

Evaluation of Full and Partial Stability Systems on Tractor Semi Trailer Using Hardware-in-the-Loop Simulation

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Bendix Commercial Vehicle Systems LLC

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ABSTRACT

The application of stability systems on heavy vehicles clearly has numerous advantages, when the cost of the cargo, the service life of vehicles, and the vehicle potential for damage are taken into account. The primary objective of such systems is to assist the driver to maintain control in the face of uncertain driving conditions. The dynamic effects of such system, however, are not widely tested by the industry. The study presented in this paper will present an evaluation of the effects of full and partial stability systems on tractor-trailers using hardware-in-the-loop simulation. With the advancement of simulation capabilities that enables the repeatability of maneuvers, the study presented attempts to provide various deterministic “what-if” scenarios under various vehicle stability system combinations.

INTRODUCTION

Electronic stability control (ESC) has proven that it is effective for assisting drivers to maintain control of light passenger vehicles, especially for SUVs and light trucks. In the passenger car industry, the ESC can help drivers maintain control in oversteer or understeer situations, which may result in vehicle rollover when the vehicle is tripped on the curb or slides off the road.

In heavy commercial vehicles, the risk of accidents are higher because of the fact that the vehicles are heavier, longer and the driver may or may not have any foreknowledge about how the vehicle is loaded. According to the FMCSA [15,16], it was estimated that between 1,422 and 2,037 combination vehicle rollover crashes in curves could be prevented through use of the some form of vehicle stability system. Aside from accidents arising from direct vehicle on vehicle impacts, there are two common types of instability that can potentially cause

accidents to happen to heavy commercial vehicles. The first type of instability is yaw instability, where the yaw rate of the vehicle builds up to a point where the driver is unable to maintain control. Examples of yaw instabilities are depicted in [Figure 1](#). In combination vehicles, yaw instability commonly results in jackknifing of the combination vehicle. The second type of instability is roll instability. Roll instability often results in the heavy vehicle tipping over and ending up on its side. In most cases, yaw instability may result in roll instability, especially when the vehicle slides off the road or trips on a curb during an evasive maneuver [13]. Due to the fact that commercial vehicles have a much larger mass than other vehicle on the roads, at the onset of any of these instabilities, it is typically difficult for the driver to maintain control of the vehicle. Moreover, ESC prevents semitrailer jack-knifing by simultaneous measured braking of the semitrailer, even if it is equipped with just a conventional braking system [13].

RSC stands for rollover stability control, and is typically a subset of ESC. The application for RSC on commercial vehicles typically means that it is set up to prevent rollover only, but typically may only have minimal capabilities (e.g. ABS wheel cycling when wheels lock up) to intervene in situations where yaw instability is developing in the vehicle, especially on low μ surfaces. In addition to potential loss of life and injuries, commercial vehicle accidents also have the likely potential to cost the vehicle owners loss of income, and cargo. According to studies by the FMCSA ([15], [16]) and NHTSA [14], there are various costs that can result from a heavy truck crash. The costs include, but are not limited to:

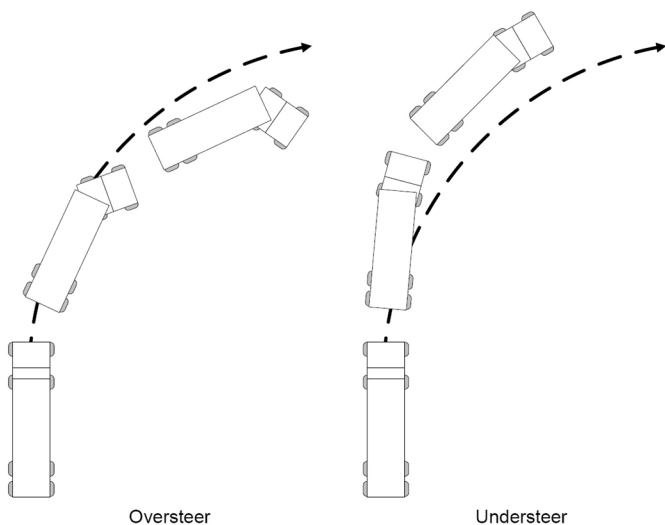


Figure 1. The potential outcome of yaw instability on a combination vehicle. The dashed line represents the intended path of the vehicle. In both cases, the combination has a very likely chance of departing the lane and being involved in a serious accident.

