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Attribute-based Development of Advanced Driver Assistance Systems

Advanced driver assistance systems and automated driving are a megatrend in the automotive industry. The following questions arise: Will vehicle manufacturers still be able to differentiate themselves brand-specifically in the future or will all vehicles be perceived as the same when being driven? How can a brand DNA be implemented and how to achieve the transfer from fun-to-drive to fun-to-be-driven? In order to provide solutions, clear driving characteristic goals – in front of the customer – must be defined and the requirements for vehicle systems and components shall be derived from this. But what are driving characteristics in the context of assisted and automated driving and how can those specifically be realized in development? Porsche has addressed this challenge together with the University of Applied Sciences Kempten and MdynamiX.

1 MOTIVATION

Previous studies of the University of Applied Sciences Kempten and MdynamiX with over 120 test persons and current benchmark vehicles with regard to automated lateral control have shown the following: The functional characteristics and driving characteristics, which are currently achieved, still offer a great upward potential, and customer acceptance is still relatively poor [1-3]. The challenge for vehicle manufacturers in the development of Advanced Driver Assistance Systems (ADAS) and Highly Automated Driving (HAD) lies in the additional difficulty of differentiating themselves (brand typically). The brand-specific characteristics and the brand position of the vehicle brands have hardly been taken into account in the ADAS/HAD development. For Porsche, it is very important to design both the product and the brand in the age of ADAS/HAD so that they can be experienced according to the brand. Customers shall experience special emotions, differentiable from other brands and products. Using the example of assisted lateral guidance, a generic procedure model should be developed to translate subjective customer experiences into subjective expert evaluations and finally into objective Key Performance Indicators (KPIs) with defined driving maneuvers [4]. This should make it possible to define objective attribute targets for a Porsche typical characteristic and to validate them at any time in all phases of development – from simulation up to road tests. The procedure model should then be transferable to the assisted longitudinal guidance and to driving functions of higher automation levels.

2 EVOLUTION OF ADVANCED DRIVER ASSISTANCE SYSTEMS

Until the first Panamera was launched in 2009, Porsche, as a sports car manufacturer, only offered its customers few safety functions and a cruise control system. In the following years, Porsche pursued a late-follower strategy in the expansion of ADAS, focusing primarily on the Panamera and the SUV model series. The introduction of the second generation Panamera in 2016 initiated a trend reversal. With pre-view longitudinal control functions such as Porsche InnoDrive, Porsche introduces for the first time an in-house developed ADAS function and optimizes existing functions by means of Porsche typical extensions, such as sportiness recognition [5]. Porsche pursues the approach of offering driver assistance functions with their own DNA by complying brand-typical attributes such as reliability, sovereignty, performance, intelligence and trust. In order to address this claim for future assisted and highly automated driving functions, professional methods are required for an attribute-based development.

3 METHOD

A generic procedure model was developed using the example of assisted lateral guidance. Principles and approaches of vehicle dynamics and chassis development were applied [6].

3.1 EVALUATION LEVEL MODEL

In numerous expert workshops, benchmark tests and measurement campaigns, the relevant attributes for assisted lateral guidance were systematically and structurally developed. The defined subjective and objective characteristics were transferred to a so-called level model and linked accordingly [4], **FIGURE 2**. This model consists of the levels subjective customer evaluation, subjective expert evaluation, measurement signals and KPIs to be collected in defined driving maneuvers/driving scenarios. At the highest customer level, there are key criteria such as track guidance quality, driver-vehicle interaction, vehicle reaction, avail-

