Simulation-Based Homologation of Truck ESC Systems

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Summary

Due to the high diversity in designs and variants, the mandatory introduction of Electronic Stability Control Systems (ESC) for commercial vehicles of new generations at Daimler AG poses a task that can only be accomplished with a comparatively high cost in time and money using prototype vehicles. Based on the revised regulation ECE-R13, a simulation-based approach is feasible.

After a short outline of the legal requirements, like the usage of an acknowledged simulation tool, the integration of a software or hardware module in a vehicle simulation environment and the validation of this tool by calibration, their realization in the Daimler Trucks division will be demonstrated. On an example of the new ACTROS generation the flow of the simulation-based certification process will be described. It spans the basic maneuvers for measurement and simulation, calibration and validation of simulations and the applied methodology, documentation and release management approved by the “Kraftfahrt-Bundesamt”.

In this context the specifically developed and certified simulation tool EBSim will be presented, highlighting the TWT TestSuite as the central operating environment, triggering the simulation tools, managing and varying vehicle and simulation parameters, as well as providing automated validation and documentation. Thus it is possible to cover the whole range of commercial vehicles and identify critical types and variants for ESC homologation.

1 Introduction

The safety system ESC (Electronic Stability Control) is today mandatory in the European Community in passenger cars and has proven to be an essential factor for reducing traffic accidents. For heavy trucks and buses with pneumatic braking systems, electronic stability control systems are available on the European market since 2001. Additional to the ESC for passenger cars, which prevents understeer or oversteer of the vehicle by braking individual wheels, the system for trucks and buses also prevents rollover by braking all wheels when the vehicle reaches a limit of lateral acceleration that is load-dependant. However, until now stability control for
commercial vehicles has only been available as an optional equipment for coaches and for tractor-semitrailer combinations, and the percentage of commercial vehicles equipped with such a system is still low.

This is why the legislation committee of the European community has decided to make stability control systems for trucks and buses compulsory. The newly-defined legislation ECE-R13 has come into effect last year, starting with mandatory stability control systems for coaches and for tractor-semitrailer combinations, where the system was already available. All other heavy trucks and buses except vehicles with more than three axles and vehicles for construction purposes will have to follow from 2015 on.

In addition, the equipment of heavy trucks and buses with the systems “lane departure warning” and “emergency braking assist” will also become mandatory until 2015.

This makes it necessary for the truck and bus manufacturers and the braking system suppliers to develop and apply these systems for a big variety of commercial vehicles. As the amount of vehicles which can be used for proving the system functionalities in field testing is limited, it is feasible to use vehicle dynamics simulation to support the development of the systems for the whole variety of commercial vehicle parameters, such as different axle configurations, different wheelbases, tire variations, varied loading conditions, and others. Furthermore, testing of ESC relevant driving situations is cost-intensive because of the necessary safety equipment of the test vehicles (rollover bars, outriggers, anti-jackknife device, see Fig. 1).

Fig. 1: ESC Field Testing

Fig. 2 shows the simulation approach deployed for ESC development. Field testing results of few vehicle types are used to validate the basic simulation model, which is
at first parameterized according to the test vehicle. The results of the simulation concerning the vehicle’s dynamic performance and the functions of the ESC system have to show a good correlation to the measurements. For this model validation, internationally standardized driving maneuvers are used both in simulation and field testing. On the basis of a successful validation, the simulation is then used to cover the whole range of vehicle variations by varying vehicle parameters inside the model and to cover the whole range of possible driving situations by varying the maneuvers inside the simulation process.

Fig. 2: Simulation-assisted ESC development

Another advantage of using simulation tools for the support of the development of stability control systems is the fact, that the new ECE-R13 regulation allows type approval of the vehicle stability system by simulation, if the following requirements are fulfilled by the applied simulation tool:

- The vehicle stability control must be implemented into the simulation tool either by using a software-in-the-loop code integration or by using a hardware-in-the-loop test stand with an integrated ECU of the stability control.
- The simulation tool must be able to cover the whole range of investigated vehicle variants.
- A validation of the simulation tool has to be proven to the authorities on the basis of measurement and simulation of standardized driving situations selected from a list of maneuvers within ECE-R13. At least two maneuvers have to be chosen in order to demonstrate the functionalities of both directional control and rollover control.
- The simulation has to show the vehicle performance with and without stability control and in the unladen and fully laden loading condition.
- A simulation-based type approval document corresponding to an example shown in ECE-R13 has to be handed over to the authorities.
Following this approach, the simulation tool EBSim, which is used by the CAE division of Daimler Trucks for vehicle dynamics simulation with brake control systems, was certified by the German authorities in February 2011, at the same time conducting a simulation-based type approval for the electronic stability system of the new ACTROS.

