Virtual Development and Validation Platform for Advanced ADAS and RDE Applications

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ABSTRACT

A number of global drivers, including increasingly stringent safety and emissions standards, and the call for autonomous driving with a connected powertrain, demand that we find new methodologies for vehicle development.
In order to reach development targets, both in terms of timeline and product attributes, and to master the complexity of vehicle variants, a common approach includes extensive usage of advanced simulation methods from the early concept phase all the way to the integration and system tests.For efficient frontloading of expensive prototype-based validation and its replacement with simulation/model-based development a number of challenges needs to be addressed.

Advanced applications in area of ADAS* and RDE* require collaboration of different teams (powertrain, exhaust aftertreatment, thermal management, control function development, power electronics, vehicle dynamics, sensor integration, traffic environment etc.) in order to balance out often conflicting product attributes such as emission vs. driving pleasure, autonomous driving vs. safety etc. For capturing development scenarios in a virtual world, multi-domain simulation models, consisting of sub-models of different level of detail, different performance (even faster than the real time), from different vendors, in different tools and different environments (virtual and real) are necessary.

The development and validation environment must ensure easy, fast and accurate integration and co-simulation of the models, as well as seamless transition from the virtual to the real world, automatized testing and optimization, consistent data handling along the entire process, and still be open for new models and new testing and evaluation techniques.

This work presents and discusses real life examples and application scenarios of a consistent model-based development approach for ADAS applications (Platooning, Predictive and Adaptive Cruise Control etc.) and RDE development and validation (in the office and on the engine testbed), which combines advanced modelling and simulation technologies with lab, testbed and on-road tests.

INTRODUCTION

Many advanced applications in automotive industry are recently focusing on control systems development, especially in the area of energy management, emission control, autonomous driving, to mention just a few. All these control systems have in common that they are not focusing on a single component, but rather on the interaction between different sub-systems integrated in on overall vehicle system. In order to meet development time targets, the concept development of control functions needs to start before the hardware component prototypes are even available. This is only possible by introducing advanced simulation methods for creating a digital twin of the system under development in order to start as early as possible with control function concept development on one side and with the system integration on the other side. The usage of virtual models doesn't stop there; virtual models of the good quality, both in terms of accuracy and performance can also be used for the virtual testing and for mixed software/hardware testing methods such as using environment simulation models on the component testbed in the lab. This process of using simulation for testing earlier in the development process is called the frontloading.

Figure 1: Frontloading in the automotive development process

It is a consensus in the automotive industry that the ambitious development plans in terms of product complexity, number of variants, safety standards, product quality and development time can only be reached by an efficient frontloading in the development process, ergo with a massive usage of virtual prototyping, integration and testing methods.
In an efficient frontloading process, it is essential to re-use simulation models from the concept phase as far as possible in the integration and validation process in order to save resources and ensure compatibility with the previous development stage. For many different applications, simulation models can be re-used across the team and application boundaries. Collaboration of different teams on one virtual system prototype requires clear interfacing standards which can be established by a software framework which focuses on integration of software and hardware systems regardless of the tool of origin (sometimes also called "authoring tools") and the automation of testing procedures.

To empower frontloading in the numerous development and testing projects, AVL has developed an integration and co-simulation platform Model.CONNECT which supports creation of a virtual prototype consisting of heterogeneous software simulation models and their re-usage in HiL (hardware-in-the-loop) and testbed environments. With the industry partners such as BOSCH Germany [1], AVL has implemented this workflow in the past several years across different applications, automotive industries and market segments. In the following chapters, several frontloading use-cases in the area of ADAS and RDE development, based upon co-simulation and HW/SW integration and validation, will be introduces.

1. ABOUT VIRTUAL TESTING

So-called stationary component test which were dominant in the automotive testing process for decades in ICE and controls development are being replaced with more realistic tests related with the real driving. The legislative measures behind that are motivated by a need to limit the impact of the traffic not in an artificial testing surrounding, but in a real driving conditions to the environment (RDE regulations regarding CO2, NOx, particle emissions etc.). Realistic testing conditions are also required everywhere where the safety of the participants in the traffic might be compromised, which is the case in all driver assistance and autonomous driving systems. The problems with all the systems requiring test conditions close to the real-world ones are:

- Expansive setup in an isolated test grounds or on the real roads
- Legal constraints to test in the real traffic
- Large effort to test all possible variants of the system
- Repeatability of the test – it is very hard to anticipate and repeat the situations that arise in the real driving conditions (traffic jams, weather, unexpected events, etc.)

For these use-cases, simulation of the real-world conditions in the office environment or on component testbeds in one possible way to reduce the complexity of the real-world test and even provide the final product validation for certain sub-variants of the system, which was otherwise testing in the real-world conditions. We will elaborate such an approach on example of several cases performed by AVL List GmbH related to RDE and ADAS/AD function development and validation.

