Vehicle Model Factory for an efficient and correlated virtual ADAS/AD validation

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Abstract: To increase trust in simulation, the virtual validation of automated driving functions requires maximum model quality along with a transparent proof of the correlation to reality. This paper presents a novel solution for (a) accelerating this model build-up and (b) assessing model correlation in an automated way. To this end, an automated data processing method was developed, where the correlation between simulation and real-world is analyzed and visualized for two different data layers: (1) overall vehicle dynamics and (2) ADAS system behavior & actuation. A specific set of key performance indicators (KPIs) is used for each layer. The presented method is demonstrated for an Automated Emergency Brake (AEB) use case, and the results underline the importance of a validated digital twin on the complete vehicle system level.

1 Introduction and customer challenge

ADAS (Advanced Driving Assistance Systems) and AD (Automated Driving) simulation has a wide field of applications from deriving basic specifications in the system engineering phase, software bug-fixing and testing during components or system development, to complete vehicle and traffic scenario validation close to start of production, or even in the aftersales for validation of functions before they will be updated. Requirements and challenges are specific and different across these application fields. Hence, this article focuses on the virtual validation of ADAS features, where the dynamic vehicle behaviour has highest relevance, and the correlation quality of simulation decides about meaningful usage.

With recent legislative requirements for OEMs, e.g. [EUR19, UNI21], simulation has become essential for testing. It is necessary to not only use trustworthy simulation models but also to approve their quality and correlation to reality [DUE21, SCH22]. This is especially important for the certification of ADAS/AD functions in multiple vehicle variants, supplemented by simulation. Figure 1 illustrates an Automated Emergency Braking (AEB) simulation and the difference between a low-fidelity vehicle dynamics model and a high-fidelity model, which was correlated with real-world measurements. There is a clear difference in braking distance, which underlines that a proven quality of vehicle dynamics is essential for virtual validation. For example, validated suspension models will affect the virtual sensor output, such as radar, lidar or camera, in a realistic manner, including e.g. pitching and rolling motion of the chassis. Accurate tire models will result in realistic tire-surface interaction, especially on rough, non-even surfaces.

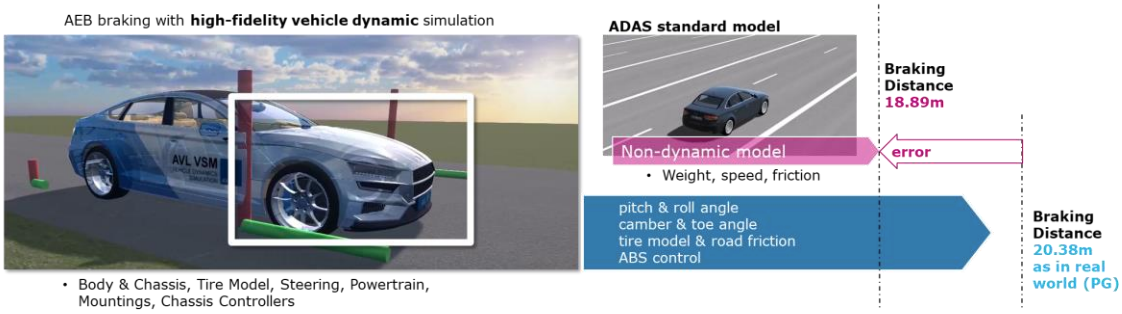


Figure 1: Effect of accurate vehicle dynamics on simulation results, for the example of an AEB simulation

Depending on the application, system simulation engineers may spend up to 60% of their working time on building up validated vehicle and component models. Significant time is often spent by gathering input data and checking its plausibility, robustness and correctness. In addition, simulation models are often built up manually by conducting procedures to ensure model validity e.g. by manually correlating simulation results to measurement data and comparing characteristic behaviors. This is traditionally an iterative and relatively time-consuming process until a vehicle model can be released for the actual development task (see Figure 2). Beside this effort, time- and cost-intensive component measurements (e.g. on a tire test rig) might be necessary to achieve the required accuracy quality on vehicle-level.