## 2 Simulation Tools

To investigate the vehicle behavior with incorporated ESC-Systems multiple different simulation tools are used by the CAE analysis division of Daimler Trucks. Within EBSim the TWT TestSuite is the central graphical user interface used to define, conduct and document vehicle dynamics simulations for the evaluation of electronical brake systems in a highly automated fashion.

Integrated into the simulation Process is Simpack as a standard multi body simulation tool for different purposes [1]. The Simpack models are fully parametrized and cover the whole range of possible commercial vehicle configurations such as different axle configurations and truck-trailer combinations (see Fig. 3).

The vehicle model consists of detailed component based models of axles and cab mounting as well as the steering system. The frame includes torsional bending behavior [2]. Since the ESC simulation makes a realistic model of the longitudinal and lateral dynamics necessary, the tire model has a major influence on the simulation results. Daimler Trucks CAE is using the MF-TYRE model for simulation of vehicle dynamics. The simulation model contains a controller for the steering input and the control of velocity including characteristic gear shifting. Alternatively, a measured steering angle-signal can be used as input for the vehicle model to compare the vehicle dynamics in field testing and simulation.

![Fig. 3: Simpack vehicle model](image-url)
For the integration of system codes into the simulation, Simpack offers various possibilities. Within EBSim, the ESC code is integrated either directly as a C code library triggered by a user-defined Simpack routine, or Matlab/Simulink is used as an integration platform using S-functions of both Simpack vehicle model and ESC code, depending on supplier (see Fig. 4).

The exchange of information between the vehicle model and the ESC code delivered by the system supplier is shown schematically in Fig. 5.

**Fig. 4:** Simulation with exported Simpack model and ESC code

**Fig. 5:** Information exchange between vehicle model and ESC code
3 Validation of the Simulation

For the validation – which was conducted for the acceptance of EBSim for type approval, measurement and simulation of the vehicle behavior – two trucks were compared and shown to the authorities – a 2-axle (4x2) leaf spring truck and a 3-axle (6x2) air spring truck.

The correlation between measurement and simulation was shown in several steps:

- Steady-state vehicle behavior without stability control
- Transient vehicle behavior without stability control
- Interventions of the stability control system via powertrain and braking system for both stability control and rollover protection
- Vehicle reaction to the system interventions

Out of the list of possible maneuvers within ECE-R13, for the first type approval two driving situations were chosen:

- Steady state cornering on dry road surface (ISO 14792, [3]) for demonstration of the rollover control, including both powertrain and brake system interventions by braking all wheels.
- Single lane change (ISO 14793 [4]) with changing coefficients of friction for demonstration of the directional control, including both understeer and oversteer interventions by braking single wheels.

For type approvals conducted later with EBSim, two more maneuvers were used additionally:

- Closing curve (ISO 11026, [5]) for demonstration of the rollover control in a driving situation that is better comparable to real world driving.
- Double lane change (ISO 3888-1,[6]) on dry road surface for demonstration of both dynamic rollover control and directional control.

The following figures (Fig. 6 to Fig. 8) show an excerpt of the validation results, which were presented to the “Kraftfahrt-Bundesamt” and the “TÜV-Rheinland”. They also show the process of validation mentioned above validating at first the dynamic behavior of the vehicle with deactivated stability control and then moving on to maneuvers with an activated ESC.

The first diagram always shows the vehicle velocity and the steering wheel angle. For the comparison of measurement and simulation results, the steering wheel angle of the field test was used as input for the simulation model. The second diagram shows the lateral acceleration and the yaw-velocity measured by the ESC-sensor. The last two diagrams show the ESC-intervention. The first one shows the engine control and the desired brake pressures of the simulation, the second one shows the same signals which were measured during the field tests.
The results from the steady state cornering test show, that the behavior of the vehicle model is comparable to the real vehicle since the characteristics of lateral acceleration and yaw rate correspond to the measured signals. Also the ESC-intervention occurs at the same lateral acceleration and is comparable to the test results (at first only engine control, then engine and brake control), see Fig. 7.