2. SIMULATION AIDED DEVELOPMENT OF ADAS/AD FEATURES

Autonomous driving is one of the strongest development drivers in automotive industry in recent years, both in passenger car and in commercial vehicle sector. IF we need to boil down the requirements the OEMs are facing, we can state that time-to-market and safety are the most important ones. Both can be achieved only by an efficient development process which utilizes all the capacities available in the organization and allows for performing sufficient number of reliable tests to guarantee the safety and the quality of the features. Everybody wants to be the first to provide a cool autonomous driving feature on the market, but nobody wants to be the first making headlines about the accidents caused by them. In this early phase of the introduction of the ADAS/AD features, negative publicity regarding safety aspects could be fatal for the organization, causing the loss of the market ground for a long period. The examples shown further will focus on those to criteria, time and safety, on hand of the examples of platooning (commercial vehicles) and ACC (passenger cars)

2.1. *Platooning – easy start in development and optimization*

Truck platooning is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems. [2]

Figure 2: Illustration of platooning on the road

The benefits of platooning are:

- Reduced fuel costs and emissions (due to reduced air-drag friction while driving in the “wind-shadow”)
- Reduced driver engagement
- Increased safety

Here are the most important challenges faced by the development engineers:

- **Fuel savings:** how to evaluate the saving potential of platooning for different vehicles, different loads and routes and different driving modes?
- **Safety**: how to validate the system for risky traffic situations and minimize safety risks?
- **Driver comfort**: platooning requires the presence of the drivers in the subsequent vehicles to monitor the drive and intervene if necessary. They need to feel safe and comfortable. Only a premium feature, taking into account the driver’s engagement can be a success on the market!

Target: The goal of the AVL R&D project presented here (reference) was to establish the model for rapid prototyping of platooning function re-using realistic environment, fuel consumption and air-resistance model and setting up an environment for further optimization regarding safety, fuel consumption and driving quality.

Simulation Model: the following set-up was performed:

- Track and environment modelling were done in an open-source environment SUMO
- Vehicle and fuel consumption model for a long haul diesel engine truck was done in SW package AVL CRUISE, a well-established and validated powertrain modeling commercial tool present in the automotive and commercial vehicle development market for 20 years. Actually, the truck models were already available in the demo example model pool of the tool, so the re-using of the existing models was a big benefit
- Air resistance models were derived from AVL database of stationary maps based upon similar CFD simulation models.
- Platooning control functions were written in a C-code and later on transferred to MATLAB/Simulink and compiled to an FMU (functional-mockup-unit reference) by a tool called fmi.LAB which is included in the Model.CONNECT integration platform.

- For the integration of the whole system (track, environment, velocity profiles, vehicle, driver, controls, air resistance models) and execution of the tests, Model.CONNECT, AVL software platform for co-simulation and integration was used. AVL CRUISE vehicle models and platooning control model were integrated with the dedicated interfaces, while an interface to SUMO was custom made using python code generic interface for user defined integration of new elements of the system.

It is important to mention that the whole set-up, from scratch till the model was setup took less than two weeks!

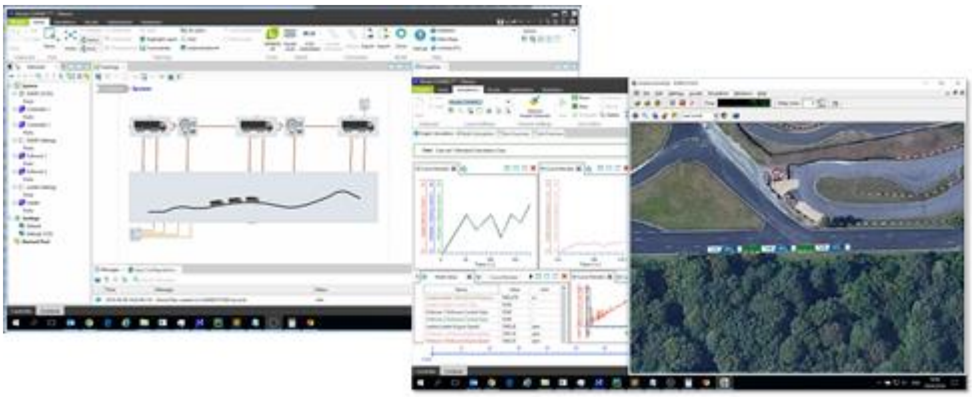

Figure 3: Platooning modeling and simulation environment

Safety criteria and fuel consumption results were influenced by simulation model parameters such as minimum time distance between the vehicles, maximum braking force, etc. The variation of the driving scenario was defined regarding the speed of the leading vehicle and traffic obstacles on the track.

Results: During the evaluation, different level of automatization were performed including also some rad predictive and adoptive features and also different engine operating modes.
Somewhat simplified results show saving potential of 3-10% depending on the complexity of the feature, while preserving minimum safety distance. [3]

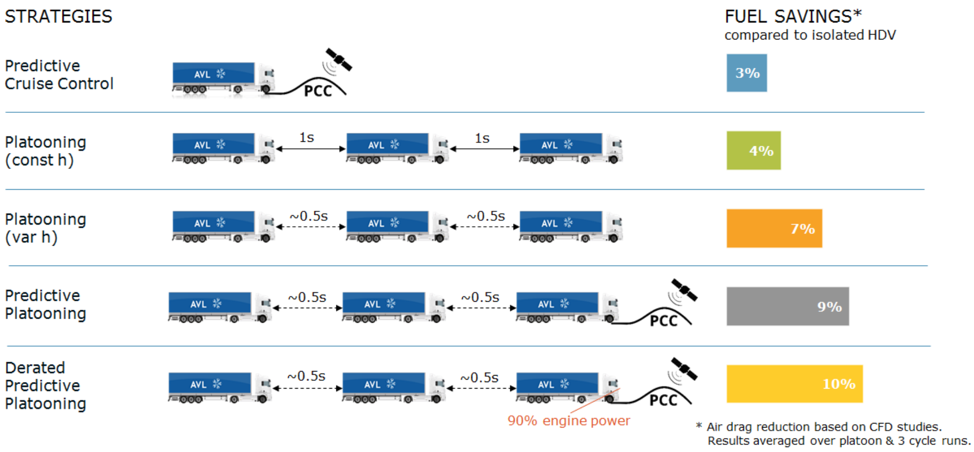

Figure 4: Platooning simulation results overview

Outlook: Once set-up and with basic model validation performed, this model can be easily modified for the further applications. A follow-up project being in preparation will focus on:

A. A detailed analysis of the traffic influence such as cut-in maneuver in front of the leading truck or between the truck. In this case the environment model of SUMO can be easily replaced by specialized traffic simulation tools, but preserving the overall system layout and element connections.
B. In order to evaluate driving quality, the model, as being real-time capable could be brought to a driving simulator with an AVL real-time workstation Testbed.CONNECT and results can be evaluated with AVL DRIVE4ADAS, a specialized software package for objective evaluation of subjective driving perception, for which there is also a dedicated plug-in component in the Model.CONNECT platform.
C. Optimization of a more complex system in regard to driving quality and testing of critical traffic scenario can be performed by parallel simulation execution on a HPC (high performance computing cluster) using the JMS (Job Management System) built-in in the Model.CONNECT platform.

The setup of the possible further investigation, for which the existing model can easily be re-used and extended is showed on the following picture.

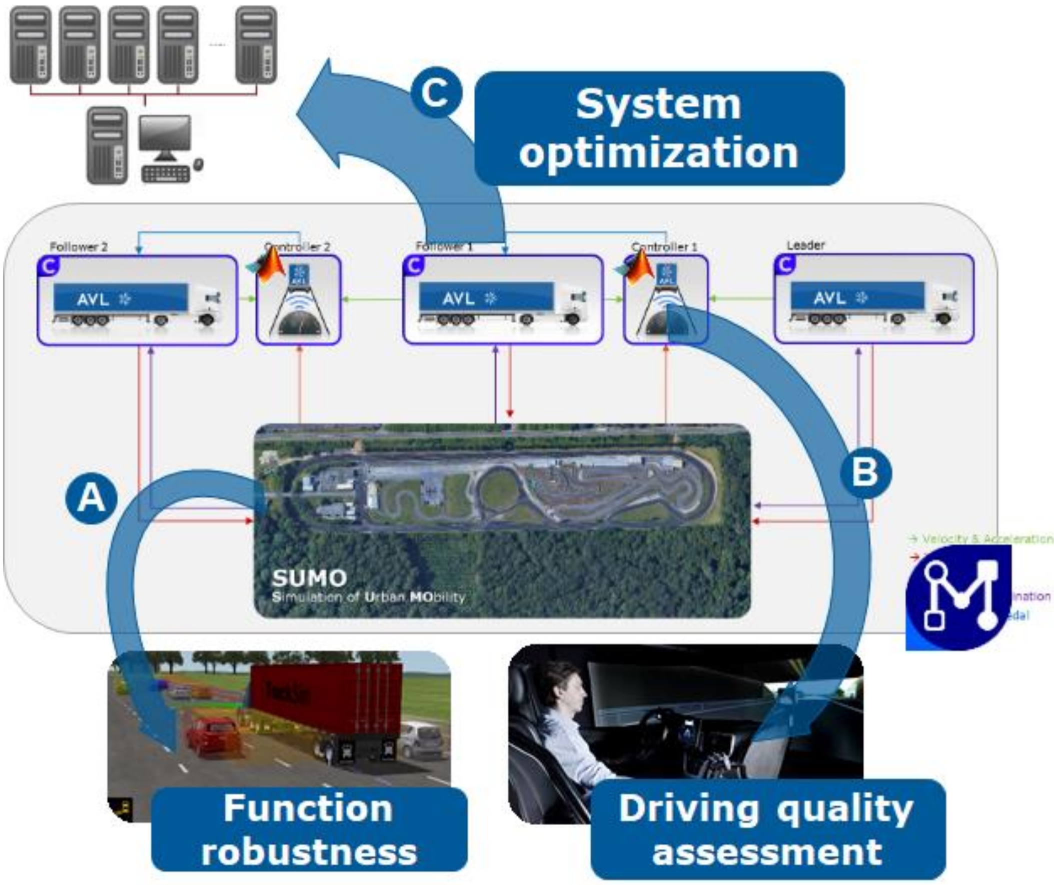

Figure 5: Platooning simulation system evolution and optimization

Summary: Platooning is an advanced driver assistance function which requires analysis of different system aspects. A complex development model set-up can be easily performed in Model.CONNECT using existing or customized component interfaces as well as optimization framework support. Simulation setup allows for various kinds of virtual safety tests and system optimization regarding fuel saving potential and driving quality in realistic driving conditions.

2.2. Adaptive Cruise Control – co-simulation in the cloud

Adaptive cruise control (ACC) is an available cruise control system for road vehicles that automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead.

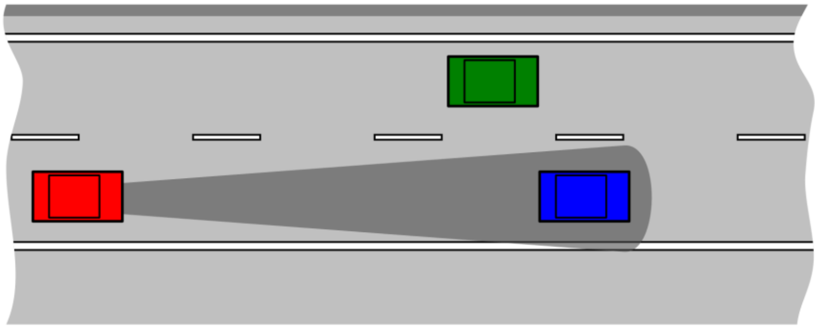

Figure 6: ACC (Adaptive Cruise Control) illustration [4]

It is one of the first features to be released by OEMs since it brings an immediate benefit on driver relief and has a wide acceptance at the customers due to already existing cruise control unit in most of the modern cars.

