

Field Study of Heavy Vehicle Crash Avoidance System Performance

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ABSTRACT

This study evaluated the performance of heavy vehicle crash avoidance systems (CASs) by collecting naturalistic driving data from 150 truck tractors equipped with Meritor WABCO OnGuard™ or Bendix® Wingman® Advanced™ products. These CASs provide drivers with audio-visual alerts of potential conflicts, and can apply automatic braking to mitigate or prevent a potential collision. Each truck tractor participated for up to one year between 2013 and 2015. Videos of the forward roadway and drivers' faces were collected along with vehicle network data while drivers performed their normal duties on revenue-producing routes. The study evaluated the performance of CAS activations by classifying them into three categories based on whether a valid object was being tracked and whether drivers needed to react immediately. The highest urgency activations (e.g., Automatic Emergency Braking events and Impact Alerts) were most likely to require an immediate driver response, as opposed to "advisory" activations, which identified a valid threat but may not have required an immediate response. False activations were also observed, and suggestions are offered to reduce their prevalence in future technology generations. Drivers typically received more advisory alerts than high urgency alerts. Advisory alerts may help drivers maintain awareness of surroundings, but may also be bothersome. Speed, headway, brake reaction time, and decelerations were analyzed for changes, and participants did not appear to adapt these behaviors while using CASs. CAS activation, likewise, did not change meaningfully over time. Characterizations of CAS activations, including environmental conditions, were provided to help model their potential benefits across the industry.

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INTRODUCTION

In 2014, 3,903 people were killed and an estimated 111,000 people were injured in crashes involving large trucks [1]. Eighty percent of fatal crashes involving heavy vehicles were multi-vehicle crashes, and the truck's front was typically the impact point in a fatal truck crash [1]. In recent years, crash avoidance systems (CASs) have become commercially available for truck tractors and may help reduce the number of fatal crashes. CASs have the ability to warn drivers of impending forward collisions, and can automatically apply the brakes to help mitigate or prevent such collisions. These systems use radar sensors mounted to the front bumper to detect the speed and distance of potential threats in front of the truck. These technologies are currently recommended by the National Highway Traffic Safety Administration for heavy vehicles in the US and are required for heavy vehicles by the European Commission in the EU [2, 3]. However, both fleets and policy makers need more data to better understand the effectiveness of CAS technology to make informed decisions about its adoption and implementation. Data on how well these technologies perform can help the industry develop a better understanding of their potential safety benefits.

In order to investigate the real-world performance of CAS technology, the five following research objectives were defined:

1. Evaluate the performance of CAS technology.
2. Assess frequency of CAS activations.
3. Assess changes in overall driving behaviors.
4. Provide data on real world conflicts.
5. Generate inputs that could help improve safety-benefit models.

METHODS

Crash Avoidance System (CAS) Technologies

The CAS technologies investigated in this study included five different types of activation: Automatic Emergency Braking activations (AEBs), Impact Alerts (IAs), Stationary Object Alerts (SOAs), Following Distance Alerts (FDAs), and Lane Departure Warnings (LDWs). AEBs, IAs, SOAs, and FDAs are generated based on a forward-looking radar system mounted to the front bumper of the truck. LDWs are generated based on a camera mounted to the center-top of the truck windshield. AEBs give the driver an urgent audio-visual alert and automatically engage the engine retarder and foundation brakes to slow the truck if a crash is imminent. IAs give the driver an audio-visual alert when a conflict is unfolding but no physical action is taken by the system. SOAs give the driver an audio-visual alert to a stationary object or stationary vehicle that is in the path of the truck. FDAs give the driver a less urgent audio-visual alert to a potential conflict in front

of the truck. The LDW system uses a separate sensor and provides audible alerts to drivers when the camera detects that the truck is departing the lane boundaries. Separate speakers on the left and right side of the cab provide directional audio feedback depending on whether a left or right lane boundary is being crossed. The two systems included in the study have differences in how these audio-visual alerts are presented to drivers, but the types of alerts generated by the systems are the same. Differences within each type of activation, such as multiple levels of FDAs or IAs, have been collapsed in order to report results anonymously.

