

On the Use of Driver-in-the-Loop (DIL) Systems in Commercial Vehicle Chassis Development

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ABSTRACT

A vehicle simulation model is developed, validated and integrated into a closed-loop virtual driving environment using a state-of-the-art hexapod driving simulator. Thirty variant states are implemented and evaluated subjectively on steering and handling performance quality and quantity. Standard open-loop objective testing manoeuvres are simulated and performance metrics are calculated, allowing for a systematic cross-correlation process. Graphical analysis of the correlation metrics proves that chassis changes may accurately be felt through the simulator interface. It is proposed how obtained correlation models may serve for driver-feel optimizing target setting in early vehicle development stages, frontloading a great deal of costly prototype testing. System requirements are established and benefits and limitations are portrayed.

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INTRODUCTION

Two main trends are recently sweeping through the industry to modernize chassis system. Regarding chassis components and systems, intelligence and adaptivity is being achieved through actively controlling mechatronic parts based on real time on-board sensor measurements. In parallel, the development processes of chassis systems are being modernized and play a key role in today's modern chassis. Progressively increasing use of virtual tools such as CAD and CAE and hybrid methodologies such as HIL testing is cutting development times and costs by significant amounts. Pursuing the drive for a modern and fully-virtual product development cycle, the commercial vehicle division of Hyundai Motor Company (HMC), in partnership with IDIADA, VTI (Swedish National Road and Transport Research Institute) and rFactorPro, has studied the benefits of driver-in-the-loop (DIL) systems in a front-loading virtual chassis tuning scenario.

BACKGROUND

In the development of a commercial vehicle, any design decision is always closely linked to a great variety of performance requirements. Such requirements are usually monitored making use of objective metrics, i.e. numerical values obtained from real and/or virtual testing and related with specific aspects of the vehicle's performance. The development engineers are used to set target values (typically a target range) for each and every performance metric and they need to make sure that the vehicle as a whole and all the different subsystems are capable to meet those targets [1].

The definition of metrics for Ride and Handling is an especially complex task because these performances are strongly related with the subjective feeling of the driver. For the same reason, it is difficult to set targets in the early stage of the development, when the professional drivers have no physical prototype that can be used to validate them.

The driving simulator is potentially a strong tool to improve this situation as it allows evaluating the Ride and Handling of the vehicle since the early stages of the development, ideally since the target setting phase. This doesn't mean that objective metrics and targets shall be relieved by subjective evaluations performed on the simulator: this would imply too high cost and too much dependency on the subjective feeling. However the driver simulator can be used to validate the metrics in the target setting phase and to monitor the performance along the complete development process. In the early stages they overcome the lack of physical prototypes. In later stages they allow to evaluate efficiently several design solutions that would be expensive and time consuming to manufacture and test.

In this context, HMC and IDIADA defined a project that was aimed at consolidating the link between objective metrics and subjective evaluation using both open-loop and driver-in-the-loop (DIL) simulations.

METHODS

A real-time virtual parametric model of a commercial bus, developed by IDIADA, was built and validated, forming the baseline vehicle of this study. Thirty variant states were prepared for the evaluation, which were composed of fifteen design attributes being individually increased and decreased.

Objective performance metrics were obtained through open-loop simulations to analyse Straight Line Controllability, Cornering Ability and Transient (Yaw-) Stability.

Additionally, two expert drivers were allowed to subjectively evaluate all vehicle states at VTI's driving simulator in Sweden (Sim IV). The virtual test environment was provided by rFactorPro with extremely low latency to minimize visual response lag.

After having performed open-loop simulations and DIL evaluations, quantitative and qualitative response ratings were correlated to the objective metrics using first and second order regression analysis.

Correlation quality was used to provide an evidence of the correlation between the objective metrics and the subjective ratings. At the same time, it was used to conclude if driving simulators successfully allow for evaluation, and therefore development, of the vehicle dynamics performance.