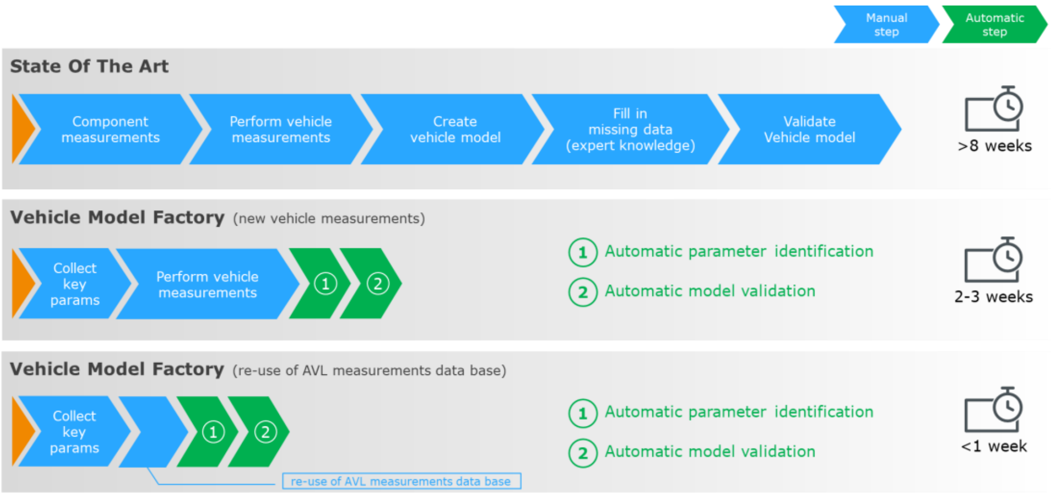


Figure 2: Time savings due to automatic vehicle model build-up

In certain situations, validation engineers do not have access to proper component data for the modelling process. Either component measurement data is not available at all or models cannot be generated because of any other reason. To solve this disadvantage, AVL provides a novel approach that aids the identification of system level behavior to build up and validate system simulation models in a more efficient and faster way. With the Vehicle Model Factory (VMF), up to 80% of modelling time can be saved due to automated processes for model build-up.

2 Methodology: Vehicle Model Factory for automatic model build-up

The VMF approach requires three main inputs. Firstly, a minimal amount of key vehicle parameters, which can be obtained by OEM datasheets or workshop measurements (e.g.: vehicle corner weights, wheelbase, track width, tire dimensions, etc.). Secondly, the test vehicle must be equipped with a minimum set of measurement- and recording equipment (CAN bus logger, inertial measurement unit, accelerometer and GPS). This instrumentation does not require any structural modifications to the vehicle. Finally, a set of predefined maneuvers must be performed on a test track. Usually, equipping the vehicle and performing the tests does not take more than 2-3 days. The workflow for the VMF is shown in Figure 3.

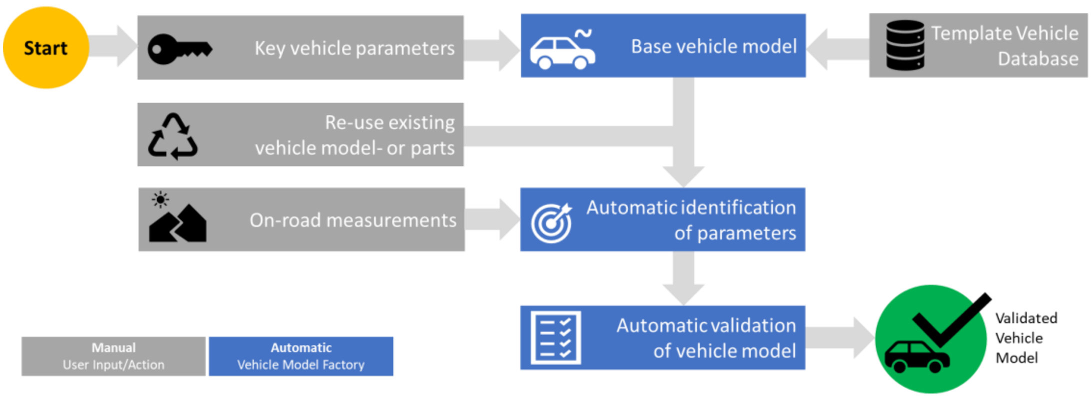


Figure 3: Vehicle Model Factory workflow

VMF is fully integrated into AVL VSM™, AVL’s vehicle simulation tool [AVL21], and wizards guide the user through the identification- and validation process from start to finish. The wizards are divided by parameter groups, so that only the desired or necessary parts need to be performed. Currently available parameter groups are driving resistance (driving resistance coefficients), vehicle weight distribution (center-of-gravity position), suspension (dynamic roll- and pitch behavior) and powertrain (motor/engine torque- and pedal-maps, gearbox- and total ratios). Parameter groups for future releases are high-voltage battery (open circuit voltage, inner resistance, capacity, SOC/capacity), tire parameters (longitudinal Paceijka- and dynamic parameters), automatic gearbox shift patterns/scheduling, braking system (distribution, capability) and steering system (e.g. steering ratio).

