

Heavy Vehicle Hardware-in-the-Loop Automatic Emergency Braking Simulation with Experimental Validation

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ABSTRACT

Field testing of Automatic Emergency Braking (AEB) systems using real actual heavy trucks and buses is unavoidably limited by the dangers and expenses inherent in crash-imminent scenarios. For this paper, a heavy vehicle is defined as having a gross vehicle weight rating (GVWR) that exceeds 4536 kg (10,000 lbs.). High fidelity Hardware-in-the-Loop (HiL) simulation systems have the potential to enable safe and accurate laboratory testing and evaluation of heavy vehicle AEB systems. This paper describes the setup and experimental validation of such a HiL simulation system. An instrumented Volvo tractor-trailer equipped with a Bendix Wingman Advanced System, including the FLR20 forward looking radar and AEB system, was put through a battery of different types of track tests to benchmark the AEB performance. Two heavy vehicle crash scenarios were tested: (1) Slower-moving lead vehicle scenario, where the subject vehicle's AEB detects and responds to a vehicle moving more slowly in its immediate forward path ("lead vehicle"), and the (2) Decelerating lead vehicle scenario, where the lead vehicle suddenly decelerates in the path of the subject vehicle. These tests were then performed on the HiL simulation system using the same type of Bendix Wingman System and radar, and the results were compared.

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INTRODUCTION

Rear-end collisions account for roughly 20% of all police-reported heavy truck crashes based on General Estimates System data published in 2004 [1], and the heavy truck was the striking vehicle in 60% of these cases. In light of these statistics, it is believed that a means of mitigating or avoiding frontal collision in heavy vehicles through electronically assisted braking systems, such as Automatic Emergency Braking (AEB), could have significant safety benefits.

Field testing of such systems using vehicles is necessarily limited by the dangers and expenses inherent in crash-imminent scenarios, especially when the system is not designed to eliminate all collisions but rather to reduce their severity. Moreover, testing of heavy vehicles is generally restricted to lower speeds because of space availability within proving ground facilities and safety requirements. HiL (Hardware-in-the-Loop) systems allow the expansion of testing to include aggressive scenarios not possible on the test track, like shorter following distances at higher speeds, aggressive lead vehicle

decelerations, and other configurations reasoned impractical or dangerous with real vehicles. HiL systems for heavy trucks also allow simulations of different configurations of heavy vehicle classes, i.e., multiple loads and inertial configurations.

NHTSA constructed a HiL heavy truck pneumatic braking system operated through dSPACE hardware and integrated with Matlab/Simulink and TruckSIM co-simulation. This system was previously described in depth in [2] and validated for electronic stability control (ESC) testing in [3].

The system currently supports the Bendix EC-60 Electronic Control Unit (ECU) in various configurations. For this paper, a version of this ECU is used which includes the Bendix Wingman Advanced radar-based collision mitigation system. Specifically explored here is the AEB application. A single straight lane is used with one forward-moving vehicle (or target) to replicate NHTSA's test track ones scenarios designed to evaluate AEB systems' safety performance.

Two scenarios are used to compare simulated results with test track experiments. The first is the slower moving lead vehicle scenario (SMLV), which evaluates the ability of the AEB system to detect and respond to a slower-moving vehicle in the immediate forward path of the truck. The second is the decelerating lead vehicle scenario (DLV). In this test, the lead vehicle is initially moving at a constant speed in the immediate forward path of the SV, then after a short period the lead vehicle decelerates at a constant rate to a low constant speed in the range of 8 km/h (5 mph).

HIL HARDWARE AND SOFTWARE SYSTEM

The HiL system uses identical radar hardware as is used in the Volvo Truck retrofitted with a Forward Collision Warning (FCW) and AEB system with a software option that accepts target position and speed injection through a CAN bus designed for testing and simulation. This capability allows for the testing of the logic and communication built into the radar, which is responsible for emergency brake activation signals. State-of-the-art radar technologies, like the FLR20, are smart sensors that detect targets and make appropriate calculations, sending brake commands to be executed by the vehicle's main ECU brake safety controller. The braking actions are finally executed by the vehicle dynamics ECU.

Figure 1 shows the Volvo tractor retrofitted with the Bendix FLR20 radar located on the center of the front bumper. This radar is integrated with the Driver Interface Unit (DIU) mounted on the vehicle dashboard. The placement of these units, as well as the ECU, in the HiL system can be seen in Figures 2 and 3. Both the simulated and experimentally tested tractor/trailer systems were loaded according to Federal Motor Vehicle Safety Standard (FMVSS) No. 121 GVWR requirements.



Figure 1. Volvo truck with Bendix FLR20 radar and DIU



Figure 2. Bendix ECU and FLR20 radar on HiL system

The Controller Area Network (CAN) connections required for the HiL pneumatic braking system are shown in Figure 4. Note that the simulation hardware must simultaneously communicate on three different CAN networks.

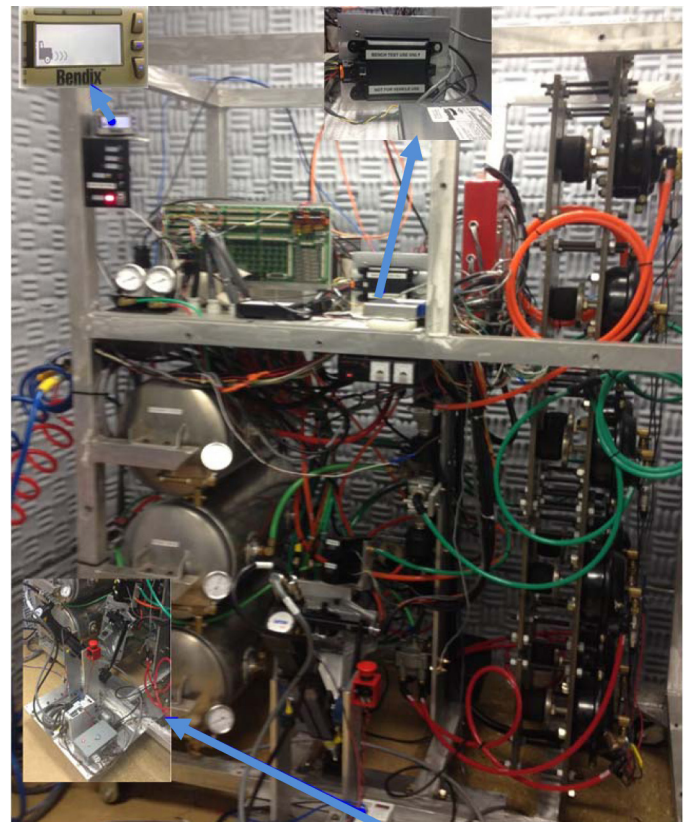


Figure 3. HiL pneumatic braking system with AEB - Arrows in the picture point to zoomed view-

DYNAMICS SIMULATION AND RADAR CONFIGURATION

The simulated sensor range sensitivity is set at 100 m with a $\pm 10^\circ$ field of view. A school bus is chosen for the forward moving vehicle or target (Figure 5). The detection area is modeled as a box with length = 6.45m, height = 2.65m, and width = 2.44m. The simulated