDW systems in such scenarios is difficult to estimate. Therefore, as a supplement to LDW systems, AEB systems for oncoming vehicles are being considered to help reduce kinetic energy in frontal VTV collisions. This study estimated the potential fatality rate reduction using the relationship between velocity and the probability of a fatality occurring in a frontal collision. To enable safe activation of AEB in response to an oncoming vehicle, additional analysis of field data will be required to ensure that the system does not interfere with the normal operation of the driver. However, if this can be achieved, an AEB system for oncoming vehicles may help to reduce fatalities in traffic collisions in the U.S. Consequently, this paper also estimates the approximate benefit of this system.

INTRODUCTION

The U.S. has adopted a dual approach to help reduce fatalities and injuries caused by traffic accidents through both active and passive safety initiatives. While organizations such as the government and the Insurance Institute for Highway Safety (IIHS) are introducing regulations and safety assessment ratings, industries are working to develop and encourage the use of safety technologies.

Active safety technologies already in widespread use include antilock brake systems (ABS) and electronic stability control (ESC) systems. More recently, automatic emergency braking (AEB) systems targeting vehicles and pedestrians in front of the driver's vehicle, as well as lane departure warning (LDW) and lane keeping support (LKS) systems that help drivers to maintain lane discipline have also been launched on the market. The objective of these systems is to help mitigate damage caused by a collision (AEB), and to help prevent the vehicle from leaving the lane unsafely or from driving off the road altogether (LDW and LKS). As these systems become more widespread and functionally capable, the number of such accidents, as well as the resulting number of fatalities and injuries, may well decrease.

At the same time, advances in passive safety performance are being stimulated by the establishment of injury criteria for frontal and side collisions. These criteria have helped to encourage wider use of airbags and other restraint systems, as well as optimized vehicle body deformation characteristics. In recent years, the IIHS has introduced the small overlap (SOL) crash test, and the National Highway Traffic Safety Administration (NHTSA) is currently considering introducing a new frontal oblique test. The adoption of tests such as these has the potential to help reduce fatalities and injuries under a wider range of real-world collision conditions.

Another recent trend is the wider adoption of an integrated approach to enhancing safety by activating and controlling passive safety restraint devices using information from active safety sensors that monitor the situation around the vehicle, which are being installed on more and more vehicles [1][2].

Statistics for 2013 showed that passenger vehicle occupants accounted for the highest proportion of traffic accident fatalities in the U.S., and that frontal collisions were responsible for the most fatalities [3]. Research has already estimated the potential benefit of LDW systems in these accidents [4]. Therefore, this paper focuses on estimating the benefit of AEB systems in frontal collisions as a supplement to LDW and LKS systems.

First, this study analyzed the fatality rate for recent vehicle models, and estimated the fatality breakdown once these latest models become more widespread based on 2013 data in the Fatality Analysis Reporting System (FARS). This approach was used to confirm the proportion of frontal collisions in the total number of fatal accidents. Furthermore, data from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) was used to confirm the details of these frontal collisions from both active and passive safety standpoints to help analyze the potential benefit of an AEB system for oncoming vehicles.

Next, this study estimated the relationship between changes in collision velocity and fatality risk in vehicle-to-vehicle (VTV) frontal collisions. Finally, based on these results, this paper discusses the potential reduction in fatality rate and future benefit of AEB systems for oncoming vehicles.

Through these estimations and analyses, this paper identifies a potential relationship between the use of AEB to reduce collision velocity and passive safety performance in a broad sense, as well as to help enhance active safety performance. Further motivation for research was provided by this study, which identified the potential of AEB for oncoming vehicles as a promising system for the future.

FRONTAL COLLISION RESEARCH

This section discusses the potential benefit of AEB for oncoming vehicles based on accident analysis from the standpoints of passive and active safety.

Breakdown of Fatalities after Popularization of Recent Vehicle Models

This section uses the fatality rate for each model year (2013 FARS data) and the difference between the fatality rates of belted and unbelted occupants in frontal collisions (2005 to 2013 NASS-CDS data) to estimate the fatality rate breakdown of collisions involving the most recent vehicle models, assuming that the occupants are wearing seatbelts.

First, the current fatality breakdown in 2013 FARS data was analyzed. Tables 1 to 3 show the data classifications, and Figs. 1 and 2 show the results. Figure 1 indicates that occupants of passenger vehicles or light trucks (LTVs) accounted for 60% of the total number of fatalities over the whole of the U.S. (19,756 out of 32,719), and that frontal collisions were responsible for the most fatalities

(11,303, 35%). Figure 2 categorizes these frontal collisions into single-vehicle collisions, VTV collisions, collisions fatal for front seat occupants, and collisions fatal for occupants in other seats. The two largest categories accounted for roughly the same number of fatalities: front seat fatalities in single-vehicle collisions (5,284, 16%) and front seat fatalities in VTV collisions (5,120, 16%).

Table 1.
Classification codes of occupant and vehicle type

PER_TYPE		BODY_TYPE	
1, 2, 9	Motorist	1-10, 17	Passenger cars
5	Pedestrian	14-16, 19-22, 28, 30-32	Light trucks
6, 7	Cyclists	39, 40, 48, 49	
3, 4, 8, 10	Other	60-64, 66, 67, 72, 78, 79	Large trucks
		50-52, 55, 58, 59	Buses
		12, 42, 65, 73, 90-99	Other/ unknown
		80-89	Motorcycles

Table 2.
Classification codes of collision type

IMPACT 1	
1, 11, 12	Frontal collision
2-4, 8-10, 61-63, 81-83	Side collision
5-7	Rear collision
13, 14, 18, 19	Other
0	Non-collision
98, 99	Unknown

Table 3.
Classification codes of frontal and side collisions

VE_FORMS		Frontal collision		Side collision		
		SEAT_POS		SEAT _POS	IMPACT1	
1	Single	11, 13	Fr Seat	11	8-10, 61-63	Near side
2+	VTV	Other	Other	13	2-4, 81-83	
				11	2-4, 81-83	Far side
				13	8-10, 61-63	

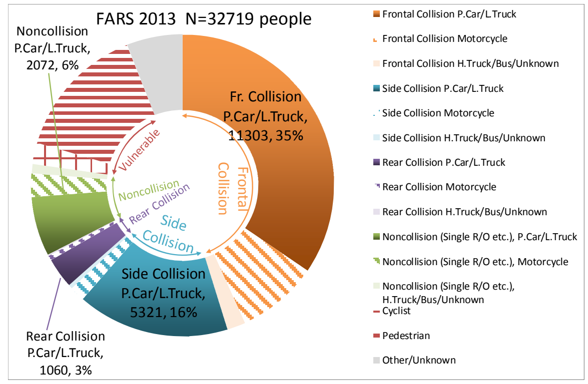

Figure 1. Proportion of fatalities by occupant, vehicle, and collision type.