Data Collection

In order to investigate the real-world performance of CAS technology, 150 drivers of truck tractors equipped with either the Meritor WABCO OnGuard™ or Bendix® Wingman® Advanced™ products were recruited to join a naturalistic driving study. These products represented the newest CAS technologies that were commercially available at the time of data collection (November 2013 - August 2015). Each participating truck was outfitted with a data acquisition system (DAS), which collected data whenever the truck was in motion. The DAS collected video of the forward roadway, video of the driver's face and truck cab, and vehicle network data such as speed, acceleration, braking, steering, and CAS activations. The DAS was also equipped with independent sensors such as a gyroscope, GPS, and cell-phone communication. The DAS was mounted in the bottom-center of the windshield where it had a clear view of the roadway but would not interfere with drivers' vision. A waiver was obtained from the Federal Motor Carrier Safety Administration in order to place the DAS in this location. Participating trucks and drivers were recruited from seven different companies across the US. While these companies were focused in the northeast, southeast, and southwest of the US, participating trucks drove through all lower 48 states while collecting data. The participating drivers performed their normal duties and drove the trucks on their normal revenue-producing routes.

Data was harvested from the participating vehicles every three months and uploaded to a secure database for analysis. In total, 188 terabytes of naturalistic driving data were collected. This included 84,447 hours and 2,466,490 miles of driving. A total of 885,000 CAS activations were observed in the data (Figure 1). LDWs and FDAs comprised a large majority of the observed CAS activations.

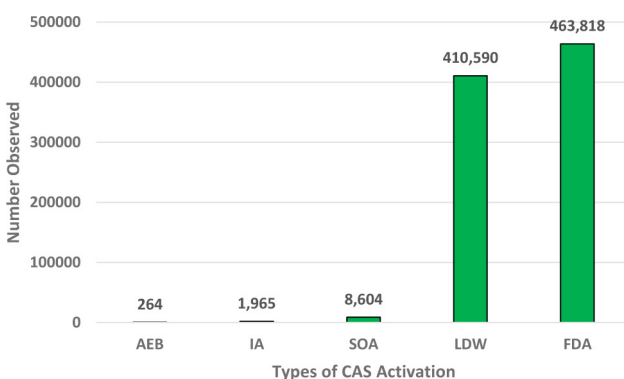


Figure 1. Quantity of each type of CAS activation within data set.

Data Analysis

In order to assess performance, a sample of 6,000 CAS activations, which included all AEB activations, all IA activations, and randomly selected SOA, FDA, and LDW activations, was created for analysis. Of these activations, 4,488 were radar-based (AEB, IA, SOA, and FDA), while the remaining 1,512 were left and right LDWs based on a windshield camera. A summary of the sampled activations, with the two product brands de-identified as "Company A" and "Company B," is shown in Table 1. These names will be used consistently throughout the results to refer to the same de-identified product. LDWs, FDAs, and SOAs were sampled relatively equally between both companies, while all observed IAs and AEBs (the most urgent types of activation) were included in the sample.

Table 1. CAS activations sampled for analysis.

	LDW	FDA	SOA	IA	AEB	Total
Company A	760	903	227	1,424	234	3,548
Company B	752	905	227	538	30	2,452
Total	1,512	1,808	454	1,962	264	6,000

The objective of evaluating performance was addressed by approaching the data from two directions. First, sampled activations were evaluated to determine if these were false warnings. Second, "valid" activations were evaluated to determine if they were warning drivers of an immediate threat or of a potential future threat (i.e., whether the driver needed to react immediately to the activation). To address these issues, each sampled CAS activation was put through an initial analysis to determine 1) whether a valid object was being tracked or a valid lane marking was crossed and 2) whether an immediate crash avoidance maneuver was required from the driver. A crash avoidance maneuver could be a braking response, steering response, or combination of the two. These criteria for crash avoidance maneuvers indicate a safety-critical event (SCE) took place, and is the same definition used in previous naturalistic driving studies [4, 5, 6]. Activations in which a valid object or lane marking did not appear to be tracked were classified as "false activations." Activations in which a valid object or lane marking was being tracked and a crash avoidance maneuver was required were classified as "activations in response to SCE." Finally, activations in which a valid object or lane marking was being tracked but a crash avoidance maneuver was not required were classified as "advisory activations." Advisory activations could be considered informational in nature, in the sense that the driver needed to be aware of the object or situation that generated the activation but did not need to immediately respond.

