

EVALUATION OF AEB EFFECTIVENESS USING COUNTERFACTUAL SIMULATIONS OF SHRP2 NATURALISTIC CRASHES

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ABSTRACT

Motor vehicle crashes remain a significant problem in the US and worldwide. Automatic emergency braking (AEB) is designed to mitigate the most common crash mode: rear-end striking crashes. However, assessing the efficacy of AEB in real-world crash scenarios is challenging given that avoided crashes are rarely documented except during naturalistic driving studies. Unfortunately, a large-scale naturalistic driving study involving AEB-equipped vehicles has yet to be conducted. In the absence of such data, AEB can be evaluated in real-world crash scenarios by retrospectively adding AEB to naturalistic crash data using counterfactual simulations. Previous counterfactual simulations have purported the potential benefit of AEB; however these studies often make simplified assumptions about vehicle dynamics. To this end, the current study aimed to conduct the most realistic AEB counterfactual simulations to date by using measured host and lead vehicle dynamics data and vehicle-specific AEB deceleration profiles as well as accounting for driver reaction and environmental conditions. The SHRP2 Naturalistic Driving Study was reviewed to identify rear-end striking crashes among teen (16-19 yrs), young adult (20-24 yrs), adult (35-54 yrs), and older (70+ yrs) drivers. Forty rear-end striking crashes that had reliable radar data were identified to serve as a basis for counterfactual simulations. Real-world AEB deceleration profiles were taken from IIHS AEB test data. IIHS AEB tests were matched to SHRP2 vehicles by selecting the most recent IIHS AEB test of the same make and vehicle class. AEB onset for SHRP2 crashes was based on a brake threat number (BTN) algorithm. The BTN was adjusted to match IIHS measured AEB onsets using minimum RMSE. AEB curves were then adjusted to match the speed of the subject vehicle at AEB onset. AEB deceleration curves were also scaled based on road surface conditions. Driver reaction was accounted for by beginning the deceleration curve at the current driver-initiated braking level. Counterfactual simulations were conducted using MATLAB to determine if AEB would have prevented the rear-end striking crash. AEB was found to be very effective, preventing 80% of rear-end striking crashes; greater than previously reported. Half of all crashes that were not prevented by AEB occurred during poor weather conditions. This study provides the most realistic counterfactual evaluation of AEB to date, utilizing real-world crash dynamics, driver reaction, road surface conditions, and measured AEB deceleration pulses. These data suggest that AEB is very effective at preventing rear-end striking crashes.

INTRODUCTION

Motor vehicle crashes continue to be a significant problem in the United States and worldwide. While the National Center for Statistics and Analysis found a decrease in the number and rate of fatal crashes in 2017 [1] as well as for the first half of 2018 [2] – bringing the US out of a multi-year increase in fatal crashes – motor vehicle crashes remain a leading cause of death for those 65 years and younger as well as the second leading cause of unintentional injury-related deaths [3]. Globally, road traffic fatalities remain a leading cause of death, particularly among low to middle-income countries [4].

Advanced driver assistance systems (ADAS), such as forward collision warning and lane keeping assist, have the potential to mitigate these crashes, reducing overall crash severity, injuries, and deaths. Previous injury reduction models have suggested that ADAS can prevent up to 57% of crashes and resulting injuries [6-12]. Automatic emergency braking (AEB) is designed to mitigate the most common crash mode: rear-end striking crashes. However, assessing the efficacy of AEB in real-world crash scenarios is challenging given that avoided crashes are rarely documented except during naturalistic driving studies. Several studies have attempted to illustrate the effectiveness of AEB using statistical models or counterfactual simulations. However, these studies have several limitations including (1) being based on archival data such as police reports and insurance claims which lack real-world vehicle dynamics data, (2) have used idealized AEB deceleration profiles including step or ramp pulses and have assumed constant jerk, (3) have assumed a static lead vehicle, and (4) have *not* accounted for road conditions or driver reaction. Naturalistic driving studies offer a unique opportunity to provide real-world data on these variables, which can serve as inputs for more realistic counterfactual simulations.

