POTENTIAL EFFECTS OF AUTOMATIC BRAKING ON ACCIDENT FATALITIES AND SERIOUS INJURIES

K. Friedman
G. Mattos
Friedman Research Corporation
United States

J. Paver
Center for Injury Research
United States

Paper Number 17-0152

ABSTRACT

Automatic Emergency Braking will become a standard feature in light duty vehicles beginning in 2023 due to a voluntary agreement between vehicle manufacturers, NHTSA, and IIHS. The agreed performance criteria will result in a system that reduces the incidence of low-speed crashes and will likely have little effect on severe injuries and fatalities. Opportunities for fatality reduction associated with automatic braking are significant and are based on implementation approaches. Potential fatality reductions resulting from automatic braking activation thresholds in various crash modes and closing speed ranges were considered. The effects of alternative performance requirements on potential fatality reductions were then examined.

INTRODUCTION

The potential benefits associated with Forward Collision Warning (FCW) and Crash Imminent Braking (CIB) features, collectively known as Automatic Emergency Braking (AEB) systems, have been known for over forty years. The technology has been available on production vehicles for over ten years now and in 2016 many vehicle manufacturers, representing 99% of the U.S. auto market, entered into a voluntary agreement with the Insurance Institute for Highway Safety (IIHS) and the National Highway Traffic Safety Administration (NHTSA) to make AEB systems standard equipment. The agreement, documented in a memorandum of understanding (MOU) [1], specifies that AEB be offered as a standard feature in virtually all vehicles with a gross vehicle weight rating (GVWR) of 3,856 kg or less by September 1, 2022 and for vehicles with a GVWR less than 4,536 kg by September 1, 2025.

The MOU identifies the requirements for the FCW and CIB functionalities of the AEB system. The FCW system, as tested according to the NHTSA FCW Tests 2 and 3 [2], must issue an alert when the time to collision (TTC) is at least 2.4 seconds and 2.0 seconds, respectively. The requirements for CIB involve two options as defined by the IIHS test protocol [3]. The first option (A) requires a 5-test average speed reduction of greater than 16 km/h in either the 20 km/h or 40 km/h tests involving a stationary target vehicle. The second option (B) requires a 5-test average speed reduction greater than 8 km/h in both the 20 km/h and 40 km/h tests involving a stationary target vehicle. The IIHS uses a mock foam rear half of a vehicle as the lead target vehicle.

While there may be benefits associated with impacts involving pedestrians, bicyclists and fixed objects the MOU does not address testing for these situations.

The resulting crash delta-V is dependent on the mass of the two vehicles involved; smaller vehicles will receive a larger delta-v benefit than larger vehicles for the same observed AEB-produced speed reduction. Additionally, and perhaps more importantly, the real world results will depend on the implementation of the algorithms and sensors. The detection and response thresholds incorporate inputs from sensors that can include radar, cameras, infrared, and/or lidar. Only a small subset of the algorithm's performance can be evaluated in a simple test. On-road performance is likely to vary widely from vehicle to vehicle. Studies of these algorithms have demonstrated that a significant consideration in their design was the philosophy behind the activation criteria. For example, the size of the oncoming vehicle (not based on radar cross-section) could be detected and different activation strategies could be implemented depending on the risk posed by the size of the oncoming vehicle.

It is well known that the optimal safety system performance differs depending on organizational priorities [4] [5]. Manufacturers, suppliers, the insurance industry, and NHTSA all may have differing objectives that would result in different system performance characteristics. For example, these organizational priorities could involve tuning system performance to minimize: a) fatalities, b) moderate-to-serious injuries, c) whiplash injuries, d) low-speed crash costs, and/or e) system cost. The present state of AEB performance testing and the agreements set out in the MOU indicate that low-speed crash costs are the current priority. The NHTSA estimates that the proposed AEB systems will favorable affect approximately 897,000 rear-end crashes; this includes preventing approximately 4,000 serious injuries and 100 fatalities annually [6] . The remainder of those affected include approximately 893,000 minor and property damage only crashes. Thus, there are opportunities for industry, suppliers, and/or governments to pursue regarding improved AEB performance and outcomes.