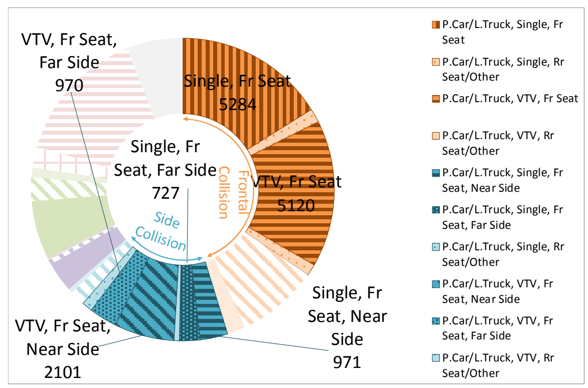

Figure 2. Proportion of fatalities by single-vehicle or VTV collisions and seat position in frontal and side collisions.

Next, the study estimated the fatality rate per model year for the main accident patterns involving passenger vehicle occupants. The fatality rate was calculated by dividing the estimated number of vehicles on the road by the number of fatalities. Figure 3 shows the number of fatalities per model year for frontal and side collisions and fatal accidents that did not involve a collision (non-collision accidents such as single-vehicle rollovers). Figure 4 shows the number of vehicles on the road per model year. This number of vehicles was estimated by multiplying the number of vehicles registered each year by the rate that vehicles tend to remain in use over time, which was identified in previous research [5]. Based on this approach, the fatality rate per 10,000 vehicles was calculated for each model year. Figure 5 shows the results. The thin lines show the fatality rates for each model year and the bold lines show the moving average over two-year periods.

The fatality rate for all types of accidents is decreasing for newer model years. This analysis identified the relationship of the fatality rate with each model year and the latest two model years (average of 2012 and 2013).

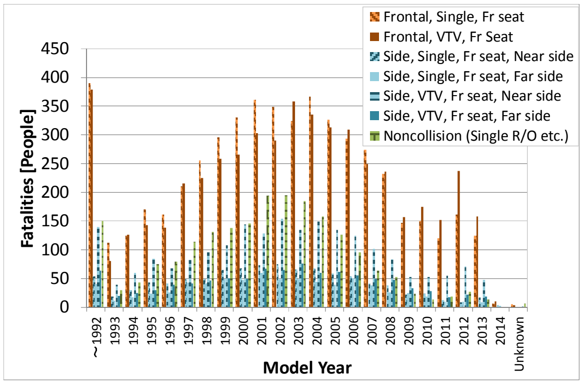

Figure 3. Distribution of fatalities by model year.

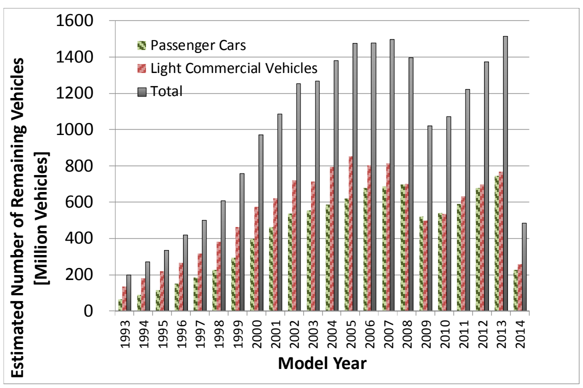

Figure 4. Estimation of number of remaining vehicles of each model year.

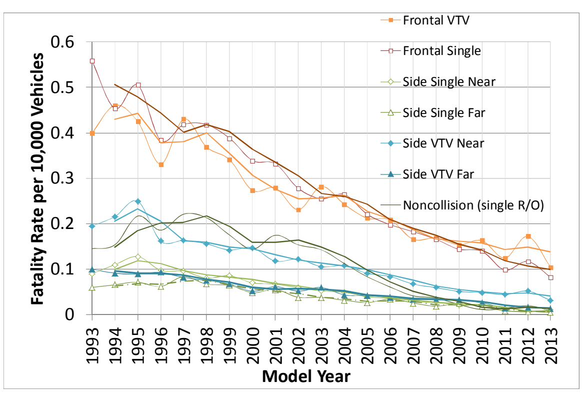

Figure 5. Fatality rate per 10,000 vehicles in each model year.

Next, this study estimated the difference between the fatality rates of belted and unbelted occupants in frontal collisions using 2005 to 2013 NASS-CDS data. The data was filtered as shown in Table 4 and classified as shown in Table 5. After removing the results in which the belted state of the occupants was unknown, the number of data items (all injuries) was 2,223 people for single-vehicle collisions and 2,063 people for VTV collisions. Figure 6 shows the proportion of fatalities in the total number of injuries. These results indicate that the fatality rate of both single-vehicle and VTV collisions was approximately 8% for unbelted occupants and approximately 2% for belted occupants.