MODEL GENERATION AND VALIDATION

The model used for the project was generated using the software CarSim [2] and was built by IDIADA, using as base a multi-body (MBS) model provided by HMC. Previously, the MBS model was validated against measurement data of the following handling manoeuvres:

- Steady State cornering [3]
- Step Steer [4]
- On centre weave [5]

The validation was performed by means of graphical comparison of simulation and measurement results for the most significant physical quantities for vehicle dynamics. As an example, yaw rate and lateral acceleration are compared in Figure 1.

Some of the components of the MBS model were directly exported to the CarSim model. One significant example is the tyre model, which was the same MF-Tyre, based on the Magic Formula of Pacejka. However, in order to make the model capable to run in real time (RT), some elements were simplified. E.g., the suspension characteristics were described by splines obtained from K&C simulations of the MBS model. The validity of the CarSim model was also verified in the handling manoeuvres and compared with the MBS simulation results (Figure 2). The process ensured that the RT model was close enough to the MBS model and to the real vehicle.

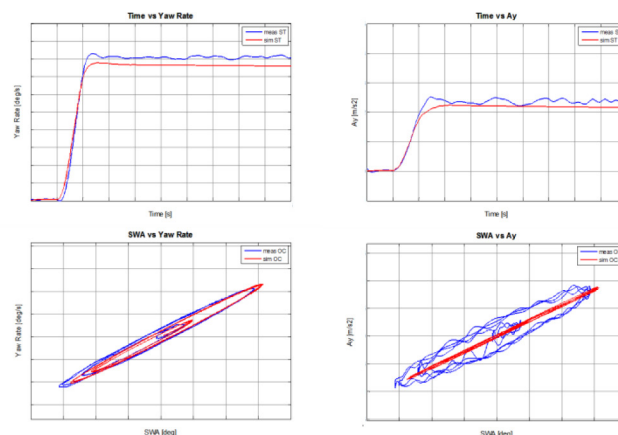


Figure 1. Example of model validation diagrams for step steer (above) and oncentre (below) manoeuvres.

Finally, the RT model was connected with a simplified hardware and with the visual environment through the rFactorPro software. The hardware consisted of a gaming steering wheel and pedal set, while the graphics was made visible by a standard projector. This simplified set-up constituted a simple static simulator that proved to be very useful to check that all the correct signals were exchanged between the physical model and the hardware. Additionally it was used to debug the model in a wide range of driving scenarios, especially considering longitudinal and combined (lateral and longitudinal) dynamics.

The preliminary work on the static simulator made it possible to minimise the time needed to set up the model in the VTI simulator.

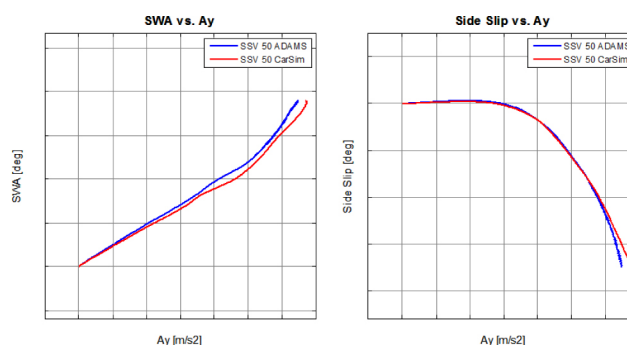


Figure 2. Example of comparison between MBS and CarSim simulation results (Steady State cornering manoeuvre).

MODEL VARIANTS

Once the baseline vehicle was generated and validated, IDIADA and HMC defined the variants to be tested on the VTI simulator. Also in this case, the variants were prepared beforehand in order to minimise the time to switch from one configuration to another.

Each variant represented a modification in the model that affected the dynamics behaviour of the vehicle. In total, 30 model variants were created, which composed of 15 design attributes being individually increased and decreased. The complete list of design attributes is provided in Table 1.

Table 1. List of vehicle variants evaluated on the simulator.