Predictive Adaptive Cruise Control is an addition to the "traditional" ACC feature, mostly used as a term for commercial application, where in addition to the influence of the traffic ahead, also the geometry of the road is taken into account in order to adopt cruising speed within certain limits in order to minimize braking, maximize energy recuperation and save fuel in general. [5].

Target: The goal of the AVL R&D project, the outcome of which is presented here, was the reduction of critical safety scenarios (3rd car cut-in maneuver) using active DOE approach and virtual validation in the cloud.

Testing Scenario: Here is a definition of a simplified 3rd party (TSV1 – test simulation vehicle 1) cut-in maneuver interfering with ACC feature of the vehicle under test (VUT), following the VTS2.

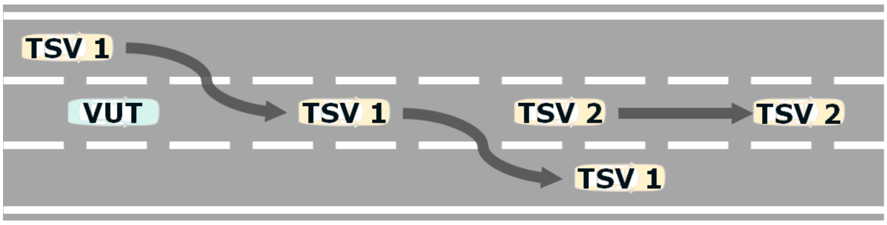

Figure 7: ACC (Adaptive Cruise Control) illustration

For the critical scenario test, the following variables were defined:

- VUT velocity

- VTS1 velocity
- VTS2 velocity#
- VTS1 cut-in time
- VTS1 cut-out time

For the simplified safety test, the target value of the “distance to crash” was taken. **Simulation Model**: The model was set in Model.CONNECT integration environment, with AVL VSM vehicle models and VTD Vires traffic and environment model, controls being written as a user defined C-Code.

Full factorial number of possible scenario variants within reasonable speed/time limits and increments would require 660 years of simulation on a single core stat-of-the-art computing device.

In order to reduce this time to practical level, two actions were undertaken:

- Differentiation between uncritical and potentially critical safety scenarios using an active DOE preparation method in a simplified environment, thus reducing the number of potential test cases for the more detailed investigation
- Detailed investigation of the potentially critical scenarios with more detailed simulation models and reducing overall simulation time preforming large-scale parallel computation in the cloud environment

Results: Active DOE process was conducted with a AVL CAMEO, a software tool specialized in performing DOE, optimization and creation of surrogate models based upon simulation or measurement results. The main feature of the active DOE process of AVL CAMEO is that it narrows down the space of potential use cases to the ones complying with predefined result band with after each new simulation. AVL CAMOE is orchestrating the simulation defined in Model.CONNECT through a standardized scripting interface which can be utilized also by other specialized commercial optimization tools such as ModeFRONTIER, iSIGHT, Optimus etc. More information about active DOE and connection to simulation can be found in product manuals of AVL CAMEO and Model.CONNECT. (reference)
The outcome of the active DOE design was a reduction of potential parameter variation space by facto of 40 with 2 simulation days on a 4-core office workstation.

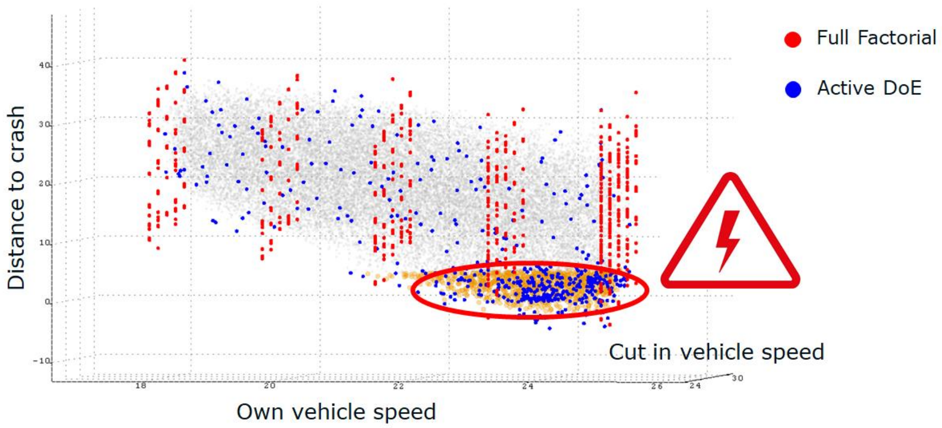

Figure 8: Reduction of the full factorial design space by an active DOE method [6]

A reduced set of parameter variation was simulated in the second step in a commercial cloud environment as a scalable docker-container based simulation service. Co-simulation of dockerized models is an extension of standard Model.CONNECT job management system designed for co-simulation on the local multi-core environment, especially adopted for different cloud environments and has already been performed in several model set-ups on several different cloud environments. [7] Below is a schematic overview of the dockerized co-simulation Model.CONNECT solution in the cloud:

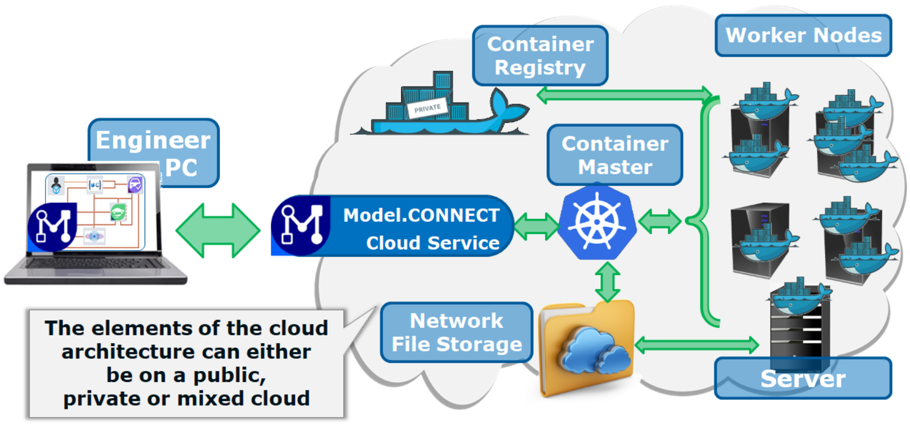

Figure 9: Docker-container based cloud computing set-up

One important aspect in the evaluation of critical scenarios is the accuracy of the co-simulation. Data exchange in a co-simulation of models running in general case in different time steps, either fix or variable, requires interpolation and extrapolation of the signals which necessarily brings inaccuracy and energy loss in the system [8]. Different interpolation techniques in a closed loop co-simulation lead to signal delay and oscillations which can be improved by reducing the synchronization time step. This, however lead to worse performance and longer overall simulation time. Model.CONNECT co-simulation algorithm applies a patented co-simulation error elimination algorithm called NEPCE (Near Energy Preserving Connection Element) which compensates numeric energy losses in the system, stabilizes the performance and guarantees accurate result of the simulation. This is very important in the analysis of the “distance to crash” where co-simulation between controls, vehicle and environment models can otherwise lead to the inaccuracy of the braking way of up to 2 m, which again makes invalid the evaluation if the simulation test was successful or not.

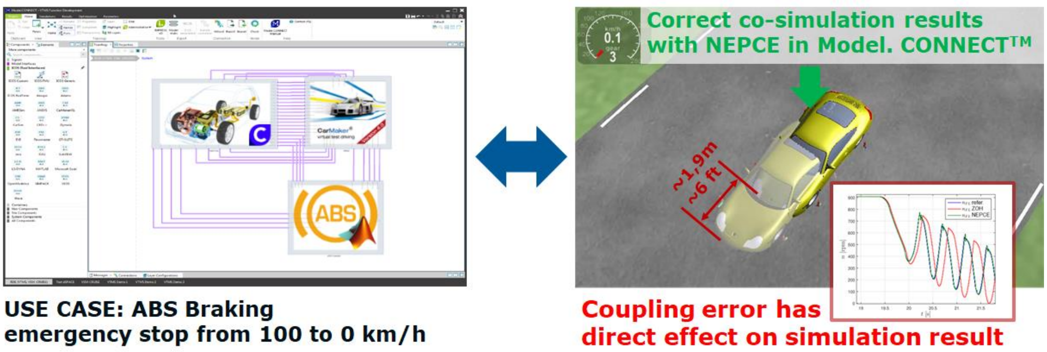

Figure 9: Influence of co-simulation error on the result accuracy

Depending on the computing power available, which can be scaled up significantly in a short period of time, it was able to achieve overall computing time reduction by a factor of 1000. Combining these 2 techniques, the full space of scenario variants was analyzed with high reliability rate within one week, which is widely acceptable time frame for a single ADAS/AD feature software validation.

Outlook: Out of the virtual validation, a minimized set of crash-critical scenarios can be derived, which is later a subject of testbed and on-road tests.

Summary: Adaptive Cruise Control is one of the ADAS/AD features expected to be among the first to be introduced on the fleet level. A large-scale variety of different scenarios and boundary conditions can not be all performed on the road due to time and cost limits. A successful reduction of the uncritical tests' variants can be achieved by an active DOE approach in a simulation environment, while further analysis of critical scenarios can be accelerated by parallel c-simulation in the cloud based upon docker container technologies. For the reliability of the results, essential is the co-simulation error elimination technique NEPCE as a part of Model.CONNECT co-simulation and synchronization algorithm. Strongly reduced remaining scenario variants with near-critical outcome can be further used as a setup for testbed and road tests.

3. SIMULATION AIDED DEVELOPMENTF FOR RDE

For a long time, certification of passenger cars was based upon clearly defined and reproducible test cycles such as NEDC (New European Driving Cycle) in Europe. These cycles are continuously being replaced by more dynamic international standardized cycles such as WLTC (Worldwide Harmonized Light Duty Test cycle). Not only due to recent scandals, but also due to the political environmental initiatives from around the world, a new approach for certification has been developed which ensures more realistic test coverage of the vehicle usage and is covered by RDE (Real Driving Emissions) tests.

RDE test foresee a certification procedure on the chassis dyno testbeds and in addition to that a road test in RDE compliant conditions. Road test conditions must cope with a broader band of environmental conditions (e.g. temperature range from -7 to +40 °C and elevation of up to 1300 m), different road profiles (City, Countryside, Highway) and a number of other constrains related with speed limits and driving dynamics. An RDE test is basically random and enforces testing of entire engine operating range [9].