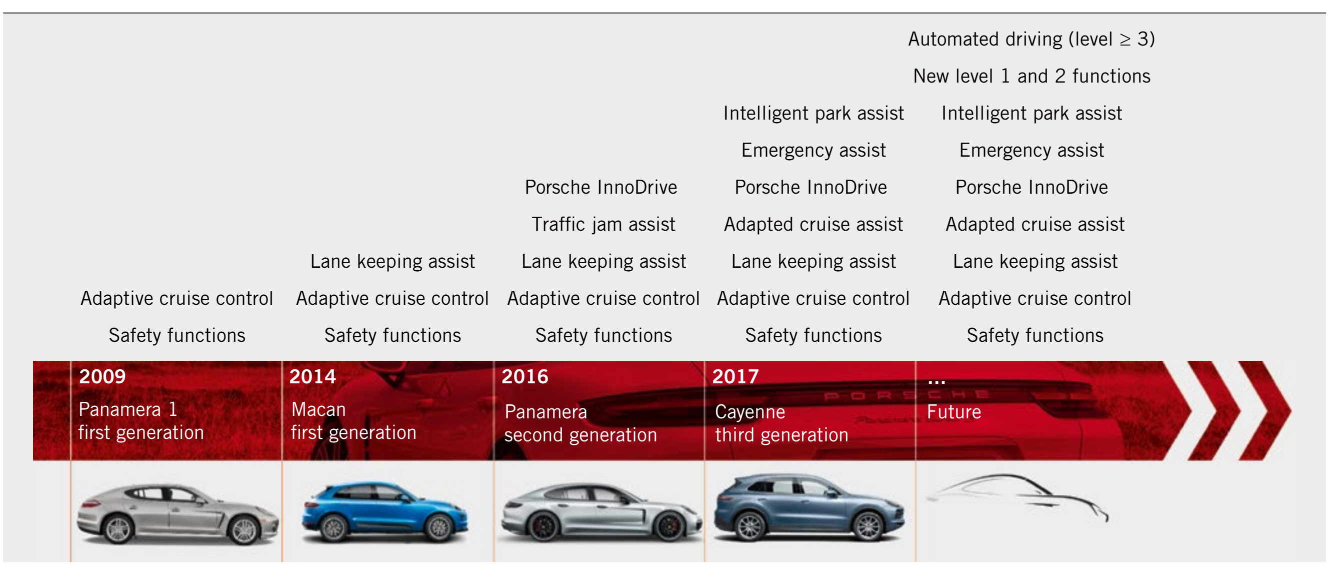

FIGURE 1 Evolution of driver assistance systems at Porsche (© Porsche)

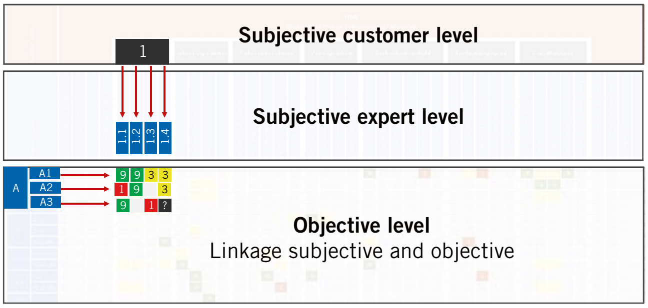

FIGURE 2 Evaluation level model (© University of Applied Sciences Kempten)

ability, degree of relief, sense of safety and HMI (operation, display, monitoring and warning). At the expert level, the main criteria were broken down into four to six sub-criteria. In the next step, all relevant and measurable vehicle signals were worked out in expert workshops, in which the subjective expert criteria were expected to be clearly visible. Based on the expert knowledge, subjective and measurable vehicle signals then were linked. The experts rated the degree of visibility to be expected as high (9), moderate (3), low (1), none (0) or unknown (?), **FIGURE 2**. Therefrom, KPIs for the relevant signals were developed according to the individual expert criteria in analogy to characteristic values of vehicle dynamics.

3.2 GROUND TRUTH MEASUREMENT METHOD

New measurement and test methods had to be developed for the objective evaluation of driving characteristics in the ADAS/HAD context. In the assessment of vehicle dynamics, it is common knowledge that when evaluating the driver/vehicle/environment control loop should be considered. Therefore, the input into the vehicle, such as driver input, road and traffic, control intervention, and the resulting vehicle reaction/movement is evaluated in its six degrees of freedom. Applied to the automated lateral control, it is necessary to obtain a high level of knowledge of the road excitation (essentially road markings and surface condition) and the driver input in order to be able to evaluate the resulting vehicle reaction accordingly. In the case of assisted longitudinal guidance, a high level of knowledge of the surrounding traffic is required.

Like all sensors, environmental sensors such as camera, radar or lidar [7] are faulty and not available or sufficiently accurate in all situations. This can have a significant impact on the driving characteristics. For example, the camera may not be able to identify the curvature of road accurately, which can cause difficulties for the lane-keeping controller. This repeatedly leads to uncertainties if the experienced driving characteristics are a result of the moderate performance of sensors, trajectories, controllers, actuators or the moderate response of the vehicle influenced by steering, suspensions, tires and chassis control systems. In order to analyse this cause and effect chain, a much more accurate reference measurement method must be used as Ground Truth. The chosen approach was to integrate both a highly accurate measured vehicle position and movement into highly accurate digital Ground Truth maps, **FIGURE 3** (left). Atlatec has developed a method to generate digital Ground Truth 3-D maps with high accuracy. It was used to measure various country roads and highways around Weissach and Kempten (Germany). An ADMA pro from Genesys (Inertia Measurement Unit, IMU) with fiber optic gyroscope technology, Kalman filter, RTK-DGPS and Sapos correction service was used for vehicle position and motion measurement [8].