1. Labor Costs
2. Worker's Compensation Costs
3. Operational Costs
4. Property Damage and Auto-Liability Costs
5. Environmental Costs
6. Legal Costs

Based on the cost benefit analysis conducted by the FMCSA [15], a typical PDO rollover crash would cost \$196,958, an injury rollover crash would cost \$462,470, and a fatal rollover crash would cost \$1,143,018, in total costs. However, the total costs of having a truck equipped with some form of stability control system is estimated to range from approximately \$440 to \$866 per vehicle. Hence when compared against the cost of a truck crash, the long-term benefits of ESC for heavy vehicles outweigh the cost of the system.

HIL SYSTEM

For the purpose of determining the effectiveness of stability systems on trucks and combination vehicles, a HIL system has been developed, with the architecture shown in Figure 2. It is often more convenient to do some of the level of testing 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.

Although some level of testing can be done with Software-In-The-Loop (SIL), the last level of testing for any electronic

control system is often done via Hardware-In-The-Loop. The advantages of HIL testing include the ability to account for the latency of the actual electronic hardware, and for air-brake systems, the inherent characteristics of the mechanical systems. Thus, the development of a HIL system for the purpose of enabling the testing of any combination of the tractor/truck ESC/ABS and the trailer ESC/ABS in a virtual proving ground has many cost-saving, repeatability and efficiency advantages from an engineering standpoint.

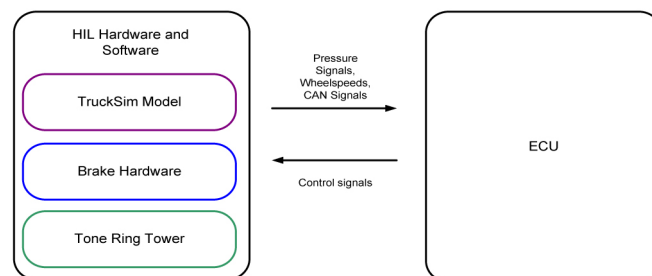


Figure 2. General HIL Interface architecture for both the tractor and the trailer systems.

The HIL setup is composed of a dSPACE HIL hardware and software combination, working in combination with the truck brake hardware for simulating inputs onto the vehicle simulation computer model. The simulated truck dynamics are modeled using TruckSim. In addition to that, the road surface and geometry can be generated in the TruckSim environment to provide a virtual proving ground. The truck hardware that can be simulated include the individual valves, brake chambers and even the sensors such as the wheel speed sensors. The wheel speed information is fed to a servomotor setup on the tone-ring tower which then actuates the tone wheels to generate wheelspeed inputs to the ECU [10]. Using a rack that contains the brake hardware and air lines, such as the ones shown in Figure 4 and Figure 5, all the chamber dynamics and hysteresis can be represented without using complex models [9].

The brake torque-pressure relationship was acquired from brake dynamometer tests and applied to the model as a look-up table. All timing information is adjusted to just barely fulfill FMVSS121 for this study, in order to simulate a legal worse-case scenario, as far as the air brake system is concerned.

The tractor HIL system is set up to communicate with the trailer HIL system using CAN so that brake pressures and wheelspeeds can be passed back and forth, as shown in Figure 6. This ensures accurate control of the timing between the tractor and the trailer hardware. By adjusting the timing of the brake pressure to the trailer, various worse-case scenarios can be simulated.



Figure 3. The tone ring tower used to generate wheel speed sensor signals.