The Strategic Highway Research Program 2 (SHRP2) Naturalistic Driving Study (NDS) offers a unique opportunity to evaluate the potential efficacy of AEB on real-world crash scenarios. SHRP2 crashes include vehicle dynamic data such as radar data, vehicle velocity, and vehicle acceleration [13], which can be used to provide more realistic inputs to counterfactual simulations. Additionally, the Insurance Institute for Highway Safety conducts test-track-based AEB evaluations of currently available vehicles and provides year/make/model specific information on deceleration profiles and activation times through IIHS TechData [14]. Therefore, the current study aims to evaluate to efficacy of AEB by recreating SHRP2 rear-end striking crashes with the presence of AEB using measured deceleration profiles to determine if the application of AEB would have effectively prevented rear-end crashes.

METHODS

This study protocol was approved by the Institutional Review Board at the Children’s Hospital of Philadelphia.

SHRP2 Dataset

A subset of the SHRP2 NDS data set was obtained via a data use license with the Virginia Tech Transportation Institute (VTTI). Scene videos, incident type, and times series data pre- and post-event including vehicle velocity, acceleration, and radar data were obtained for all crashes (n=1317) previously identified by VTTI for four age groups: teens (16-19 yrs), young adults (20-24 yrs), adults (35-54 yrs), and older adults (70+ yrs). Time series data ranged from 20 s prior to 10 s post event and were collected at 10 Hz.

Data Reduction

Rear-end striking crashes were defined as events where the subject vehicle contacted a lead vehicle. Rear-end striking crashes were identified using scene videos and event narratives by two independent video coders. Any discrepancies were reconciled by the study team. Rear-end striking crashes were then reviewed for reliable radar data. Events with missing or unreliable radar data were excluded from the analysis. Event data including vehicle velocity and acceleration, relative distance to the lead vehicle, and road surface conditions were used to conduct counterfactual simulations.

AEB Counterfactual Simulations

The SHRP2 database includes the year, make, and classification (*car, SUV/crossover, pickup, truck, van*) for each vehicle involved in the NDS. To generate realistic AEB deceleration profiles, measured deceleration curves for 20 kph and 40 kph AEB tests conducted by the Insurance Institute for Highway Safety (IIHS) [14] were downloaded

from IIHS TechData (<https://techdata.iihs.org>) and used as inputs for the counterfactual simulations. IIHS AEB tests were matched to each SHRP2 rear-end striking events by selecting the most recent IIHS AEB test with the same vehicle make and classification. If a particular make or classification was not tested by IIHS or the SHRP2 subject vehicle was no longer in production, a classification-matched vehicle from the parent OEM was selected.

A brake threat number (BTN) algorithm [15] was used to determine the onset of AEB for each rear-end striking event. To increase the accuracy of the BTN algorithm, the BTN activation curve was scaled to match the AEB onset times measured during the IIHS AEB tests. Goodness of fit of the BTN activation curve was assessed using a minimum root mean square error (RMSE) criteria.

If the vehicle velocity at the time of AEB onset was ≤ 20 kph, the 20 kph IIHS AEB tests were used for the counterfactual simulation. Contrarily if the vehicle velocity at AEB onset was >20 kph, the 40 kph IIHS AEB tests were used. Counterfactual simulations were conducted in MATLAB 2015a. To account for changes in the AEB deceleration profile due to road surface conditions, the deceleration profile was scaled by a road surface friction factor [16]: dry=1.0, wet=0.7, snowy=0.3, icy=0.1. To account for the driver's braking reaction prior to AEB onset, the AEB deceleration curve was initiated at the vehicle's current braking level. To ensure that AEB deceleration profile was proportional to the subject vehicle's velocity at the time of AEB onset, the deceleration curves were either (1) truncated by proportionally scaling down the AEB curve in both magnitude and duration or (2) extrapolated by extending the steady-state portion of the AEB deceleration using a spline fit.

To simulate changes in vehicle dynamics due to AEB activation, the following equations were used:

$$\left. \begin{aligned} V_{aeb}(t) &= \int_{t_{aeb}}^{t_{crash}} A_{aeb}(t) + V_{SV}(t_{AEB}) \\ X_{aeb}(t) &= \int_{t_{aeb}}^{t_{crash}} (V_{SV}(t) - V_{aeb}(t)) + X_{LV}(t) \end{aligned} \right\} t_{aeb} \leq t \leq t_{crash} \quad \begin{array}{l} \text{(Equation 1)} \\ \text{(Equation 2)} \end{array}$$

t_{aeb} = time of AEB activation
 t_{crash} = time of original SHRP2 crash
 A_{aeb} = subject vehicle acceleration with AEB
 V_{SV} = velocity of subject vehicle
 V_{aeb} = velocity with AEB activation
 X_{LV} = relative distance to lead vehicle
 X_{aeb} = relative distance to lead vehicle with AEB activation

