

Forward Collision Mitigation Systems: A Safety Benefits Analysis for Commercial Vehicles via Hardware-in-the-loop Simulation

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ABSTRACT

Forward collision mitigation systems (FCMS) are becoming standard in passenger car vehicles with the current trend of safety technologies development. Currently, safety systems are on the road towards widespread acceptance in the commercial vehicle industry. Whereas the full Electronic Stability Control (ESC) system attempts to sense the states of the vehicle to assist the driver to maintain directional control of the vehicle, current FCMS attempts to sense the environment around the front of the vehicle and either warns the driver to react or intervenes by slowing down the vehicle autonomously. Some of the latest developments in FCMS for commercial vehicles will be discussed, together with an outlook of future systems. This study will also examine some of the common scenarios that forward collision mitigation systems can be beneficial in, especially for commercial vehicles. The scenarios will be investigated using Hardware-in-loop-simulation, and the results discussed.

INTRODUCTION

Systems that attempt to assist drivers to mitigate the effects of forward collisions have been in the market for quite some time. Most premium passenger cars have developed some sort of predictive braking system that allows for the vehicle to react and possibly apply braking in an attempt to mitigate the effect of rear end crashes.

For commercial vehicles, there are already currently systems that are available as Forward collision mitigation systems (FCMS) [2, 12]. Most systems are available to work with Adaptive Cruise Control (ACC), and provide the capability to slow down the vehicle either by applying the engine brake and/or the foundation brakes. Under most cases, autonomous interventions are usually preceded by some form of visual or auditory warning for the driver. The objectives of these technologies include, but are not limited to:

1. Warning the driver to take control of the vehicle if he/she is not attentive.
2. Assisting the driver to maintain control of the vehicle, especially during avoidance maneuvers.
3. Reducing the speed of the vehicle to either lessen the crash severity, or avoid the collision entirely.

Most of the FCMS available for commercial vehicles use radar systems, as shown in [Figure 1](#) to supplement the cruise control/warning system with information on objects in front of it. Such systems are typically denoted as ACC systems, and usually require that the cruise is set and active for any active engine/braking intervention to occur.

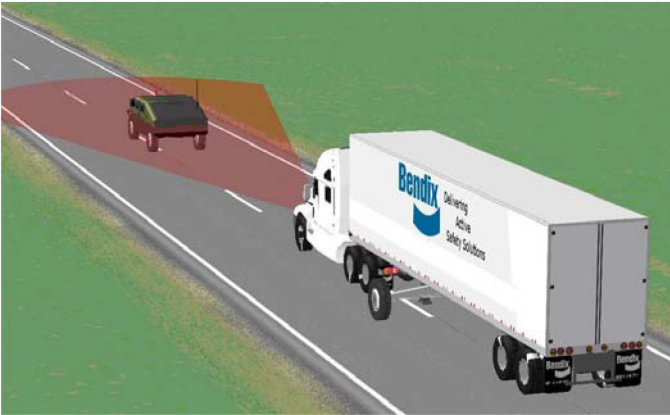


Figure 1. A tractor-trailer model, with the forward-looking radar. The field of view of the radar is shown as the sector in red.

An evolution of the ACC system is the Automated Emergency Braking (AEB) system. The AEB system typically does not require cruise control to be set or active to intervene.



Figure 2. Some of the FCMS that are available on the market include the Bendix Wingman System (a) [2] and the Wabco OnGuard System (b) [3]. Typically these systems are mounted on the front bumper of the commercial vehicle.

It must be noted, however, that the availability of ACC or AEB on a vehicle does not necessarily mean that a collision may be avoided completely. Whilst most ACC systems are often designed as a comfort feature, most AEB systems are designed to be safety features. Hence, the braking behavior of each system is typically different. The laws of physics still apply, as it takes time to reduce the momentum of the vehicle. This is especially true for commercial vehicles, where the vehicle mass may potentially change significantly depending on operation (garbage trucks and tankers) and combination length (single combination, doubles and triples). The driver warning by most systems aim to induce distracted drivers to take control of the vehicle, especially during a situation where the traffic pattern suddenly changes. With proper Human-Machine Interface (HMI), the driver could be alerted to respond to a potentially dangerous situation, and may avert a collision just because he/she has extra time to react. A study by Daimler-Benz has shown that given an

earlier time to react [8], the severity of most accidents can be reduced.

Under the circumstances whereby the driver is unable to respond in a timely manner to avoid collision, the FCMS may apply braking to slow the vehicle down. There are already various Forward Collision Warning Systems (FCWS) in the market for some time. The Federal Motor Carrier Safety Administration (FMCSA) has conducted a rather extensive study [1] about the financial benefits of FCWS. According to the study, a rear-end crash for a commercial vehicle may incur numerous costs to the carrier. The costs include, but are not limited to:

1. Labor costs
2. Workers' compensation costs
3. Operational costs
4. Property damage costs
5. Environmental costs
6. Legal costs

When the vehicle involved in the accident is carrying high value cargo, the cost vs. benefits argument shift significantly towards the benefits. According to [1], the cost estimate for a high-value cargo rear end crash with fatality is \$1,103,721, compared to a Property Damage Only (PDO) rear end crash, which only has an estimated cost of \$ \$170,150. Hence, even if the system only reduces the severity of the crash to a PDO crash, there are already significant financial benefits to be reaped. According to the FMCSA[14], collision mitigation systems can be installed by Original Equipment Manufacturers (OEMs) when the vehicles are manufactured and costs approximately \$2,500 over the costs of anti-lock braking systems and stability control systems, but the price may potentially vary depending on the number of units acquired. Even with such costs, it is noted that the benefits of such systems outweigh the costs.