In this study we examine the maximum number of fatalities that are likely to be addressed with forward-looking AEB systems in passenger vehicles involved in front-to-front, front-to-rear, and front-to-fixed-object crashes. The implications of alternative testing strategies that likely would affect design approaches are discussed. The authors suggest that significant benefits can be achieved by expanding the performance scope and increasing the closing speeds required for AEB performance evaluations.

METHOD

Accident data from the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) from 2008 to 2014 was used in the analysis. NASS-CDS is a stratified sample of approximately 5,000 police-reported tow-away crashes collected annually by trained investigators. Crashes were included in the analysis if they involved only one or two light-duty passenger vehicles. Impact configurations were narrowed to those in which AEB systems would have the opportunity to be effective prior to impact, i.e. front-to-front, front-to-rear, and front-to-fixed-object crashes. Striking vehicles were defined as those that met the above criteria and whose first impact damage was to the front of the vehicle. Thus both vehicles in front-to-front impacts would be considered striking vehicles.

The injury severity, determined from the Maximum Abbreviated Injury Scale (MAIS), was identified for all occupants in each striking vehicle. Occupants coded with MAIS = 6 or that died within 30 days of the crash were coded as fatally injured. The potential benefits to occupants of vehicles impacted in the rear, i.e. the struck vehicle, were not addressed and these occupants are not included in the results below. All values were weighted based on the ratio inflation factor for each case.

The cumulative percentage of occupant casualties by injury severity, as identified from MAIS, was determined for two threshold values of impact closing speed: 20 km/h and 40 km/h. By using this approach the total number of casualties that would be addressed by the AEB systems outlined in the MOU could be determined. The closing velocity for each striking vehicle was derived using the recorded delta-V along with the impact force direction using Equation 1:

$$V_{cl_1} = \frac{m_1 + m_2}{m_2 \cos\theta} \cdot \Delta V_1, \qquad \text{(Equation 1)}$$

where m_1 and m_2 are the masses of vehicles 1 and 2, θ is the impact force direction, and ΔV is the change in velocity for the striking vehicle during the crash.

Finally the effects of alternative testing strategies considering the effects of testing in front-to-front configurations were then determined and compared with those found for the front-to-rear testing paradigm.

RESULTS

Of the occupants identified that were in the striking vehicles involved in front-to-rear impacts, 60% had known injury severity. The cumulative percent of occupants, by injury severity, for the two AEB closing speed thresholds are summarized in Table 1. For impacts with up to a 20 km/h closing speed there were no injuries identified as more severe that AIS 2. The 40 km/h closing speed impacts accounted for only 0.01% of all striking-vehicle fatalities and 0.09% of AIS3 injured occupants in this configuration.

Table 1.
Cumulative percent of striking-vehicle occupants, by injury severity, involved in front-to-rear crashes for AEB threshold closing speeds.

	Cumulative Percentage of Occupants by MAIS in Front to Rear					
Closing speed	0-1	2	3	4	5	Fatal
20 km/h	1%	0%	0%	0%	0%	0%
40 km/h	52%	1%	0%	0%	0%	0%

Of the weighted occupants identified in front-to-front crashes, 55% had known MAIS. Table 2 summarizes the cumulative percent of occupants involved in front-to-front crashes by their maximum injury severity. Crashes up to 20 km/h, closing speed of 40 km/h, constitute 3% of all fatalities and 7% of all AIS3 injuries. Crashes in which vehicles were moving at 40 km/h made up approximately 15% of all fatalities and 65% of all AIS 3 injuries.

Table 2.
Cumulative percent of occupants, by MAIS, involved in front-to-front crashes for equivalent AEB threshold closing speeds.

Each vehicle impact speed	Cumulative Percentage of Occupants by MAIS in Front-to-Front					
	0-1	2	3	4	5	Fatal
20 km/h	46%	21%	7%	0%	0%	3%
40 km/h	94%	73%	65%	26%	34%	15%

Of the weighted occupants identified as being involved in a forward collision with a fixed object, 55% had known MAIS. Fixed object collisions resulted in greater injury severity than front-to-rear or front-to-front crashes. Table 3 summarizes the proportions of occupants, by MAIS, according to estimated closing speed. A closing speed of 20 km/h represented 5% of all fatalities and 21% of all occupants with MAIS 3 injuries in the front-to-fixed object crash mode. At a closing speed of 40 km/h these proportions rose to 27% and 63% respectively.