Table 4.
Filtering codes of frontal single-vehicle and VTV collisions

<table>
<tr><th colspan="2">Frontal single</th><th colspan="2">Frontal VTV</th></tr>
<tr><td>TOWPAR</td><td>1</td><td>TOWPAR</td><td>1</td></tr>
<tr><td>VEHFORMS</td><td>1</td><td>VEHFORMS</td><td>2</td></tr>
<tr><td>EVENTS</td><td>1</td><td>EVENTS</td><td>1</td></tr>
<tr><td>ROLLOVER</td><td>0</td><td>ROLLOVER</td><td>0</td></tr>
<tr><td rowspan="2">DOF1</td><td>1, 11, 12, 21, 31, 32, 41, 51</td><td rowspan="2">DOF1</td><td>1, 11, 12, 21, 31, 32, 41, 51</td></tr>
<tr><td>52, 61, 71, 72, 81, 91, 92</td><td>52, 61, 71, 72, 81, 91, 92</td></tr>
<tr><td>GAD1</td><td>F</td><td>GAD1</td><td>F</td></tr>
<tr><td>SEATPOS</td><td>11, 13</td><td rowspan="2">Opposite Veh. DOF1</td><td>1, 11, 12, 21, 31, 32, 41, 51</td></tr>
<tr><td></td><td></td><td>52, 61, 71, 72, 81, 91, 92</td></tr>
<tr><td></td><td></td><td>Opposite Veh. GAD1</td><td>F</td></tr>
<tr><td></td><td></td><td>SEATPOS</td><td>11, 13</td></tr>
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Table 5.
Classification codes of belted and unbelted occupants

MANUSE	
4, 14	Belted
0, 2, 3, 5, 8	Unbelted/Other

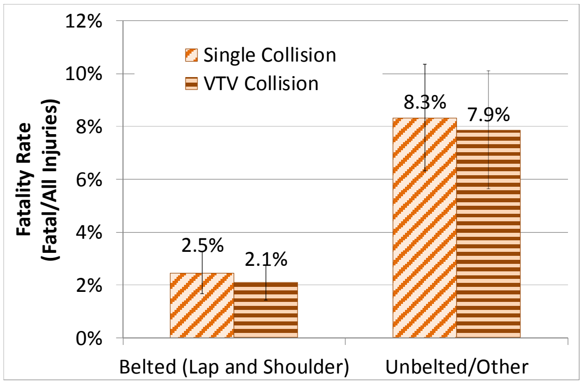

Figure 6. Comparison of fatality rate between belted and unbelted occupants.

Finally, the number of fatalities was estimated for the most recent vehicle models assuming that the occupants are wearing seatbelts using 2013 FARS data. Figure 7 shows the estimated results for frontal collisions. The reduction rate used the results of Figs. 5 and 6. Additionally, Fig. 8 shows the estimated number of fatalities involving the most recent models for other collision types. These results indicate that frontal collisions are responsible for more collisions than other collision types. According to this data, the number of front occupant fatalities in single-vehicle and VTV collisions was 1,307 and 2,308, respectively.

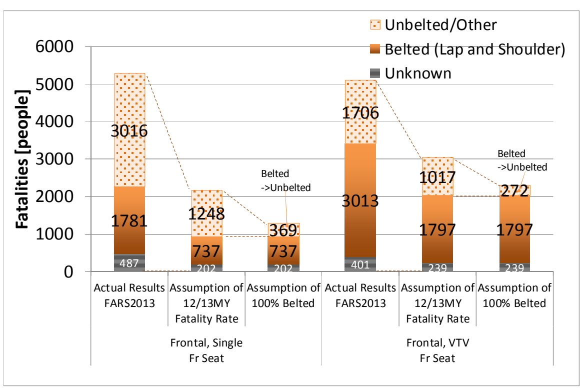

Figure 7. Estimation of fatality reduction in frontal collisions, assuming all vehicles are from most recent model years and all occupants are belted.

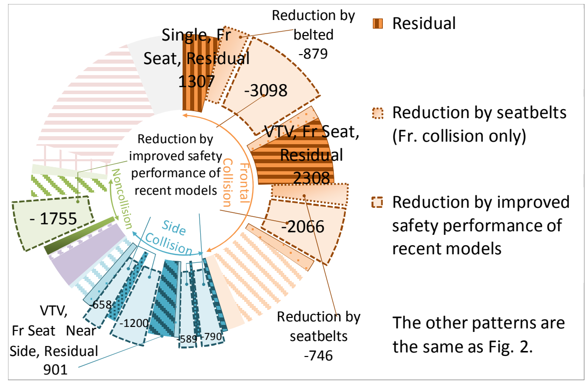

Figure 8. Proportion of fatalities by occupant type, assuming all vehicles are from most recent model years and all occupants are belted.

Situation Immediately before Frontal VTV Collision

In this section, 2013 FARS data is used to identify the situation immediately before a collision, focusing on frontal VTV collisions based on the results in Fig. 8. The data was filtered as shown in Table 6. Data items were analyzed from a total of 2,088 people. Table 7 lists the pre-collision states and Fig. 9 shows the results.

Table 6.
Filtering codes of frontal VTV collisions

INJ_SEV	4	Fatal injury
PER_TYP	1, 2, 9	Motorists
BODY_TYP	1-49	P. Cars/LTV
IMPACT1	1, 11, 12	Front
VE_FROMS	2+	VTV
SEAT_POS	11, 13	Front seat
MOD_YEAR	1998+	Later than 98'MY
AIR_BAG	1, 8, 9	Deployed
REST_USE	3,12	Lap and shoulder belted

Table 7.
Classification codes of pre-collision behavior

P_CRASH1	P_CRASH2	
1, 2, 3	10-13	Going straight and driver's vehicle departs from lane
1, 2, 3, 5	62, 63	Going straight and other vehicle encroaches into lane
50, 51, 52	ALL	Other vehicle in lane and traveling in same direction
14	10-13	Negotiating a curve and driver's vehicle departs from lane
14	62, 63	Negotiating a curve and other vehicle encroaches into lane
6, 15, 16	10-13	Overtaking, changing lanes, or merging
ALL	54	Other vehicle in lane and traveling in opposite direction
ALL	1-9	Driver's vehicle loses control
Other Combinations		Other

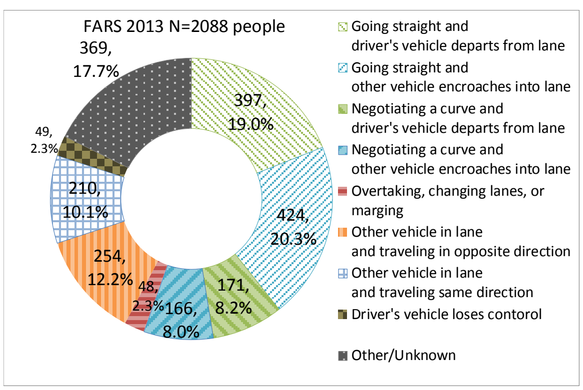

Figure 9. Proportion of fatalities by pre-collision behavior in frontal VTV collisions.