In a first step, a suitable template vehicle model is selected by the user. AVL VSM™ provides a library of template vehicle models for this purpose. Models from various vehicle classes and segments, such as compact, luxury, sports or SUV vehicles as well as different powertrain- and driveline configurations, such as front-, rear- or all-wheel-drive and combustion, hybrid and pure electric vehicles are included. After that, the key vehicle parameters are entered and, optionally, more detailed component parameters may be added. Already available vehicle models, or parts thereof, can also be imported and reused as a basis for VMF.

In the next step, the required data from on-road measurements is selected and the necessary channels are mapped. It depends on the parameter group, which maneuvers and measurements are necessary for identification and validation

The identification is fully automated. After the parameters are identified, they are inserted into the AVL VSM™ model and a simulation for validation is performed automatically in the background. Finally, the user can review the simulation results, as they are shown/plotted against the on-road measurements.

3 Methodology: Assessment of quality proof for ADAS/AD

As described above, the VMF is a method to efficiently create a validated digital vehicle twin from existing measurements. This means that the vehicle dynamics are accurately modelled. However, for ADAS/AD testing, additional data layers must be considered, namely the ADAS/AD system behavior. This includes the actuation of the controller, and ultimately, how the vehicle dynamics react to this actuation.

Figure 4 shows the workflow for the model quality assessment based on KPIs. The initial test split between measurement and simulation is defined by the test plan. However, a proper split is hard to define in advance, before knowing the quality of the simulation models. Therefore, the presented method includes a decision-making function that feeds back the results of the correlation analysis and decides whether and which additional measurements or simulations are needed to improve the quality. As soon as every KPI meets the quality threshold, e.g. 95% accuracy, the simulation can be upscaled to complete the remaining tests and vehicle variants, without the need for any more measurements. For the example of an AEB function verification, the simulation variants can include different weight distributions, types of tires (e.g. summer, winter), surface friction etc. The resulting test report, along with the so-called model quality matrix, can be used for certification bodies to provide proof of simulation accuracy.

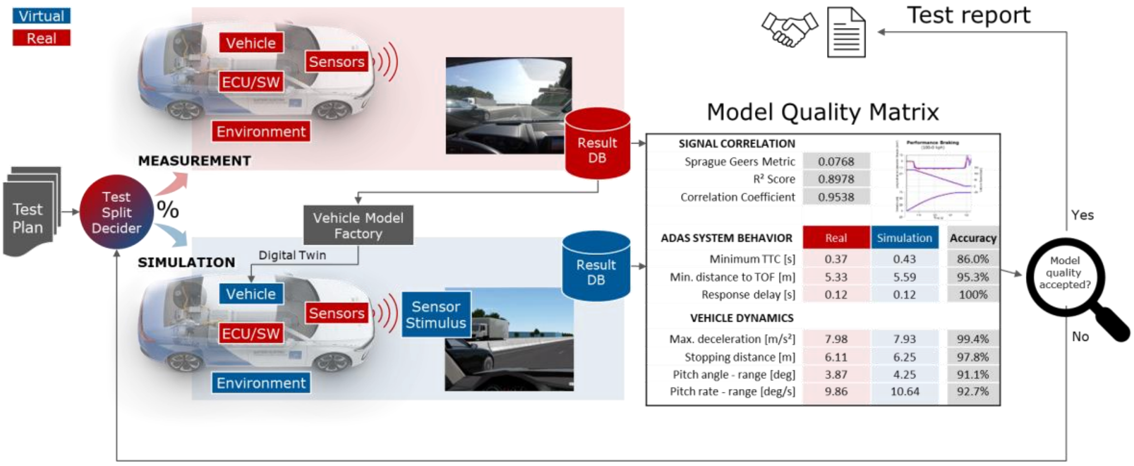
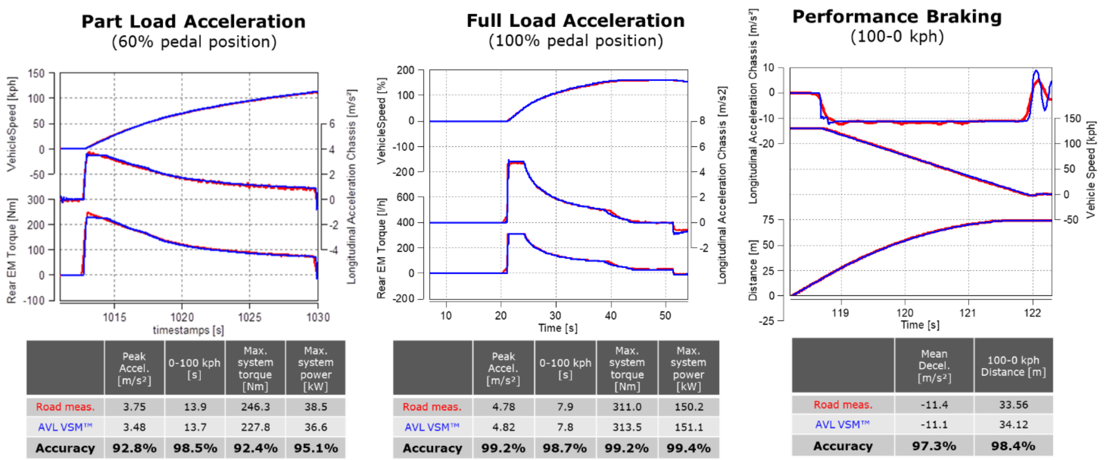