Table 3.
Cumulative percent of occupants, by MAIS, involved in front-to-fixed object crashes for AEB threshold closing speeds.

	Cumulative Percentage of Occupants by MAIS in Front-to-Fixed Objects					
Closing speed	0-1	2	3	4	5	Fatal
20 km/h	43%	28%	21%	3%	41%	5%
40 km/h	95%	64%	63%	67%	73%	27%

Table 4 lists the relative frequency of MAIS 3+ outcomes and deaths between the front-to-rear and front-to-front or front-to-fixed object impact modes. There are approximately 12 times as many deaths and nearly 3 times as many seriously injured occupants in front-to-front than front-to-rear crashes. Similarly, fixed-object collisions are much more severe than front-to-rear collisions with 21 and 15 times more fatalities and serious injuries, respectively.

Table 4.
Ratios of occupants with MAIS 3+ and fatal injuries in front-to-front and front-to-fixed object vs front-to-rear impacts.

	Ratio to Front-to-rear	
	Front-to-front	**Front-to-fixed objects**
MAIS3+	2.7	15
Fatal	11.9	20.5

Table 5 summarizes the total estimated benefit to occupants involved each frontal crash mode by injury severity and closing speed.

Table 5
Summary of maximum estimated population affected by AEB performance at 40 km/h

Injury Severity	Front-Rear	Front-Front	Front-Fixed Object
Fatal	0%	15%	27%
MAIS 3+	0%	65%	63%

DISCUSSION

The performance of AEB systems which will become standard on virtually every light duty vehicle by model year 2026 will have an extremely limited effect on serious injuries and fatalities. Virtually no fatal or serious injuries are estimated to be mitigated for occupants in the striking vehicle in front-to-rear impacts. Such performance represents a sub-optimal use of the available technology that clearly has an opportunity to provide greater benefit. This is especially clear given that initial testing of AEB systems by the IIHS indicate that a large proportion of vehicles that performed well at the 20 km/h tests had little or no speed reduction in the 40 km/h tests [7]. While it is not clear where the cutoff point was in the algorithms implemented in these vehicles, is seems that there was a decision not to work above a certain speed. Will this continue in the future? It would seem that the competitive pressures may drive such systems out of the marketplace and the penetration of the marketplace by systems working to at least 40 km/h can be expected. This suggests that the 20 km/h test should not be used as an Option through which a positive evaluation can be achieved, but rather as a required part of the overall test evaluation where the expectation is that performance at higher speeds is also required.

It also appears that some systems claim to only work in rear impact orientations, while others do not restrict themselves. Again competitive pressures may force restrictive systems out of the marketplace so that systems work with impacts from the front to the front, side and rear of other vehicles as well as fixed objects. In order for the competitive pressures to come into play IIHS or others need to create such test methodologies to commend those systems that have these capabilities. The vast difference in the number of serious injuries and fatalities that occur in front-to-front vs front-to-rear crashes, for equivalent closing speeds, suggest that an AEB test configuration should include an oncoming vehicle scenario. This would address far more serious injuries and fatalities.

While it can be understood that the intention associated with limiting testing to low-speed rear impacts is to encourage development, the technology is already beyond what is being tested for, and hence a restructuring of objectives and testing protocols should be accomplished, and, perhaps, is already in process.

How quickly this transition in testing protocols happens is dependent on organizational priorities. The focus on low-speed systems is potentially serving primarily the insurance industry but that industry has also been instrumental in improving overall crashworthiness performance even though their primary costs are associated with low-speed and property damage crashes that dominate the Weibull curve that represents the distribution of their claims frequency. So they are certainly to be commended for taking a lead in this area and hopefully that lead will continue to evolve. Meanwhile other groups like SAE and NHTSA could also follow suit and apply resources to encourage performance under higher closing velocities and using the front-to-front impact mode.