Table 8 adds classifications based on the presence of evasive driving maneuvers by the driver and vehicle stability. Figure 10 shows the results. It should be noted that there is no pre-collision evasive maneuver or stability data when considering cases in which the other vehicle departed from its lane.

Table 8.
Classification codes of pre-collision evasive maneuvers and vehicle stability

P_CRASH3	P_CRASH4	
1	1	No avoidance maneuver and no skidding
Other Combination		Other

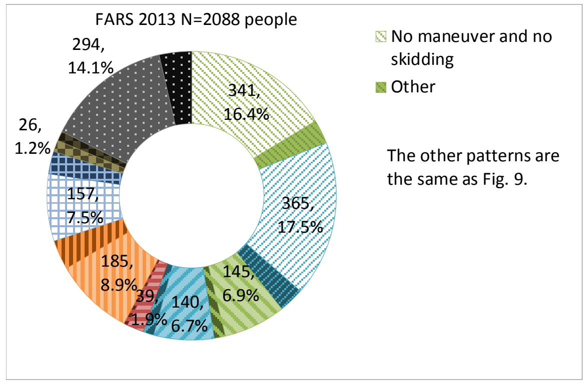

Figure 10. Proportion of fatalities by pre-collision behavior in frontal VTV collisions.

Therefore, it was assumed that these results were the same as for cases in which the driver's vehicle departed from the lane.

Current safety assessment ratings of AEB systems simulate rear-end collisions with the vehicle in front. The proportion of rear-end collisions when the driver's vehicle was stable and no evasive maneuvers were carried out was 7.5%.

Although safety ratings in the U.S. have yet to introduce assessments of LKS, LDW assessments are currently carried out on straight roads. The proportion of lane departures on straight roads when the driver's vehicle was stable and no evasive maneuvers were carried out was 16.4%. The proportion of lane departures on straight roads when the other vehicle was stable and no evasive maneuvers were carried out was 17.5%.

In addition to lane departures, other common cases when the driver's vehicle was stable and no evasive maneuvers were carried out include when the other vehicle is traveling toward the driver's vehicle in the same lane (8.9%), when the driver's vehicle departs from its lane while negotiating a curve (6.9%), and when the other vehicle departs from its lane (6.7%).

Frontal VTV Collision and Occupant Conditions

In this section, 2005 to 2013 NASS-CDS data is used to identify the situation during a collision, focusing on frontal VTV collisions based on the results in Fig. 8. This was achieved by analyzing the contribution of each collision and occupant condition on the number of fatalities. In addition, the contribution of each condition was also analyzed for the number of severe injuries, which have more data items.

The data was filtered as shown in Table 9. Data from a total number of 956 people was used. This data included 163 (17.1%) people that suffered a severe injury rated 3+ on the Maximum Abbreviated Injury Scale (MAIS) and 21 fatalities (2.2%).

Table 9.
Filtering codes of frontal VTV collisions in driver's seat

TOWPAR	1	Towed
VEHFORMS	2	2 vehicle forms
EVENTS	1	1 event
ROLLOVER	0	No rollover
DOF1	1, 11, 12, 21, 31, 32, 41, 51	Direction of force is 11 or 12 or 1 o'clock
	52, 61, 71, 72, 81, 91, 92	
GAD1	F	Deform location is front
Opposite Veh. DOF1	1, 11, 12, 21, 31, 32, 41, 51	Direction of force is 11 or 12 or 1 o'clock
	52, 61, 71, 72, 81, 91, 92	
Opposite Veh. GAD1	F	Deform location is front
MODELYR	1998-2014	Later than 98' MY
SEATPOS	11	Driver's seat
MANUSE	4	Lap and shoulder belted
BAGDPLY	1	Air bag deployed

As an example of the quantification process, the calculation of the contribution of the collision delta-V on the number of severe injuries is presented as follows. Figure 11 shows the severe injury rate for each delta-V. The delta-V data is categorized in 10 km/h increments. The average severe injury rate calculated from all the data is 17.1%, and the lighter shaded areas show the results above this average. Next, the number of people above the average value was calculated. However, analysis using a normal correlation coefficient that focuses only on categories with a high severe injury rate might evaluate categories containing few people as containing many people. This possibility was avoided by converting the severe injury rate data to numbers of people. Figure 12 shows the distribution for the number of severely injured people per delta-V. In Fig. 12, the numbers of people equivalent to the above-average severe injury rate are shaded in a lighter color. The total number of people is 47.0, or 33.3% of the total number of severely injured people (163). This result is used as the degree that delta-V contributes to the number of severe injuries.

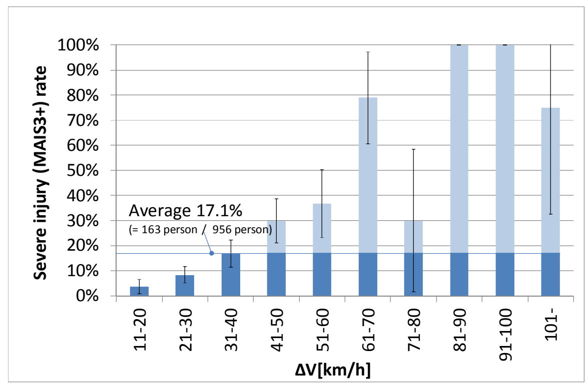

Figure 11. Distribution of severe injury rate by collision delta-V in frontal VTV collisions.