RDE compliance is a huge challenge for a vehicle development process. Alone for costs reasons, it is not realistic to perform all the development tests on the real roads with all the uncertainties. It is unimaginable, due to the stochastic nature of the test, to run so many unreproducible test variations to statistically ensure test compliance with sufficient reliability. We recognize the same development boundary conditions as in ADAS/AD function development, because the environment conditions for that are also hardly reproducible and highly random. The only way to cope with these challenges is by reducing the number of real hardware test (on engine testbed, chassis dyno and on the road) with appropriate virtual testing. We'll introduce 2 examples of virtualized RDE testing performed recently by AVL, one internal R&D effort in purely virtual environment, validated with the real road test measurement results, and the other one, in collaboration with industry partners, dealing with RDE complaint drivetrain and environment simulation on AVL PUMA engine testbed.

3.1. ***RDE modeling and validation in the office***

The first step in the virtualization of the RDE compliant development process is to make sure that high quality simulation models are available. Validation of the models was performed using road measurement obtained by a PEMS (Portable Emission Measurement Station) AVL M.O.V.E as shown on the following picture.

Target: The goal of this AVL R&D project was to establish a simulation tool chain capable of reproducing RDE complaint virtual driving set-up.

Simulation model: Requirement on the simulation models are:

- Realistic physical emission and aftertreatment model in a broad operating range

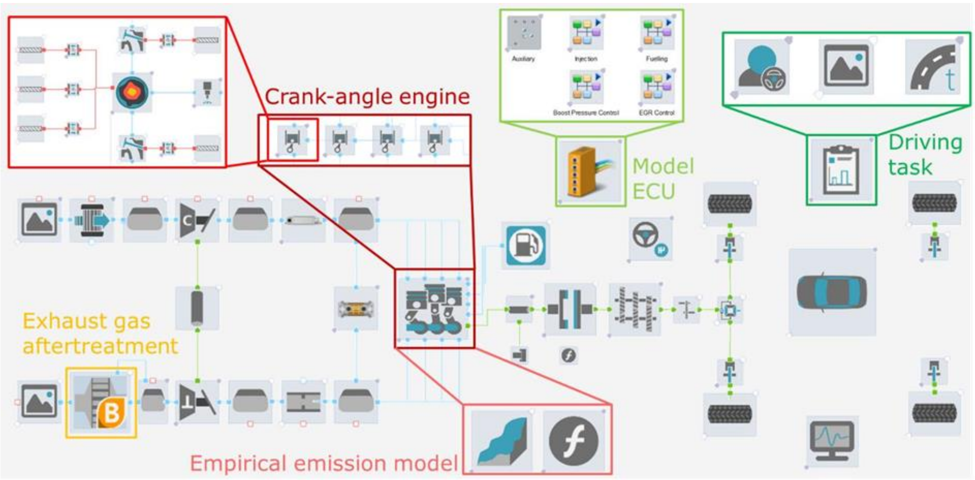

Figure 10: Powertrain simulation model including engine and aftertreatment [10]

- Realistic dynamic vehicle models which can also be used for driving performance and quality assessment so that the trade of between emissions and driving quality can be analyzed at the same time
- Real time capability of the model, so that it can be used for validation of control function unit prototype and virtual calibration
- Built-in RDE compliant virtual route and velocity profile generation tool, for checking the robustness of the model by multiple randomized testing procedures.

Such a model was achieved using the following models:

- AVL CRUISE M for powertrain, engine and aftertreatment model. In addition to the transmission system, AVL CRUISE M Engine delivers a real-time capable crank-angle resolved physical model of the emission and aftertreatment
- AVL VSM for real time capable vehicle dynamics model with sufficient accuracy for driving performance and quality evaluation
- AVL DRIVE was used for online driving performance and quality assessment
- AVL RDE Generator was used for generation of RDE compliant test routes and velocity profiles

- Model.CONNECT was used for putting all the partial models together while ensuring optimal accuracy and performance in a multi-core computing environment

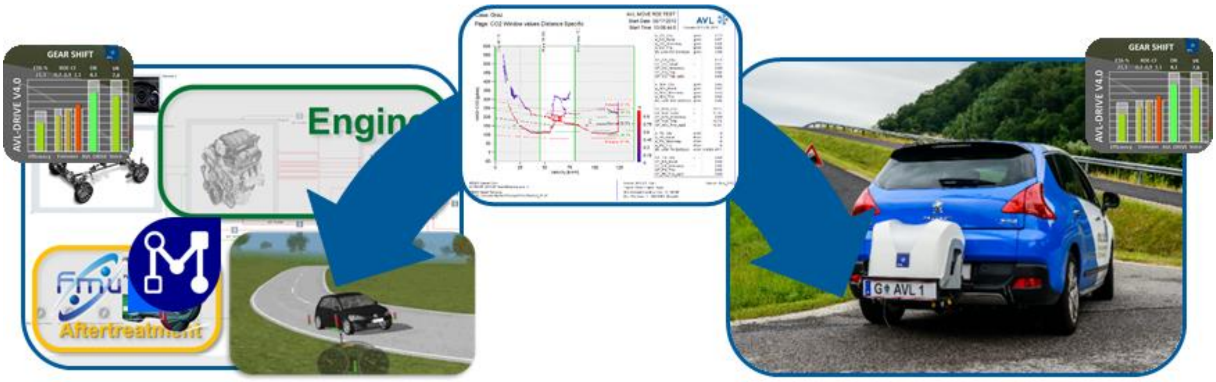

Figure 11: Validation of RDE simulation model with AVL M.O.V.E measurement data

Results: Validation of the model with measurement data in terms of emission, velocity profile, driving quality rating and RT performance was performed and with the minor model parameter tuning was achieved in a sufficient quality. [10]