If V_{aeb} reached zero prior to the time of the original SHRP2 crash, it was concluded that AEB prevented the crash. If the addition of the AEB deceleration caused the simulation to extend beyond the time of the original SHRP2 crash, the lead vehicle velocity was assumed to be constant and the equations below were used:

$$V_{aeb}(t) = \int_{t_{crash}}^t A_{aeb}(t) + V_{SV}(t_{AEB}) \quad \text{(Equation 3)}$$

$$X_{aeb}(t) = \int_{t_{crash}}^t (V_{LV}(t_{crash}) - V_{aeb}(t)) + X_{AEB}(t_{crash}) \quad \text{(Equation 4)}$$

If V_{aeb} reached zero and $X_{aeb} > 0$, it was concluded that AEB prevented the crash.

RESULTS

A total of 99 rear-end striking crashes among 95 drivers were identified from the four age groups. Among these rear-end striking crashes, 30 events had no radar data. An additional 29 events were removed due to unreliable radar data. The final dataset for counterfactual simulations consisted of 40 rear-end striking crashes.

Exemplar counterfactual simulations for a prevented and non-prevented rear-end striking crash are shown in Figure 1. AEB was found to be very effective, preventing 80% (n=32) of simulated SHRP2 rear-end striking crashes with reliable radar data. Half (4 of 8) crashes that were *not* prevented occurred during poor weather conditions.

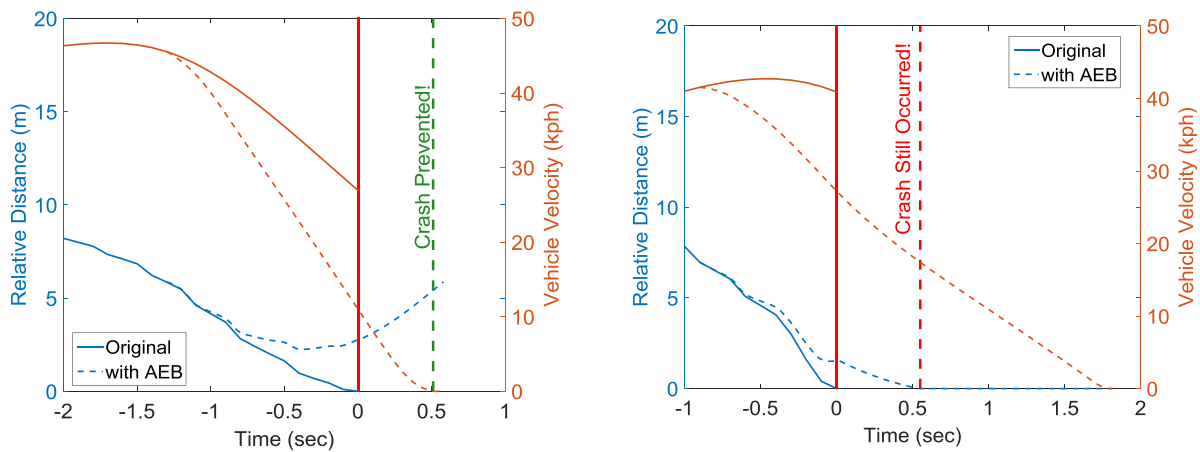


Figure 1. Exemplar prevented crash (left) and non-prevented crash (right).

LIMITATIONS

Several limitations warrant discussion. First, AEB is typically coupled with forward collision warning (FCW). The current study assumed the FCW did not alter the driver’s reaction to the crash. Consequently, these counterfactual simulations represent the “worst-case” scenario for AEB. Of note, drivers executed an evasive braking maneuver in 33 (82%) of the simulated rear-end striking crashes. Furthermore, among the seven events where the driver had no evasive maneuver, AEB was capable of preventing all seven crashes. Consequently, the influence of FCW on these results is likely limited. The current study also assumed AEB activated at all speeds. However, this is not the case with all manufacturers. While some OEMs are releasing high-speed FCW and AEB systems, most low to moderate speed systems have a peak AEB activation speed of 36 mph. Consequently, the current study represents the potential of high-speed AEB to prevent rear-end striking crashes. Finally, radar data were only available for a subset (40%) of rear-end striking crashes. This possibly introduced selection bias because this subset may not be representative of all rear-end striking crashes in SHRP2.