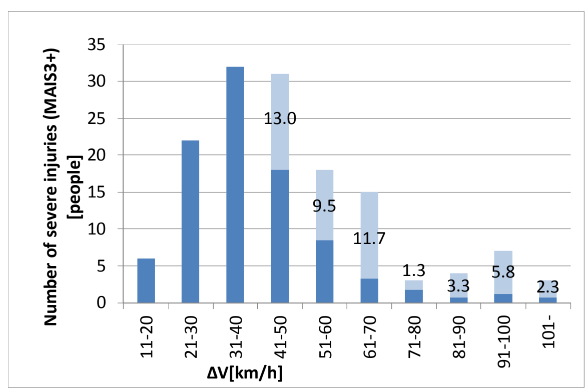

Figure 12. Distribution of number of severe injuries by collision delta-V in frontal VTV collisions.

Table 10.
List of analyzed factors

Factor	CDS code	Category
Magnitude of steering Intrusion	INLOC1-10, INCOMP1-10, CDRIR1-10, INMAV1-10	No intrusion, 3.0cm-7.9cm, 8.0cm-14.9cm, 15.cm-29.9cm, 30.0cm-45.9cm, 46.0cm-60.9cm, 61.0cm-
Collision delta-V	DVTOTAL	At each 10km/h
Occupant age	AGE	At each 10 Y.O.
Occupant weight	WEIGHT	At each 10kg
Vehicle compatibility	Opposite veh. BODYTYPE	Passenger car, LTV
Occupant height	HEIGHT	At each 10cm
Direct damage width (small overlap)	DIRDAMW	At each 15cm
Underride/ override	FOVERIDE	No override/ underride, Override, Underride
Direction of force (Oblique collision)	DOF1	11 o'clock, 12 o'clock, 1 o'clock

The same calculation was carried out for the other items shown in Table 10 and for the number of fatalities. These results are shown in Table 11 and Fig. 13. In descending order, the most significant contributing factors to the number of fatalities were as follows: intrusion of the steering post into the cabin, delta-V, occupant age, and occupant weight. This order was similar to that for the number of severe injuries.

ESTIMATION OF BENEFIT OF ON-COMING AEB

This section estimates the potential benefit of AEB for oncoming vehicles based on the relationship between collision delta-V and fatality risk.

Relationship between Time-to-Collision Judgment of AEB for Oncoming Vehicles and Delta-V
The relationship between the time-to-collision (TTC) judgment of AEB for oncoming vehicles and the delta-V was analyzed as follows.

Table 11.
Contribution to number of fatalities and severe injuries

Factor	Contribution	
	Fatality	Severe injury
Magnitude of steering Intrusion	80.8%	24.2%
Collision delta-V	63.4%	33.3%
Occupant age	38.6%	13.0%
Occupant weight	30.6%	6.8%
Vehicle compatibility	15.7%	15.3%
Occupant height	15.6%	5.5%
Direct damage width (small overlap)	9.1%	1.8%
Underride/ override	Negative value*1	1.4%
Direction of force (oblique collision)	Negative value*2	Negative value*2

*1 No override/underride is highest fatal rate.
*2 12 o'clock is highest fatality/severe injury rate.

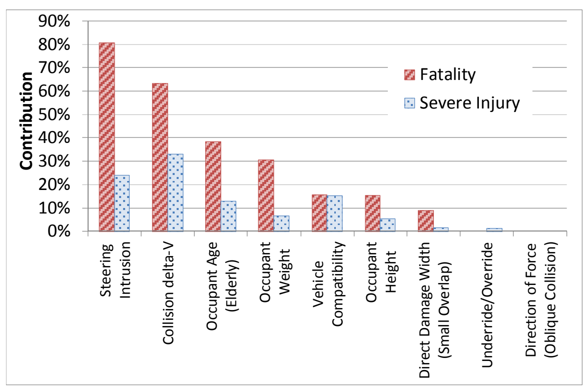

Figure 13. Contribution to number of fatalities and severe injuries in frontal VTV collisions.

The following brake characteristics were assumed. Figure 14 expresses these characteristics as a time series.
Judgment to brake operation: 0.2 sec
Jerk to maximum deceleration: 17.6 m/s^3
Maximum deceleration: 8.8 m/s^2 (0.9 G)

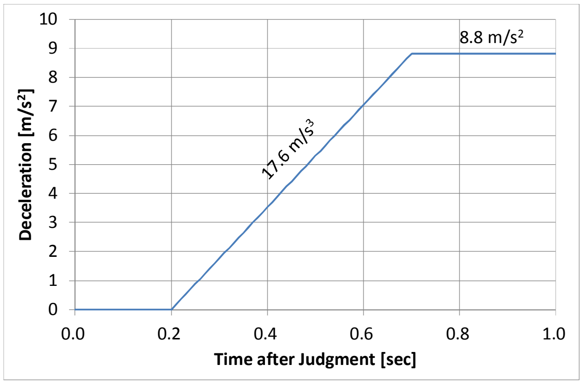

Figure 14. Assumed brake characteristics.

Next, the amount of deceleration was estimated from the iterated integral of the time series data. The estimation was performed for a total of four cases: two initial relative velocity assumptions (80 km/h and 120 km/h) and two braking assumptions (braking by the driver's vehicle only with the other vehicle approaching at a constant velocity, and the same degree of deceleration by the driver's vehicle and the other vehicle). Figure 15 shows the results.

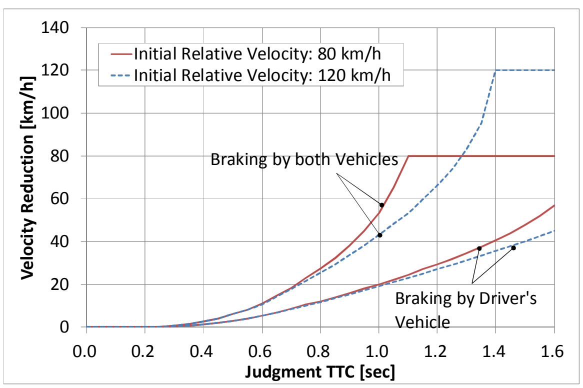

Figure 15. Relationship between TTC judgment and velocity reduction.