Great efforts have been made to achieve the objective of a relative accuracy between both absolute measurements (digital map and vehicle position) of less than ±5 cm. Even in seemingly open terrain, satellite coverage by bridges, embankments or dips can be so poor that the IMU has to continue with pure coupled navigation and internal support. The longer the gaps in the GPS coverage, **FIGURE 3** (right), the greater the position errors. This depends on the drift quality of the IMU. By means of additional speed support methods and drift corrections or by forward/backward Kalman filters, a sufficiently robust accuracy could be achieved [8].

In order to locate the vehicle precisely in the track during data processing, a route description format (Curved Regular Objects, CRO) based on OpenCRG was developed, and the Atlatec measurements were transferred accordingly. In different layers, an orthogonal regular grid can be generated in any resolution. Object types can precisely be assigned and extended at any time. Layer 1 describes the 3-D road surface, layer 2 the road marking, layer 3 the barriers and signs, layer 4 the buildings. The data format was enriched with additional information such as curvature, course angle and attributes as a lock-up table. Regular grids allow the computation-efficient calcula-

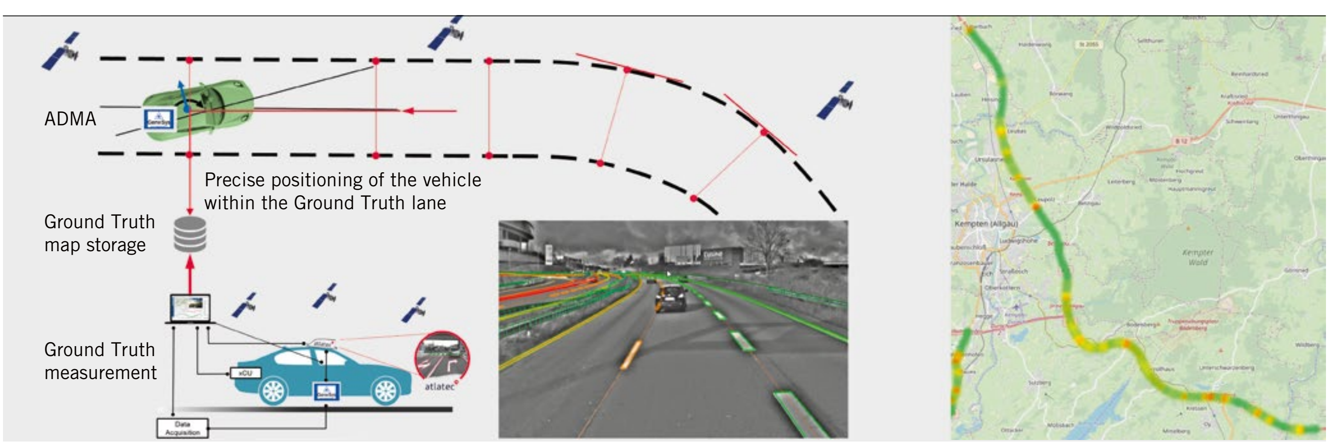

FIGURE 3 Ground Truth measurement method (left) and GPS coverage (right) (© University of Applied Sciences Kempten)