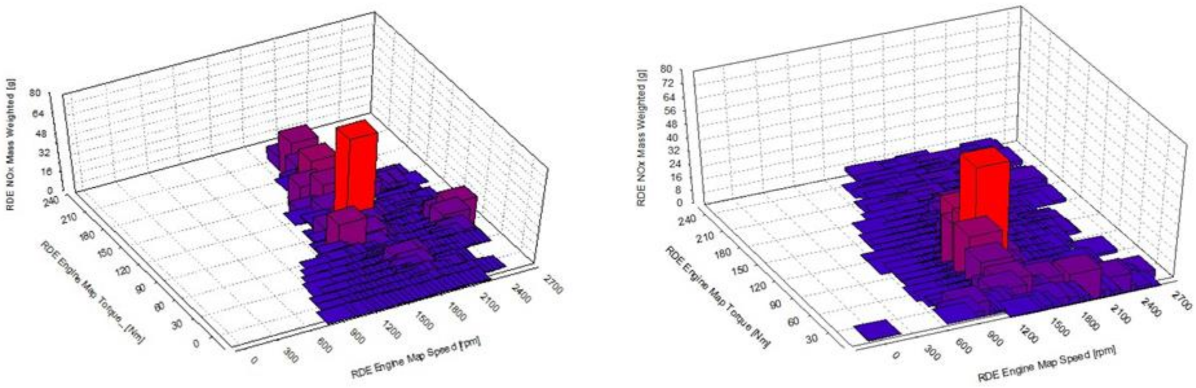

Figure 12: Weighted RDE NOx map; Comparison simulation (left) vs. Measurement (right)

Outlook: Due to its accuracy, high predicting capability, physical parametrization and real-time performance, this model can be taken as a basis for virtual ECU control function development and calibration.

Summary: combining high quality simulation models for combustion, aftertreatment, driveline, vehicle dynamics, ECU and driving quality assessment, within the Model.CONNECT simulation environment for ensuring optimal performance and accuracy of the whole system, it is possible to reproduce the quality of the road measurement data. Validation on component level and on the system, level shows good predicting capacity of the model in a wider operating range in different RDE compliant virtual test procedures. Virtual RDE testing of the different system variant reduces significantly the number of hardware and on-road test necessary to achieve RDE targets. Real-time performance of the model qualifies it for virtual ECU function development and pre-calibration in order to reach RDE certification criteria in different environment conditions.

3.2. ***RDE simulation on Engine Testbed***

Next step in RDE testing process is performance RDE compliance test on engine testbed. The test in this environment provide an additional level of certainty and are performed on a reduced number of test scenarios in order to validate pure virtual simulation test and further reduce the number of test runs necessary to be performed in the most expensive environment – on the real road.

Target: The goal of this AVL R&D project was to establish a semi-virtual methodology for performing RDE test on engine testbed. The first step was to validate the basic purely virtual model, not necessarily RT capable and then to run engine-complementary part of the system model (everything except the engine) as a co-simulation environment on the engine testbed.

Simulation Model: starting simulation model in office was set-up validated in a similar as in the previous chapter but using somewhat different simulation tool-chain.

- Engine model in GT power (not Real-Time)
- Vehicle and environment model, including RDE test input in IPG CarMaker
- Driveline in AVL CRUISE
- Virtual ECU in MATLAB/Simulink
- Integration and co-simulation in Model.CONNECT

It is worth mentioning that the co-simulation set-up in Model.CONNECT was equivalent and to large extent equal to the set-up from the previous chapter, only the content of the sub-system model and the authoring tool was exchanged. Test execution, validation methodology and connection configuration were the same.

Methodology: The model in its virtual form was found sufficiently accurate within the operating range, but not real-time capable due to the 1D engine model, so the first step was to test real time capability of the residual system model, where engine was replaced by a simple map-based 0D model. After real-time capability of the residual model was established, map-based engine model was replaced by a so-called Testbed.CONNECT interface model which represents the bridge from the PC simulation model ton the real hardware (engine!) running on the testbed. Testbed.CONNECT interface in Model.CONNECT connects the office simulation model to the real-time workstation Testbed.CONNECT where the connection to the engine testbed automation system AVL PUMA was configured. The transition from the pure virtual office system model to the system, simulation model on the engine testbed is shown on the following picture.

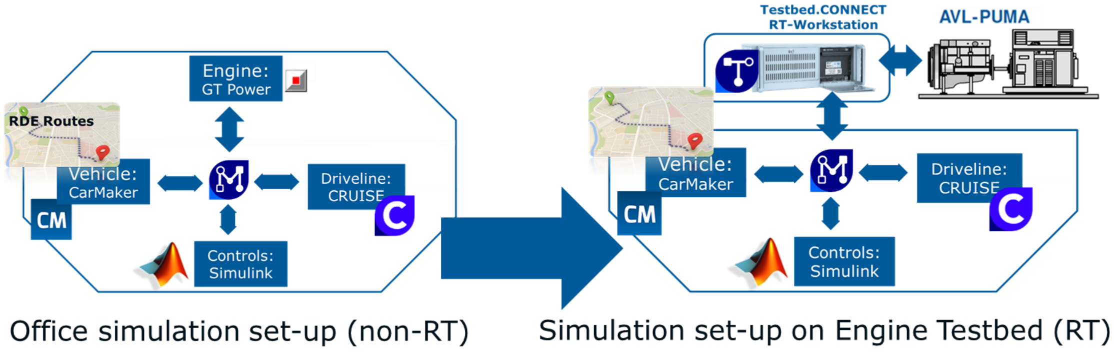

Figure 13: Transition of office RDE simulation model to engine testbed environment

Testbed.CONNECT interface element is a special one. It integrates a patented technology ACORTA (Advanced Co-Simulation Methods for Real-Time Application) which synchronizes RT and non-RT parts of the system, compensated signal latency in the system and cancels the noise in the system, ensuring smooth and stable co-simulation without real-time violation. In case of real-time violation in the system, ACORTA [12] either interpolates the missing signals until certain level or issues an error and safely stops the system.