These results indicate that virtually no reduction in velocity was achieved with a TTC judgment of 0.4 sec or less. In contrast, once the TTC judgment exceeded 0.4 sec, the amount of deceleration increased in accordance with the earliness of the TTC judgment. With a TTC judgment of 1.0 sec, the relative velocity decreased by approximately 20 km/h when only the driver's vehicle braked. When both vehicles braked, this rose to approximately 43 km/h at an initial velocity of 80 km/h and approximately 53 km/h at an initial velocity of 120 km/h.

Relationship between Collision Delta-V and Fatality Risk

This section describes the relationship between collision delta-V and fatality risk, assuming that AEB for oncoming vehicles has reduced the collision velocity. The same research has also been carried out in the past [6]. 2005 to 2013 NASS-CDS data is used for the analysis to reflect current vehicle performance as far as possible.

The data was filtered as shown in Table 9. Collision delta-V data for 723 injured people (all injuries) and 16 fatalities was used.

The relationship between collision delta-V and fatality risk was identified using survival analysis. This method is widely to calculate relationships such as that between impact force and bone fracture risk in research into physical tolerances. In this analysis, cases without sample fracture are defined as censoring data (i.e., cases in which fracture did not occur up to the maximum force and for which the results above that force are unknown). In cases where sample fracture occurred, the force applied to the sample was constantly monitored and defined as cases where fracture occurred at the maximum force, under which fracture did not occur. Based on this approach, the survival function s(x) was calculated using the integrated survival rate in each bone fracture data up to the timing of the fracture, and the bone fracture risk function R(x) was derived by subtracting the survival function from 1 (Equation 1).

$$R(x) = 1 - s(x) = 1 - \prod_{x_i < x} \left(1 - \frac{f_i}{n_i}\right) \qquad \text{(Equation 1)}$$

where, x_i is the fracture force in the case closest to force x of the bone fracture cases involving force x or less.

In addition, f_i is the number of bone fracture cases with force x_i, and is always 1. n_i is the remaining data not bounded by force x_i.

Figures 16 and 17 visualize examples of this calculation method.

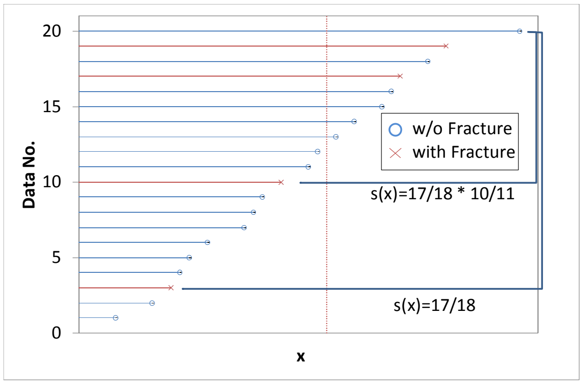

Figure 16. Example of survival analysis method.

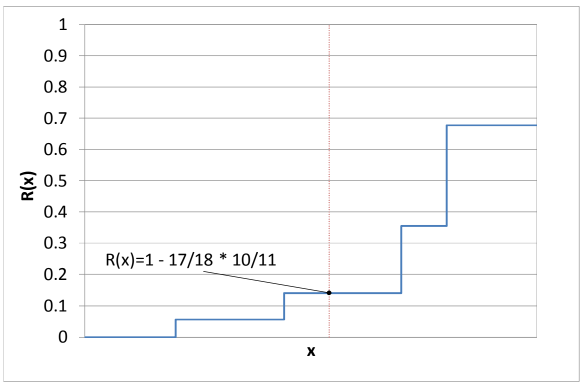

Figure 17. Calculation results for Fig. 16.

In contrast, for fatal accidents in the real-world, the fact that a bone fracture did not occur even when the force increased cannot be defined as a case in which a fatality would not occur below that velocity (unlike physical tolerance research that can be constantly monitored). Therefore, fatal cases are defined as data in which a fatality would occur at that delta-V or above, but for which the result is unknown for delta-V values below that level. Survival cases are defined as survival occurring below that delta-V, but for which the result is unknown for delta-V values above that level. Fatality risk R(x) was derived based on this approach.

$$R(x) = \frac{\bar{f}}{s+\bar{f}} \qquad \text{(Equation 2)}$$

where, $\bar{f}$ is the number of fatal cases at a delta-V of x or less, and s is the number of survival cases at a delta-V of x or less.

Figures 18 and 19 visualize examples of this calculation method.

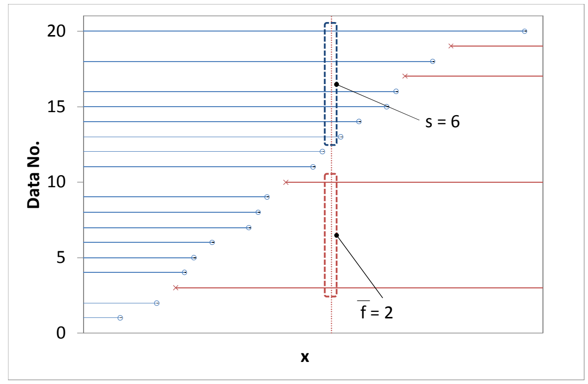

Figure 18. Example of original analysis method used in this study.

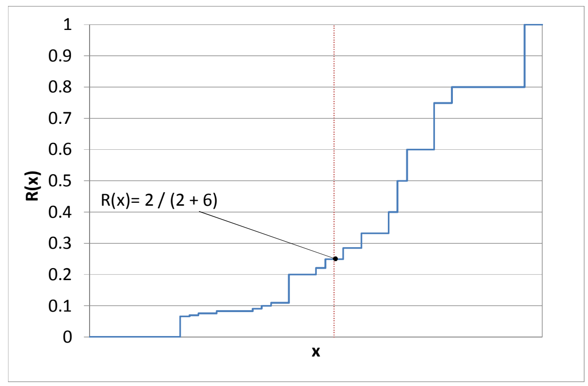

Figure 19. Calculation results for Figure 18.