Once the initial analysis was completed, a second round of analysis was performed. False and advisory activations were put through an analysis of environmental conditions to determine weather, roadway, traffic, and other conditions. Activations prior to an SCE were put through a more thorough analysis, which included environmental factors, contributing factors, driver behaviors, evasive maneuvers, and further classifications of severity. While several environmental variables were analyzed, they are not presented in this paper due to a lack of exposure data for each participating driver.

PERFORMANCE OF CRASH AVOIDANCE SYSTEM (CAS) TECHNOLOGY

The performance of CAS technology was investigated separately for each brand of CAS and each type of activation. False AEBs were further investigated to determine what impact they may have had on the driver or vehicle.

Overall Performance

The 4,488 radar-based CAS activations were analyzed to determine whether they were activations prior to an SCE, advisory activations, or false activations. For Company A, 7% of activations were prior to an SCE, 82% were advisory, and 11% were false. For Company B, 6% were prior to an SCE, 76% were advisory, and 18% were false. These results are summarized in [Figure 2](#).

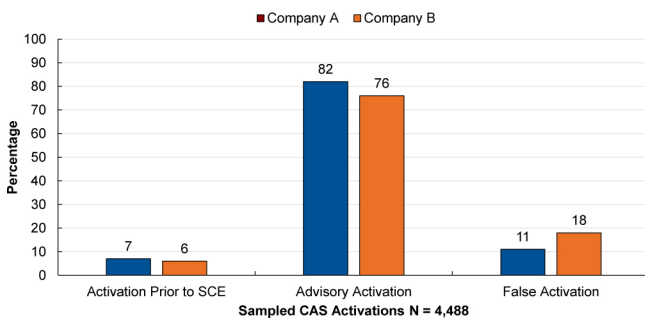


Figure 2. Performance of radar-based CAS activations across all types, separated by CAS manufacturer.

Differences in the performance of each type of activations were found. For Company A, AEBs were most likely to occur prior to an SCE (31%), followed by IAs (9%) and FDAs (<1%). Inversely, FDAs were most likely to be advisory (97%), followed by IAs (87%) and AEBs (68%). Relatively low false activation rates were observed for all three of these activation types. However, SOAs were almost entirely false activations (98%). Video analysis determined the common causes of false SOAs to be overpasses, overhead signage, and curves in the road. These results are summarized in [Figure 3](#).

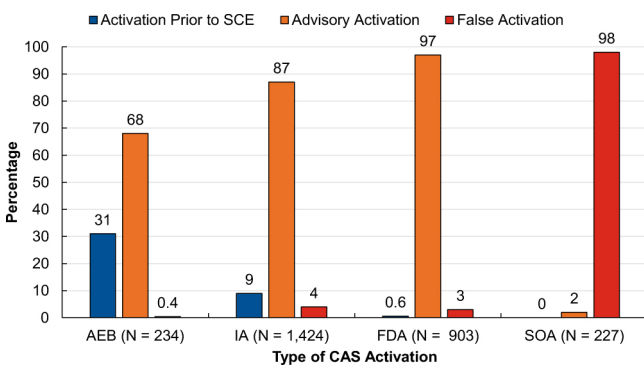


Figure 3. Performance of each type of radar-based CAS activation for company A.

A similar pattern of reliabilities was found for Company B. AEBs were most likely to occur prior to an SCE (60%), followed by IAs (15%) and FDAs (<1%). FDAs were most likely to be advisory (99%), followed by IAs (70%) and AEB activations (13%). False

activation rates were notably higher for Company B, at 27% for AEBs and 15% for IAs. Again, most SOAs were false (97%) and the most common causes of false SOAs were determined to be overpasses, overhead signage, and curves in the road. These results are summarized in [Figure 4](#).

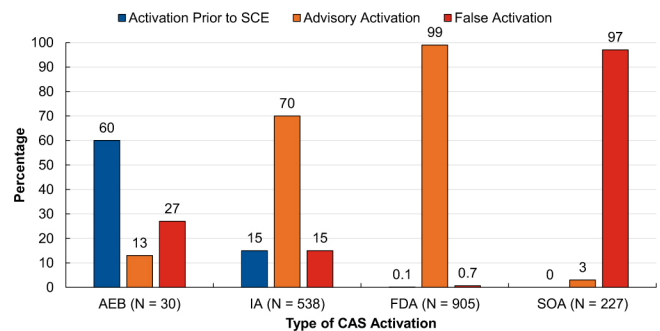


Figure 4. Performance of each type of radar-based CAS activation for company B.