Clearly regulatory mandatory requirements are not required here due to the collaborative nature of the effort to ensure that effective use of the technology is introduced. However, both NHTSA and IIHS have the ability to incorporate performance requirements as part of their NCAP and IIHS rating's systems quickly. For example, NHTSA could require, for a 5 star rating, greater speed reductions that could be phased in under a timeline such as that presented in Table 6. This would require AEB systems to work in front-to-front crash modes for which 28 km/h speed reductions would be required for each vehicle travelling at 40 km/h. Equivalent requirements could be defined for rear-to-rear impact crashes at 40 km/h into a stationary vehicle. In this way the opportunity to address fatalities will increase with the potential to achieve a reduction of 25% or more of fatalities occurring in frontal impacts with continued improvements in AEB performance and fleet penetration. The additional side impact collision avoidance could be incorporated as the technology is ready for it which would provide significant benefits to the occupants of the side impact vehicles.

Table 6.
Example timeline of requirements for improved AEB performance

Year	Required speed reduction	Test speed per vehicle			
		Front-to-Front		Front-to-Rear	
		V1	V2	V1	V2
	km/h	km/h	km/h	km/h	km/h
2019	16	25	25	25	0
2020	20	28	28	28	0
2021	25	32	32	32	0
2022	28	40	40	40	0

The test conditions could utilize either a representative vehicle that dynamically matches the speed reduction being achieved by the test vehicle, or a representation of the same vehicle as the other vehicle utilize representative cross sections as is currently being done, except representing the frontal cross section presented to the oncoming vehicle.

LIMITATIONS

The NASS-CDS contains a large amount of missing data with regard to both crash conditions and injuries. Thus, estimation techniques are often used to create the missing data, but that was not done here. Also there are large number of cases that are coded as injured extent unknown. Again methods can be used to distribute this data across the know AIS distribution for a given set of conditions; however this was not done here. The need to estimate the closing velocities based on the available information was necessitated by the generally missing closing velocity information in the database. The data in NASS- CDS is also known to have problems with regard to crash severity information; when crash severity algorithms are revised the past data is not corrected for these changes, thus leading further concerns with regard to crash severity data. That said the data is the best available for the United States on a stratified sample basis. The availability of EDR data in the forthcoming, but currently unavailable CISS will be of interest to refine analyses conducted here. However, it is known that there are potential concerns with the EDR data as well. Further, the injury severity counts do not include those occupants that were seated in struck vehicles in front-to-rear impacts.

CONCLUSION

The collision avoidance technology has the potential for significant effects on the number of fatalities and serious injuries occurring in the United States. However, the current AEB performance requirements address only the low-speed, and, consequently low severity, crash conditions. In order to achieve a greater benefit the NHTSA, IIHS and industry should adjust the performance requirements to reflect the conditions that representative of real world front-to-front and front-to-rear crashes that result in serious injury and fatality. Based up our analysis of real-world accident data, a supplemental test protocol is proposed to reduce the likelihood and severity of serious and fatal crashes in addition to minor low-speed crashes and injuries. Specifically, we suggest closing speeds on the order of 40 km/h with required average speed reductions up to 56 km/h for both front-to-front and front-to-rear impact modes.

REFERENCES

[1] NHTSA. 2016. Docket Submission of Commitments to Advancing Automatic Emergency Braking Technology," Docket No. NHTSA-2015-0101, Washington, DC.
[2] NHTSA. 2013. "Forward Collision Warning System Confirmation Test." Washington, DC.
[3] IIHS. 2013. Autonomous Emergency Braking Test Protocol (Version I). Insurance Institute of Highway Safety, Ruckersville, VA.
[4] Friedman, K., 1977. "Optimal Restraint System Selection and the Effects of Organizational Priorities: A Demonstration with a Fixed Performance Constraint," Kinetic Research- Technical report, KRI-TR-017.
[5] Nash, C, 2006."A Market Approach to Motor Vehicle Safety…That Also Addresses Tort Reform," Analysis & Perspective, The Bureau of National Affairs, Washington, DC, Vol. 34, No. 8, pp. 206-212. February 27, 2006.
[6] Johnson, T. 2015. Docket Submission of Documents from AEB Industry Voluntary Commitment Working Group Meeting. US DOT; Docket Number NHTSA 2015-0101: NHTSA.

[7] IIHS-HLDI, 2013. “First Crash Avoidance Ratings; Seven midsize vehicles earn top marks.” Status Report, Washington, DC, Vol. 48, No. 7, September 27, 2013.