It should be noted that the NASS-CDS data contains an enlargement factor (RATWGT). Therefore, each case is weighted using the enlargement factor when calculating the actual fatality risk.

Next, the collision delta-V data was normalized using the occupant weight m data. A high delta-V and occupant weight was suggested in the previous section as factors with a major impact on the number of fatalities in a frontal VTV collision. These factors have the same significance, i.e., high occupant kinetic energy E. Although an occupant kinetic energy function was considered as a way of expressing the fatality risk, the value *Norm.ΔV*, which assumed an occupant weight equivalent to that of a 50th percentile American male (AM50, 78 kg) in the conversion to a delta-V value, was used to simplify intuitive understanding (Equation 3).

$$E = \frac{1}{2} m \Delta V^2$$
$$Norm.\Delta V = \sqrt{2 \cdot E / 78[kg]} \qquad \text{(Equation 3)}$$

The thin line in Fig. 20 shows the analysis results obtained using this method. This relationship was also approximated using the maximum-likelihood method through a logistic regression line (Equation 4). The bold line in Fig. 20 shows the results.

$$R(Norm.\Delta V) = \frac{1}{1 + e^{-b(Norm.\Delta V - c)}} \quad \text{(Equation 4)}$$

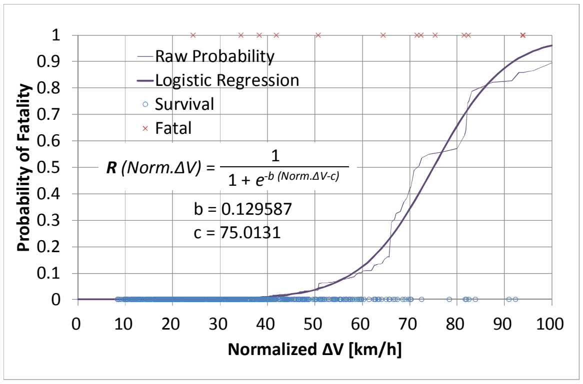

Figure 20. Relationship between normalized collision delta-V and probability of fatality.

Rough Estimation of Fatality Reduction Benefit of AEB for Oncoming Vehicles.

This section estimates the fatality reduction benefit of AEB for oncoming vehicles in frontal VTV collisions by reducing the collision velocity. This estimate was carried out assuming the conditions listed in Table 12.

Since the objective of an AEB for oncoming vehicles is to mitigate damage in high-velocity collisions, the benefit estimation was applied to cases with a collision delta-V of at least 60 km/h.

The relative velocity in the collision was set to a velocity reduction of 20 km/h based on Fig. 15, assuming AEB activation by the driver's vehicle only and a TTC judgment of 1.0 sec. In addition, the weight of the other vehicle was assumed to be the same as the driver's vehicle and the collision delta-V was set to 10 km/h, half of the velocity reduction. It should also be noted that this value increases as the weight of the other vehicle increases in comparison to the weight of the driver's vehicle, and vice-versa. It also increases if AEB also activates in the other vehicle.

AEB activation was analyzed for scenarios in which the driver's vehicle was stable and no evasive maneuvers were carried out, assuming driving in the opposite direction in the oncoming lane due to lane departure, overtaking, or the like. Figure 10 shows that these scenarios are equivalent 58.3% (=16.4%+17.5%+6.9%+6.7%+1.9%+8.9%) of fatal accidents. System activation was also limited to an overlap rate of at least 40%, which is equivalent to 85.7% of the direct damage width (Fig. 21). Multiplying these two figures gives an activation probability of 50% (=58.3%×85.7%).

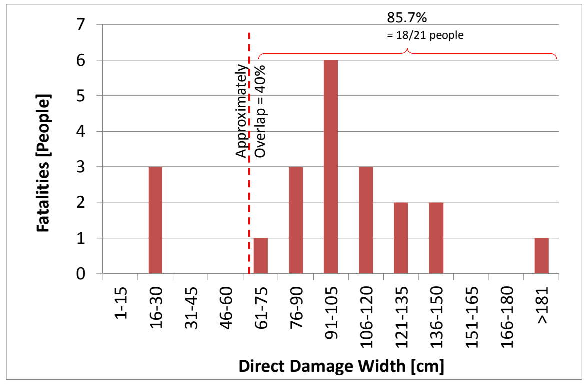

Figure 21. Distribution of number of fatalities by direct damage width in frontal VTV collisions.

Figure 20 was used for the relationship between collision delta-V and the fatality rate.

As shown in the results in Fig. 22, the number of fatalities decreased after AEB application when the collision delta V is 60 km/h or higher. Specifically, the total number of fatalities was reduced by 320 people from a total of 2,004.

Table 12.
Assumptions in rough estimation

Scope	Collision delta-V is 60 km/h or higher
Reduction of collision delta-V	10 km/h
Activation probability	50%

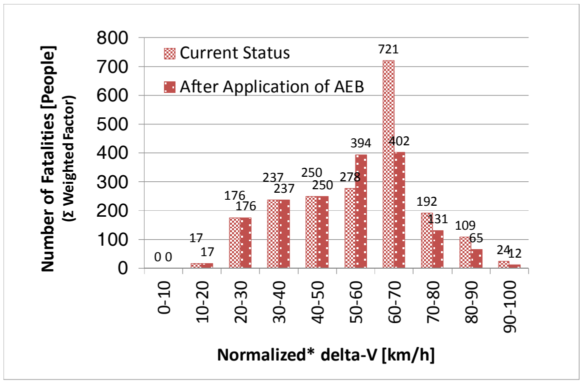

Figure 22. Comparison of number of fatalities before and after application of AEB.

CONSIDERATIONS

According to Fig. 1, the number of fatalities in frontal collisions accounted for a comparatively high proportion of the total number of fatalities in the whole of the U.S. in 2013. In addition, according to the estimation in Fig. 8, the relative proportion of fatalities in frontal collisions (especially front seat fatalities in VTV collisions) remains high, even assuming wider adoption of more recent model year vehicles and belted occupants.