CONCLUSIONS

To our knowledge, this study represents the most realistic counterfactual simulations of AEB effectiveness to date – utilizing measured vehicle dynamics, driver reaction, and road conditions from naturalistic data as well as measured AEB deceleration pulses. Our findings suggest that AEB is very effective at preventing rear-end striking crashes. However, AEB was less effective for crashes that occurred in poor weather conditions.

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REFERENCES

- [1] National Center for Statistics and Analysis. (2018a, October). 2017 fatal motor vehicle crashes: Overview. (Traffic Safety Facts Research Note. Report No. DOT HS 812 603). Washington, DC: National Highway Traffic Safety Administration.
- [2] National Center for Statistics and Analysis. (2018b, October). Early estimate of motor vehicle traffic fatalities for the first half (Jan–Jun) of 2018 (Crash•Stats Brief Statistical Summary. Report No. DOT HS 812 629). Washington, DC: National Highway Traffic Safety Administration.
- [3] Webb, C. N. (2018, February). Motor vehicle traffic crashes as a leading cause of death in the United States, 2015 (Traffic Safety Facts Crash•Stats. Report No. DOT HS 812 499). Washington, DC: National Highway Traffic Safety Administration.
- [4] World Health Organization. Global Status Report on Road Safety. Geneva, Switzerland: WHO Press; 2015.
- [5] Kusano KD, Gabler HC. Potential occupant injury reduction in precrash system equipped vehicles in the striking vehicle of rear-end crashes. *Ann Adv Auto Med.* 2010;54:203–214.
- [6] Rosen E, Kallhammer J, Eriksson D, Nentwich M, Fedriksson R, Smith K. Pedestrian injury mitigation by autonomous braking. *Accid Anal Prev.* 2010;42:1949–1957.
- [7] Edwards M, Nathanson A, Carroll J, Wisch M, Zander O, Lubbe N. Assessment of integrated pedestrian protection systems with autonomous emergency braking (AEB) and passive safety components. *Traffic Inj Prev.* 2015;16(Suppl1):S2–S11.
- [8] Edwards M, Nathanson A, Wisch M. Estimate of potential benefit for Europe of fitting autonomous emergency braking (AEB) systems for pedestrian protection to passenger cars. *Traffic Inj Prev.* 2014;15:S173–S182.
- [9] Kusano K, Gorman TI, Sherony R, Gabler HC. Potential occupant injury reduction in the U.S. vehicle fleet for lane departure warning–equipped vehicles in single-vehicle crashes. *Traffic Inj Prev.* 2014;15 (Suppl):S157–164.
- [10] Searson DJ, Anderson RWG, Hutchinson TP. Integrated assessment of pedestrian head impact protection in testing secondary safety and autonomous emergency braking. *Accid Anal Prev.* 2014;63:1–8.
- [11] Fildes B, Keall M, Bos N, Lie A, Page Y, Pastor C, Pennisi L, Rizzi M, Thomas P, Tingvall C. Effectiveness of low speed autonomous emergency braking in real-world rear-end crashes. *Accid Anal Prev.* 2015;81:24-29.
- [12] Cicchino JB. Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accid Anal Prev.* 2017;99A:142-152.
- [13] Hankey JM, Perez MA, McClafferty JA. Description of the SHRP2 Naturalistic Database and the Crash, Near-Crash, and Baseline Data Sets. Task Report. Blacksburg, VA: Virginia Tech Transportation Institute; 2016.
- [14] Insurance Institute for Highway Safety (IIHS). Autonomous Emergency Braking Test Protocol (Version I). October 2013. <https://www.iihs.org/iihs/ratings/technical-information/technical-protocols>.
- [15] Brännström M, Sjöberg J, Coelingh E, 2008. A situation and threat assessment algorithm for a rear-end collision avoidance system. In: Proceedings of the Intelligent Vehicles Symposium, 2008 IEEE, Eindhoven, Netherlands, 102–107.
- [16] Gustafsson F. Slip-Based Tire-Road Friction Estimation. *Automatica*, 1997; 33(6): 1087-1099.