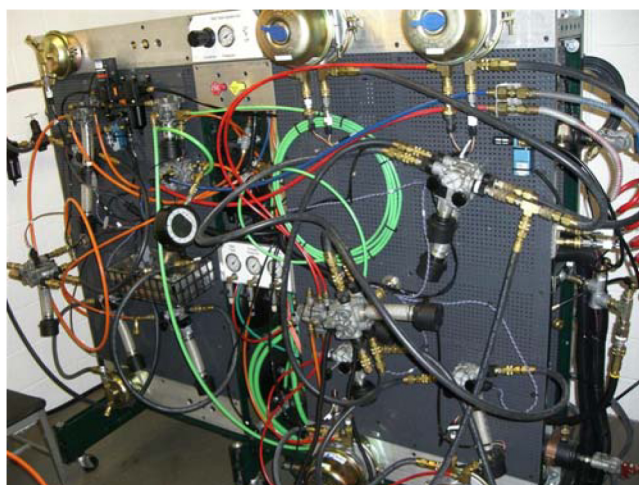


Figure 4. The tractor HIL brake hardware rack.

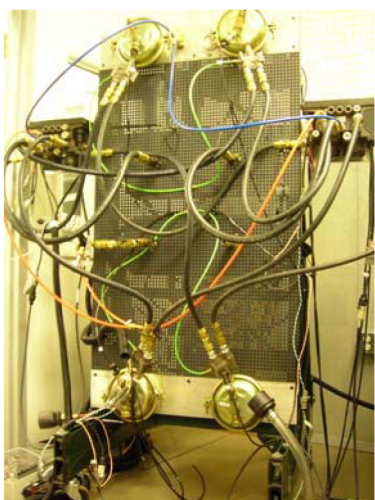


Figure 5. The trailer HIL brake hardware rack.

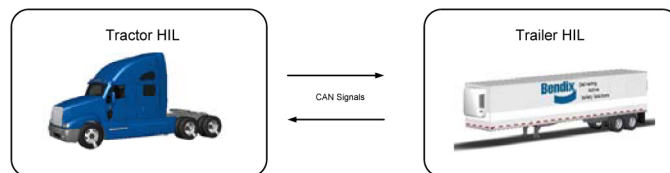


Figure 6. Communications architecture of the tractor and trailer HIL.

With HIL testing, the validation time of many products can potentially be reduced, since it enables the testing of both electrical and mechanical parts of the system in an automated manner without mounting it onto the truck. The effect of design changes can be evaluated in a consistent and repeatable manner.

DYNAMIC TRUCK MODEL

In this study, a Trucksim model was developed for the evaluation of a typical 6×4 Tractor-trailer system. Data was acquired to provide the tractor with reasonable handling characteristics, such as yaw behavior and roll speeds from vehicle testing. Supplementary data was acquired from [2], [3], [4], [5], [6], [7] and [8] to increase the fidelity of the model. The system configuration for the test tractor only is four wheel speed sensors and four control modulators, plus the trailer modulator, as shown in Figure 7. Vehicle test weight for this vehicle is 80000 pounds, which is the legal weight limit for a single combination vehicle, according to the bridge laws [17], as shown in Figure 9. The electronic stability system is provided by a Bendix EC-60 Advanced ECU in 4S/4M configuration, as shown in Figure 7.

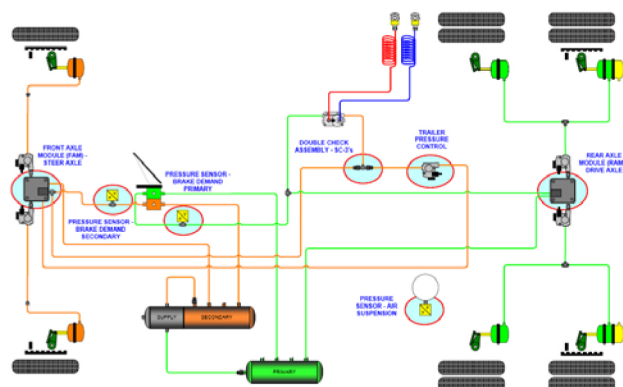


Figure 7. System configuration diagram for the tractor tested in this study (4S/4M) [11].

The trailer stability system is provided by a Bendix TABS-6 unit, operating in 4S/2M configuration, as shown in Figure 8.