LDW activations used a camera-based sensor mounted on the windshield and were analyzed separately. This feature was optional on participating vehicles and the choice of whether to equip trucks with LDWs was entirely up to the participating trucking companies purchasing the vehicles. Eleven trucks using Company A's CAS and 64 trucks using Company B's CAS were equipped with LDWs and used for this analysis. For Company A, 22% of LDWs were in response to an unintentional lane departure, 76% were advisory (intentional lane departure), and 2% were false activations. For Company B, 34% were in response to unintentional lane departures, 65% were advisory, and 1% were false activations. These results are summarized in [Figure 5](#). LDWs on the left and right side of the vehicle were similar in terms of performance.

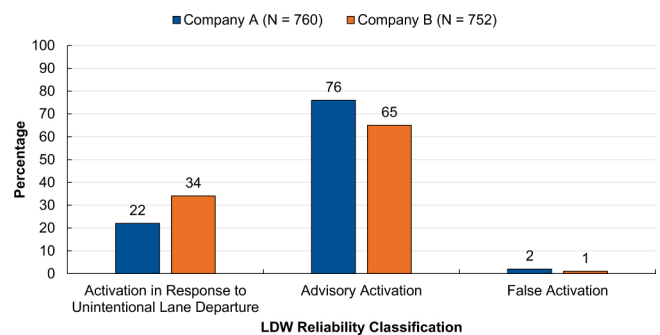


Figure 5. Performance of LDW activations, separated by company.

False Activations

Most activations that were not SOAs were either prior to an SCE or advisory, meaning the activations were in response to valid objects the driver needed to attend to. The difference between advisory activations and those prior to an SCE is one of urgency, not of validity. However, false activations were observed across all types of CAS activation, as summarized in [Figure 6](#).

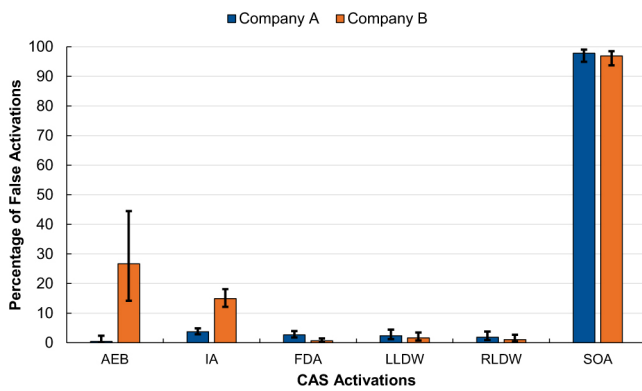


Figure 6. Percentages of false activations, separated by company and type of activation.

AEB events were relatively rare, with only 264 occurring in almost 2.5 million miles of driving. Of these AEB, nine were categorized as false activations based on video analysis. False AEB activations are concerning due to their potential effects on driver trust, driver behavior, and roadway safety. AEB activations were further investigated to determine how false AEBs might impact roadway safety. First, the durations of false AEBs were compared to the durations of AEBs prior to an SCE and advisory AEBs. For Company A, AEBs prior to an SCE and advisory AEBs averaged 1.77 s and 1.67 s in duration respectively, while the one false AEB was 0.1 s in duration. For Company B, which had a higher rate of false AEBs, AEBs prior to an SCE and advisory AEBs averaged 1.87 s and 0.79 s in duration respectively, while false AEBs averaged 0.29 s in duration. These results are summarized in Figure 7, and show that false AEBs observed in the study were, on average, shorter in duration than valid AEBs observed in the study.