Fig. 6: Validation result: 6x2-tractor, steady state cornering, ESC deactivated
For the single lane-change, the dynamic behavior of the vehicle model is compared to the measured signals. At identical speed and steering wheel input, the vehicle model shows the same dynamic behavior and characteristics of the ESC-intervention as the real vehicle.
Fig. 8: Validation result: 4x2-tractor, single lane change with change of friction coefficient from $\mu$-high to $\mu$-low, ESC activated
Slight differences in the dynamic behavior of the simulation model or in the intervention of the ESC-system may result from differences in the local tire to street friction, from differences between the measured tires and the ones which are mounted on the vehicle and many more effects that cannot be considered in the simulation-model in detail. Nevertheless, the simulation results show a very good correlation with the results from field tests since the steady-state and the dynamic behavior of the vehicle model is comparable and the characteristics of the ESC-intervention are the same. This proofs, that the EBSim-environment can be used for homologation of ESC-systems if the vehicle model is able to represent the steady-state and transient behavior of a real vehicle.

4 Large-Scale variant homologation with EBSim

Based on the validated models of tested type variants the specifically developed and certified simulation tool EBSim is used for the conduction of the large-scale variant homologation process as shown in Fig. 9.

![Diagram](image)

Fig. 9: EBSim / TWT TestSuite with integrated simulation tools

As seen, the TWT TestSuite is the central operating environment of EBSim providing a fully automated approach to the complete process, consisting of vehicle/simulation variant generation, load-case generation, simulation, validation and documentation detailed in the following paragraphs.

For the vehicle variant generation process the previously validated simulation models are used as a baseline vehicle type (i.e. 4x2 or 6x2) consisting of prefabricated building blocks that are designed to be easily interchangeable. All different vehicle
types and loading conditions can be represented by variation of the main vehicle parameters like:

- wheelbase
- c.o.g positions, masses and inertia of the MBS bodies
- tires (characteristics, types and static loads)
- and additional vehicle data for type fitting (springs and dampers, stabilizers, frame-stiffness, engine, gearbox and steering system characteristics, etc...)

Together with simulation parameters like maneuver, entrance speed and friction, a simulation matrix is then automatically generated and can be submitted for simulation.

For simulation and post-processing specialized Software like Simpack and Matlab/Simulink is triggered, while a production queue manages simulation priorities, improves license saturation and basic parallel simulation.

For the ease of validation a simplified traffic light representation of the simulation results is performed parallel to standardized signal or curve based post-processing, by checking predefined simulation conditions. These results are clustered by vehicle type with the main influencing parameters of c.o.g. height and speed as illustrated in Fig. 10. Areas which are marked red indicate a combination of entrance speed and c.o.g-height leading to unstable vehicle behavior. Yellow areas indicate driving situations, where the vehicle doesn’t rollover yet, but a wheel lift-off occurs.

Fig. 10: Simplified result representation for quick evaluation

Thus critical types and variants for ESC homologation can be identified, and detailed validation can be done for these specific cases. Found worst case variants can then be again validated by field testing.
All the simulation data is automatically stored in a database for later use and documentation, consisting of

- applied simulation software, versions, and integrated libraries
- unmodified original base model (validated)
- documentation of modified parameters and topology
- maneuver
- simulation results

According to legal regulations the simulation data as well as the documents handed over to the authorities are stored for a minimum of 10 years.

The database can also be easily sorted and searched using multitude different criteria like model names, parameters, result data and so forth, to facilitate parid access to the required data.

Concerning release management, new primary versions of EBSim (e.g. from 1.x.x to 2.x.x) and make an update of validation on the basis of the same measurements as mentioned above necessary with

- major release changes of Simpack from current version 8.x to version 9.x, 10.x etc.
- basic changes in the implementation of Software-in-the-Loop codes of the brake system supplier, e.g. by moving part of the modeling from the SiL code to the vehicle model or vice versa
- change of code implementation from Software-in-the-Loop to Hardware-in-the-Loop

Minor updates of the basic software modules (Simpack, Matlab/Simulink) are documented by changing the second release qualifier, updates of the graphical user interface by changing the third release qualifier. In this case no official reevaluation is necessary. However, an internal reevaluation is still triggered.

5 Conclusion and Outlook

First performed for the new ACTROS commercial vehicle line of Daimler Trucks, the processes described in this paper represent the first-time large-scale implementation and application of ESC homologation by simulation of a major commercial vehicle manufacturer. Within EBSim, the specifically developed and certified simulation tool, calculation, processing, validation and documentation are highly automated, leading to an increase in productivity, safety and reliability of results while meeting the regulations of the ECE-R13.
Future work will see the application of the methodology extended to additional commercial vehicle types and type series or specific special purpose vehicles. Further fields of application are Bus and Van ESC-systems, where simulation could speed up the homologation process.

In addition, as the principle methodology is not limited by specific simulation tools or software, it can easily be applied for the validation of a variety of driver assistance systems i.e. lane keeping assistance or side wind assistance systems.

6 References


[5] 11026 - Road vehicles – Heavy commercial vehicles and buses – Closing curve test