Figure 10 indicates that the future spread of LDW and LKS systems should have a certain benefit in helping to reduce fatalities in frontal VTV collisions. However, LDW and LKS are likely to be less effective in certain cases, such as when the other vehicle drives in the opposite direction in the same lane as the driver's vehicle. In these cases, AEB for oncoming vehicles may have a potential benefit when vehicle stability is ensured and the driver carries out no evasive maneuvers.

According to Fig. 13, the most significant contributing factors to the number of fatalities in frontal VTV collisions at the current time are the intrusion of the steering post into the cabin and collision delta-V. The use of AEB to help reduce the collision velocity may directly help to reduce these factors. Figure 13 also indicates that occupant weight is another significant contributing factor to the number of fatalities. Since height is also a relatively major contributing factor, this is thought to be the result of high kinetic energy due to the weight of large occupants, rather than the result of the physique of the occupants (i.e., high occupant body mass index (BMI)). The use of AEB to reduce the collision velocity may help to reduce the significance of these contributing factors.

Therefore, based on these results, collision velocity reduction by AEB for oncoming vehicles may have a certain benefit for helping to lower traffic accident fatalities across the U.S. in the future.

The next step in this research is to consider the activation timing of AEB for oncoming vehicles. Currently, the braking start timing for the activation of AEB for preceding vehicles, which is assessed in safety ratings around the world, is defined as a TTC of 1.4 sec at a relative velocity of 24 km/h (according to the technical guidelines of the Japanese Ministry of Land, Infrastructure, Transport and Tourism) [7]. This value considers evasive maneuvers by normal steering. In the event of an oncoming vehicle, it is necessary to consider evasive maneuvers carried out by both vehicles. Therefore, the lateral movement required to avoid the other vehicle is half the width of the opposing vehicle. If the lateral movement generated by steering is approximated to a constant acceleration, the activation timing can be defined as a TTC of 1.0 sec (1/√2 of the opposing vehicle).

Under these assumptions, Fig. 15 indicates that it may be possible to reduce collision velocity by approximately 20 km/h. In a collision involving the same vehicle types when AEB activates only in the driver's vehicle, it may be possible to reduce the collision delta-V by 10 km/h. According to Fig. 20, if the collision delta-V can be reduced from 65 to 55 km/h, it may be possible to reduce the fatality rate from 21% to 7%, or to around one-third.

Finally, assuming the adoption of an AEB system that activates under the conditions listed in Table 12, the estimated benefit of this AEB is a 15% reduction in frontal VTV collision fatalities (Fig. 22).

LIMITATIONS

Analysis of the collision and occupant conditions in this research was carried out for each item obtained from NASS-CDS data. For this reason, the correlation between each item was not excluded. Excluding this correlation will require the application of a method such as multivariate analysis. Furthermore, the objective of this research was to identify the contribution of items related to collision velocity on the number of fatalities. Therefore, these results will not lessen the values or benefit estimates of other safety enhancement measures adopted in safety assessment ratings and the like.

Although this research aimed to estimate the potential benefit of AEB for oncoming vehicles, various technological issues, such as the development of sensors capable of accurately recognizing objects approaching at high-velocities from far distances, must be resolved before these systems can be realized.

The objective of this research was to estimate and identify the general scale of the potential fatality reduction benefit of AEB for oncoming vehicles. Therefore, it made various assumptions for undetermined conditions. The actual benefit of these systems will vary due to a wide range of factors, such as the recognition performance of sensors to be developed in the future, brake performance, and the environment surrounding the vehicle. More accurate estimation will require the assumption of more definite characteristics as future technological development progresses.

Finally, since the benefit calculated by this research is based on statistical data, it cannot be applied to individual accident cases that are affected by a wide range of conditions.

CONCLUSIONS

The following conclusions were obtained after analyzing and carrying out desktop estimations using 2013 FARS and NASS-CDS accident data from across the U.S.

Frontal VTV collisions were one of the most frequent types of fatal traffic accidents in the U.S. in 2013. Even after reducing the number of fatalities assuming wider adoption of more recent model year vehicles and higher seatbelt use, it was estimated that the number of these fatalities would still remain relatively high compared to other accident patterns. Analysis of the detailed conditions before frontal VTV collisions identified accident cases that would be difficult to prevent using existing AEB, LDW, and LKS systems. Analysis of collision and occupant conditions also found that factors related to high collision velocities make a significant contribution to the number of fatalities.

This paper then considered the potential benefit of AEB for oncoming vehicles using these results. Based on the relationship between collision delta-V and fatality risk, this research found that AEB for oncoming vehicles has the potential to help reduce the number of fatalities by lowering the collision velocity, even if the driver does not carry out evasive maneuvers.

REFERENCES

[1] Infates, E. et al. 2013. “Evaluation of Occupant Protection During the Crash Phase Considering Pre-Crash Safety Systems Results From the EC-Funded Project ASSESS.” 23rd ESV Conference, Paper No.13-0419

[2] Prof. Dr. Schoneburg, R., et al. 2015. “Evaluation of Occupant Protection Systems: from a Preventive to a Pre-Impacting Restraint System.” 24th ESV Conference, Paper No.15-0374

[3] NHTSA. 2015. “Traffic Safety Facts 2013.” DOT HS, 812 139: 24 and 125

[4] Kusano, K.D. and Gabler, H.C. 2012. “Field Relevant of the New Car Assessment Program Lane Departure Warning Confirmation Test.” SAE Technical Paper 2012-01-0284

[5] Lu, S., NHTSA. 2006. “Vehicle Survivability and Travel Mileage Schedules.” NHTSA Technical Report, DOT HS 809 952.

[6] Gabauer, D.J. and Gabler, H.C. 2006. “Comparison of Delta-V and Occupant Impact Velocity Crash Severity Metrics Using Event Data Recorders.” 50th Annual Proceedings of the Association for the Advancement of Automotive Medicine.

[7] Ministry of Land, Infrastructure Transport and Tourism. 2005. “Automotive Technology Technical Guidelines Appendix 5: Technical Guidelines of Collision Mitigation Braking Devices for Forward Objects” (in Japanese). National Technical Report No. 1