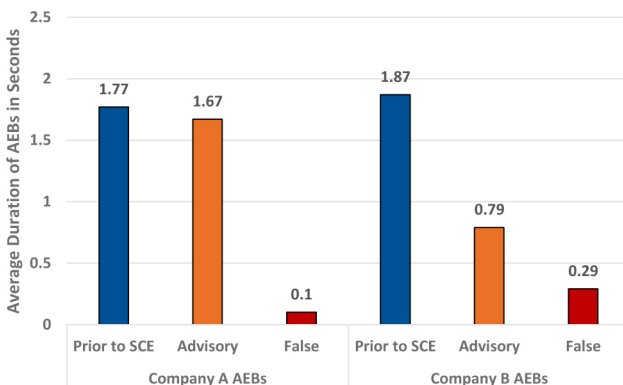


Figure 7. Average duration of AEBs in seconds, separated by company and classification of AEB.

If false AEBs are, on average, shorter than valid AEBs, then it is also possible that they have a smaller impact on speed and acceleration. This would mitigate concerns about associated roadway safety. To investigate this, the maximum deceleration values associated with false AEBs were compared to the maximum deceleration values associated with AEBs prior to an SCE and advisory AEBs. For Company A, AEBs prior to an SCE and advisory AEBs averaged a max deceleration of 0.38 g and 0.2 g respectively, while the one false AEB had a maximum “deceleration” of -0.04 g (meaning the driver was applying the gas pedal and actually accelerated through the

activation). For Company B, AEBs prior to an SCE and advisory AEBs averaged a maximum deceleration of 0.4 g and 0.26 g respectively, while false AEBs averaged a maximum deceleration of 0.15 g. These results are summarized in Figure 8 and show that false AEBs observed in the study, on average, did not decelerate the vehicle as forcefully as valid AEBs observed in the study.

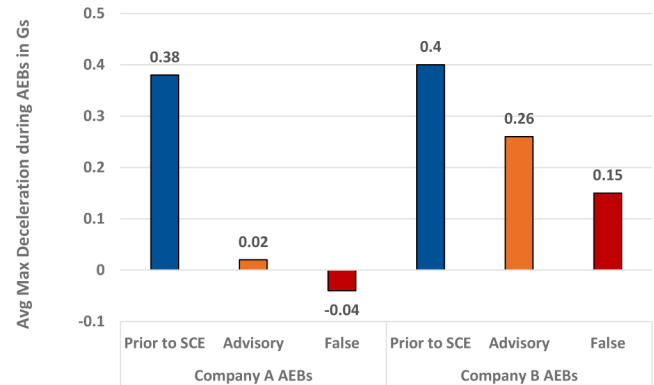


Figure 8. Average maximum deceleration during AEBs in Gs, separated by company and severity of activation.

Finally, the change in speed associated with false AEBs was compared to the change in speed associated with AEBs prior to an SCE and advisory AEBs observed in the study. For Company A, during AEBs prior to an SCE and advisory AEBs, the truck slowed by an average of 8.89 mph and 4.76 mph respectively, while in the one false AEB, the truck actually sped up by 0.01 mph. For Company B, during AEBs prior to an SCE and advisory AEBs, the truck slowed by an average of 11.12 mph and 6.05 mph respectively, while false AEBs slowed the truck by an average of 2.88 mph. These results are summarized in Figure 9, and show that false AEBs observed in the study, on average, slowed the vehicle less than valid AEBs observed in the study.

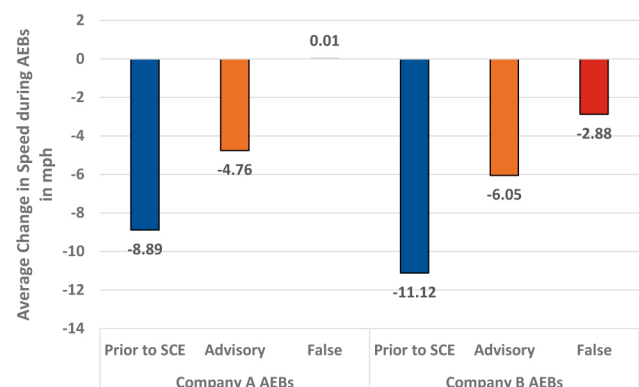


Figure 9. Average change in speed during AEBs in Gs, separated by company and classification of AEB.

ASSESSING FREQUENCY OF CAS ACTIVATIONS OVER TIME

The frequency of CAS activations was assessed by looking at the rates at which drivers received activations and how those rates may have changed over time. First, the rates of CAS activations were