Results: running of the residual simulation model (exactly the same as the original complete model, but without the engine model) was successful, with a limited customization and validation effort. The first results have shown good correlation with the pure simulation results-

Outlook: the set-up on the engine testbed is a step forward towards the real test. This methodology is proven to be useful in addition to pure simulation test, for certain variants of the system under test and as an intermediate step toward final on-road tests.

Summary: The combination of virtual test and semi-virtual test on engine testbed can significantly reduce development and testing costs for reaching RDE targets, even considering the costs invested in creation/validation of the simulation version of the system and establishment of the connection between simulation and engine testbed.

References should be numbered sequentially and listed in the REFERENCES section at the end of the paper. References should be numbered in order of appearance in the text and placed in brackets (i.e. [1]). In the example below, references [1], [2] and [3], respectively, refer to books, articles published in periodicals and electronic documents.

CONCLUSION

- The effort for development and testing of the tasks related with real world operating conditions, such as RDE and ADAS/AD controls, can be significantly reduced by using advanced simulation methods both in concept layout, function development, system integration and testing phase.
- Development and testing efficiency can be further improved by reusing existing simulation models and aligning the related development and testing teams.
- The key element in this process is an open co-simulation and integration platform, which can combine simulation models from different tools, but also connect them to the hardware test systems in a stable and accurate manner
- Pure simulation results as well as the combined results of the simulation on test systems show excellent degree of matching with the test results of the referent pure hardware systems used for different ADAS/AD and RDE development tasks.
- Presented cases show that it is possible to frontload real-word testing and perform it in a cheaper virtual and semi-virtual environment while fulfilling development goals in a shorter time with improved product quality.

REFERENCES

[1] BOUMANS, Marcus; GALLET, Ana; SCHULMEISTER, Ulrich. XDomain simulation as backbone for vehicle system engineering. Presented inGraz at "10th Graz Symposium Virtual Vehicle", June 27-28th, 2017

[2] ACEA - European Automobile Manufacturers Association web-site https://www.acea.be/industry-topics/tag/category/truck-platooning, May 4th, 2018

[3] TERRES, Simon. Development of ADAS functions within a vehicle and traffic co-simulation environment with focus on energy efficiency. Technische Universität Keiserslautern, Master Thesis, May 22nd 2018

[4] Wikipedia web-site: Adaptive Cruise Control , https://en.wikipedia.org/wiki/Adaptive_cruise_control

[5] JONES, Stephen; WIKSTRÖM, Niklas; FERREIRA PARRILLA, Alejandro; PATIL,Rohan; KURAL, Emre; MASSONER, Alexander, GRAUERS, Andres. Energy-Efficient Cooperative Adaptive Cruise Control Strategy using V2I, PResented in Paris, at IEE CoDIT Paris France, April 24th 2019

[6] DIDCOCK, Nico; IVARSON, Mats; LYONS, Gavin; RAVI, Abhishek; VITALE, Gianluca. HPC, artificial intelligence, virtualization. Presented in Stuttgart, at Automotive Testing Expo Europe 2019, May 21, 2019

[7] LEITNER, Andrea; CLEMENT, Philipp; HOLZINGER, Jürgen; VÖGL Rainer; ZEHETNER, Josef. Cloud Based Validation And Optimization Of Highly Automated Vehicles. Presented in Graz at "11th Graz Symposium Virtual Vehicle", May 15th, 2018

[8] BENEDIKT, Martin; DRENTH, Edo, Relaxing Stiff System Integration by Smoothing Techniques for Non-Iterative Co-Simulation. Proceedings of IUTAM Symposium on Solver-Coupling and Co-Simulation, pp.1-25, January 2019, DOI: 10.1007/978-3-030-14883-6_1

[9] KRAMMER, Johann. Echtzeit Simulation für RDE System Entwicklung und Kalibrierung. Presented iin Stuttgart at ATZ Konferenz: Ladungswechsel und Emissionierung, 11. MTZ-Fachtagung | October 23-24th 2018, Stuttgart, Germany

[10] KRAMMER, Johann. Engine calibration under Real-Driving Emissions require modelbased development support. Presented in Yokohama, Japan at 2018 JSAE Annual Congress, May 25th, 2018

[11] ROTHBART, Klaus. Testing of Emissions-Relevant Driving Cycles on an Engine Test Bed. Presented in Gothenburg at Annual Conference Product Development in Motion 2019, November 29th, Gothenburg, Sweden.

[12] GENSER, Simon; BENEDIKT, Martin. Extension of the Model-based Pre-step Stabilization Method for Non-iterative Co-simulation - Including Direct-feedthrough, In Proceedings of 8th International Conference on Simulation and Modeling Methodologies, Technologies and Applications - Volume 1: SIMULTECH, ISBN 978-989-758-323-0, pages 223-231, 2018.