POTENTIAL FORWARD COLLISION SENSOR COMBINATIONS

There are various combinations of different sensors in the different FCMS systems that are deployed in the market today. In most cases, the combination of sensors will have to be balanced between cost and performance. It is expected that with modern technological advances, the systems are expected to be more affordable to fleet owners and independent operators.

SINGLE RADAR

This hardware configuration on vehicles employ the usage of a single radar for detecting object forward of the vehicle. Whilst this is the simplest implementation of an FCMS, it is

proven to be rather functional and cost-effective for preventing front-end crashes for commercial vehicles. [Figure 3](#) shows how a single radar system is typically applied to a vehicle.

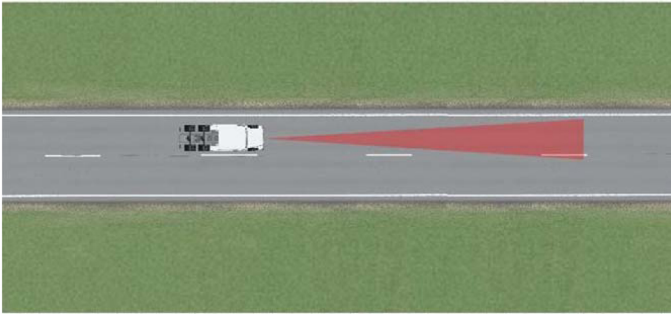


Figure 3. A commercial vehicle with single forward looking radar for collision mitigation. The red triangular area denotes the field of view of the radar.

MULTIPLE RADAR

This hardware configuration on vehicles employ the usage of multiple radar for detecting object forward of the vehicle. The advantage of this hardware configuration over the single radar is that it provides secondary sensors for target confirmation. Hence, this system has more robustness versus the single radar configuration. The robustness of such systems can be compounded with the usage of radars with different operating frequency ranges or calibrations. The system can also have one long range radar and one short range radar, such as shown in [Figure 4](#). However, because of the duplicity in radar sensors, the cost of this configuration is going to be more than the single radar systems.

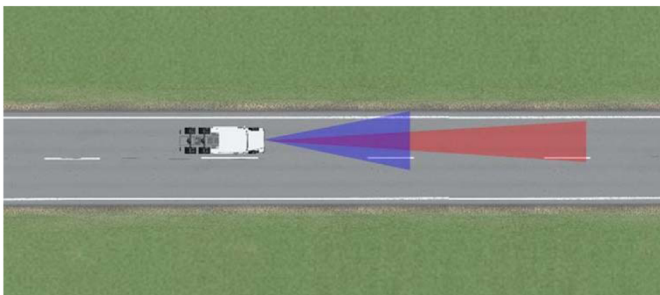


Figure 4. A depiction of potential configuration for a commercial vehicle with multiple radar used as a collision mitigation system. The red triangular area denotes the field of view of the long range radar and blue triangular area denotes the field of view of the short range radar.

SINGLE RADAR AND CAMERA/LIDAR

This hardware configuration on vehicles employ the usage of a single radar for detecting object forward of the vehicle, and a video camera and/or LIDAR for a secondary sensor, as shown in [Figure 5](#). This system aims to provide visual confirmation of the target, as opposed to just making a decision using radar signatures. The potential benefits of this configuration include path prediction confirmation and target confirmation. One of the advantages of combining a LIDAR system with a video camera system is that objects with poor contrast, compared with the surroundings, can be distinguished and classified rather effectively.

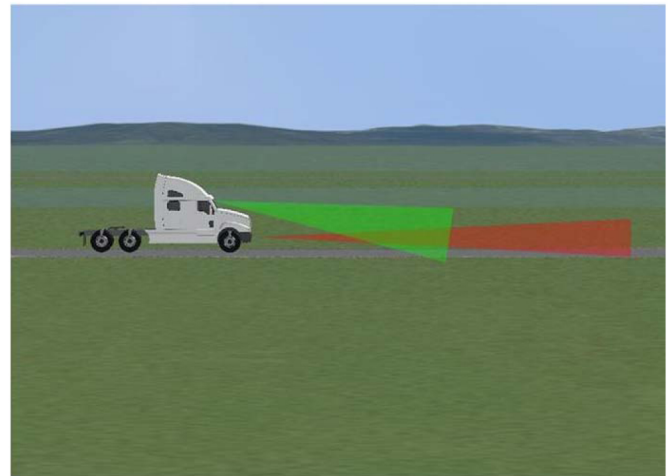


Figure 5. A depiction of a potential configuration for a commercial vehicle with a single radar and camera/LIDAR used as a collision mitigation system. The red triangular area denotes the field of view of the radar and green triangular area denotes the field of view of the camera/LIDAR.

There are also other added benefits to having a system with a camera. The camera can also be used in collaboration with Lane Departure Warning systems to assist the driver to keep the vehicle in the lane.

HIL SYSTEM

For the purpose of determining the effectiveness of FCMS systems on trucks and combination vehicles, a Hardware-In-the-Loop (HIL) system is used in this study, with the architecture shown in [Figure 6](#). The configuration that we will be testing in this study will be the single radar configuration, shown in [Figure 3](#). The system is an expansion of the system developed in [4]. It is often more convenient to do some of the level of evaluation and analysis in simulation before attempting to do testing on the track. The HIL simulator also allows for off-season testing (winter testing in the summer and vice versa), which helps with research and development efforts.