Figure 4: Workflow for model quality assessment for the example of AEB, as input for the test split between measurement and simulation (applied to Hardware-in-the-Loop with sensor stimulation)

4 Vehicle dynamics correlation results for Volkswagen ID.3

Figure 4 showed the model quality matrix used for AEB-specific KPIs, which are used for the ADAS/AD test split decider. However, usually a complete vehicle model validation procedure includes more parameters in terms of vehicle dynamics than just braking. To gather real data for the VMF, on-road measurements with a Volkswagen ID.3 were performed and a vehicle model was created. Performance results for multiple acceleration and deceleration manoeuvres are shown in Figure 6. Overall, the method achieved a model accuracy between 92% and 99%, which can be seen as satisfactory.



	Peak Accel. [m/s²]	0-100 kph [s]	Max. system torque [Nm]	Max. system power [kW]
Road meas.	3.75	13.9	246.3	38.5
AVL VSM™	3.48	13.7	227.8	36.6
Accuracy	92.8%	98.5%	92.4%	95.1%

	Peak Accel. [m/s²]	0-100 kph [s]	Max. system torque [Nm]	Max. system power [kW]
Road meas.	4.78	7.9	311.0	150.2
AVL VSM™	4.82	7.8	313.5	151.1
Accuracy	99.2%	98.7%	99.2%	99.4%

	Mean Decel. [m/s²]	100-0 kph Distance [m]
Road meas.	-11.4	33.56
AVL VSM™	-11.1	34.12
Accuracy	97.3%	98.4%

Figure 5: Full load / Part load acceleration and braking correlation for Volkswagen ID.3

5 Considerations for AEB system behaviour correlation

ADAS features operate purely on basis of software programmes. Complex decision making and trajectory planning algorithm up to machine-learned perception cannot be seriously modelled by reverse-engineering approaches. Hence, it is assumed that certification organisations do only accept modelled AEB controllers, which are provided and approved by the original suppliers and/or OEMs. Since AEB calibration parameters are usually set specifically across vehicle variants and do significantly impact braking behaviour they must be considered accordingly.

For these reasons the AVL approach connects high fidelity dynamic vehicle models with feature-owner approved ADAS simulation models, e.g. provided as black-box modules.

Together with the variant specific calibration parameters, full-factorial validation of legislation conformity can be performed over all possible vehicle configurations, defined ODD range and aging impacts during vehicle lifetime. Product liability risk is minimized with the full-factorial approach at the expense of high computing power and processing time. Therefore, given constraints, dependent on OEM strategy, are considered and well applicable in this validation approach.

6 Conclusion

Building up and validating functional virtual vehicle prototypes is one of the most time-consuming tasks for validation engineers. Often, the required data from component measurements is not readily available. This results in even higher lead times and costs for the model generation. The AVL Vehicle Model Factory makes use of on-road vehicle measurement data. Hence, no expensive and time-consuming component measurements must be carried out. Using benchmark data out of AVLs vehicle benchmark database, which includes on-road measurement data from more than 300 vehicles from the global market, segments and propulsion concepts allows to significantly reduce lead times and costs. Ultimately, this allows to save up to 60% of vehicle model-build up and validation time.

For ADAS/AD validation, the Vehicle Model Factory provides an effective tool to create digital vehicle twins, which are used for a model quality assessment in terms of vehicle dynamics behaviour and ADAS function behaviour. The KPI-based model correlation analysis is used as an input to decide about the split between real-world testing and simulation.

7 References

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