#	Parameter	Higher Variant (change wrt baseline)	Lower Variant (change wrt baseline)
1	Front Bump Steer [deg/mm]	+50%	-50%
2	Rear Roll Steer [deg/deg]	+80%	-80%
3	Front Roll Center Height [mm]	+20 mm	-20 mm
4	Front ARB Stiffness [Nm/deg]	+10%	-10%
5	Rear ARB Stiffness [Nm/deg]	+25%	-10%
6	Front Suspension Rate [N/mm]	+20%	-20%
7	Rear Suspension Rate [N/mm]	+10%	-10%
8	Front Damper [N/m/s]	+50%	-50%
9	Rear Damper [N/m/s]	+50%	-50%
10	Front Static Caster Alignment [deg]	+1.4 deg	-1.6 deg
11	Front Static Toe Alignment [deg]	+0.28 deg	-0.28 deg
12	Front Static Camber Alignment [deg]	+1 deg	-1 deg
13	Steering Ratio (Handwheel to Rack) [-]	-10%	+10%
14	Lateral Tyre Stiffness Front [N/deg]	+15%	-15%
15	Lateral Tyre Stiffness Right [N/deg]	+15%	-15%

DESCRIPTION OF THE VTI DRIVING SIMULATOR

The driving simulator used in the project is the Sim IV of VTI (The Swedish National Road and Transport Research Institute). The Sim IV (Figure 3) has an advanced motion system and is the only one of VTI's simulators to permit significant linear movement along both x and y axes [6].



Figure 3. VTI Sim IV driving simulator.

The simulator has both a passenger car compartment and a truck cab. Because the commercial vehicle considered for the project was a small van, it was decided to use passenger car cockpit.

It has three LCD displays for rear-view mirrors and the visual system comprises 9 projectors and gives the driver a 210-degree forward field of vision. The simulator's imaging system has a camera-based calibration system, making it easy to switch between different driver positions.

SUBJECTIVE EVALUATION ON THE DRIVING SIMULATOR

The subjective evaluation on the driving simulator was performed during 10 working days distributed in two consecutive weeks. Two professional drivers were involved: one from IDIADA and one from HMC. Only the HMC driver had previously driven the real vehicle, while both drivers had the opportunity to try the static simulator.

A list of 18 subjective items to be evaluated for each and every model variant was defined by IDIADA and HMC prior to the visit. The items were divided in three main groups:

- Steering (8 items)
- Handling and stability (9 items)
- Ride (1 item)

While the evaluation of steering and handling was relatively refined, ride could only be evaluated on one kind of input, making it difficult to perform a complete assessment. Additionally the model was not validated for this kind of scenario and it was decided to only provide a global rating for ride comfort and to concentrate the evaluation effort on steering and handling.

During the first three days the drivers had the opportunity to take contact with the simulator, trying out the different tracks available in the rFactorPro environment and tuning the motion cueing setting. The drivers agreed on the procedure to follow during the evaluation, linking the evaluation of each evaluation item to a specific driving scenario, on a specific track. In total 18 driving scenarios were defined; a selection of them is visible in Table 2. The tracks selected for the evaluation were the "2 miles straight" (straight line with multiple lanes and cones for lane changes) and the dynamic platform. The driver's visual interface is visible in Figure 4.

Table 2. Example of the selected driving scenarios.

Subjective evaluation procedure for VTI Driving Simulator			
Manoeuvre	SWA Input	Parameter to evaluate	Virtual Track
Straight ahead	0±	Straight ahead stability Modulation Flat ride	2 miles straight
Lane change	Single	Precision (Intuitiveness) Response Level Rear axle Stability Yaw damping Controllability	
	Double	Precision response (delay and gain) balance rear axle stability yaw damping controllability	
Single input short hold	Small	OC Response Level OC Loose Feel (Deadband)	
	Medium	Torque Level and Linearity Torque Deadband (Steering Friction)	
	Large	Off centre response Linearity Precision	