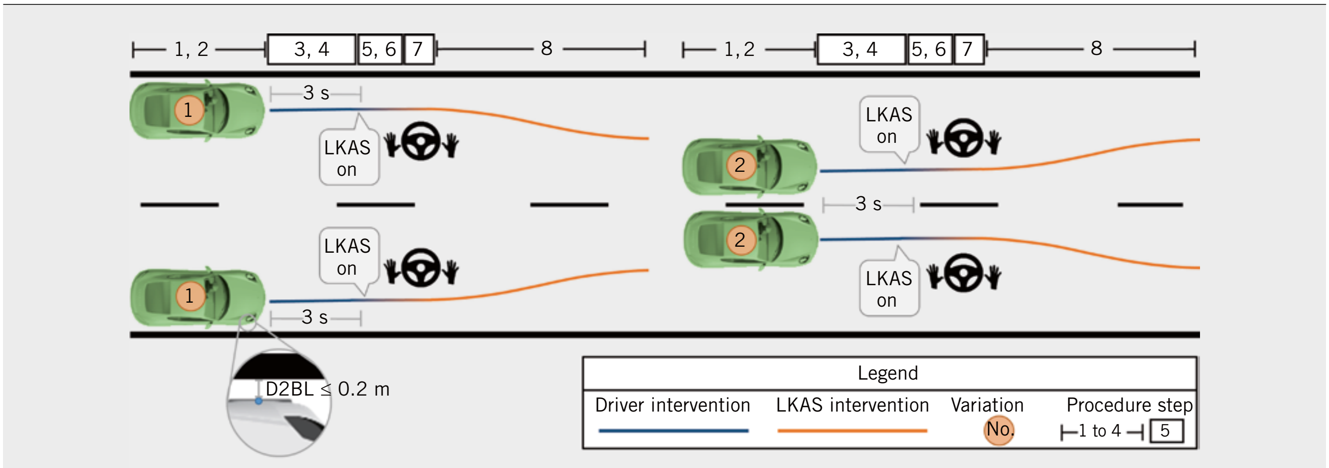

FIGURE 4 Example of a defined driving maneuver (Lane Keeping Assistance System, LKAS) (© MdynamiX)

tion of jump marks, for example to the currently measured vehicle position/direction or forecast. Thus, localization and motion calculation in the digital maps is also possible in real time [8].

In addition, a Kistler measuring steering wheel was optimized and adapted to measure the real steering angle/speed and steering torque/gradient as a reference. It was important that the original steering wheel could be used to fully preserve haptics, control functions, hands-off detection and airbag function. The measurements can be characterized in terms of driver-vehicle interaction and allow an evaluation of the quality of the on-board sensors. The measurement concept was designed in such a way that the driving characteristics can be evaluated with all benchmark vehicles without bus connection. In addition, all bus signals, such as the object lists of the sensors, can be measured and precisely assigned. This allows the quality evaluation of the environmental sensors, trajectory, controller and the vehicle response to be examined throughout the entire cause and effect chain and the requirements of the individual components to be defined with regard to the overall vehicle characteristics.

3.3 ROUTE AND MANEUVER CATALOGUE

In order to be able to evaluate the driving characteristics in comprehensive driving situations, the previous standard procedures such as Euro NCAP [9] or ISO are by far not sufficient. The variance in possible real road events such as road types, curvature, road markings, cross slopes, road entanglement and other road excitations is far too great. For this purpose, a comprehensive route catalogue was developed which corresponds to the intended use of the functions and represents the required excitation variance. In a route catalogue, the routes, sections, area and events were subdivided and typified. The waypoints and GPS positions were precisely documented and all routes were generated as reference routes for the driving test and the simulation as digital Ground Truth maps.

In addition, a comprehensive maneuver catalogue was created, in which each individual maneuver was precisely defined, **FIGURE 4**. In the so-called free ride, defined operating points in the sections, areas and events with different drivers and times of day were tested using driving instructions. Furthermore, specific driving maneuvers such as lane change test (with and without turn signals), transient test, feedback test, stationary cornering as drop and performance test, on-center handling test, and step steer test were developed and described exactly in one document analogous to an ISO.

3.4 OBJECTIVE EVALUATION OF DRIVING CHARACTERISTICS USING KPIS

Using suitable algorithms, further signals can be calculated from the measurement data and then the KPIs can be generated automatically. For this purpose, for example reference signals of yaw rate and lateral acceleration, based on the Ground Truth curvature, are generated as target and the deviation from the actual measurement is evaluated. For free travel, statistical distributions or counting methods are used, such as for the availability measurement, tracking precision measurement or jerk measurement, as well as finding specific states and events using an event finder. For example, the stationary states are selected, from which the stationary lateral position above the lateral acceleration can be displayed. In a compressed chart, **FIGURE 5** (bottom), this provides information, among other things, on how the vehicle is carried outwards (negative gradient) or on how it cuts curves slightly (positive gradient). In addition, the chart shows the center position when driving straight ahead (offset at $a_y = 0$) and the dispersion as a measure of precision. Furthermore, the lateral acceleration limits, steering wheel torque limits, dropout limits, response, lock-in and lock-in times, steering wheel torque gradients, steering hysteresis and drift speed are calculated. In this scheme, over 80 % of the subjective expert evaluations could be objectified, **FIGURE 5** (top).

4 DRIVING CHARACTERISTIC EVALUATIONS IN THE DEVELOPMENT PROCESS

Especially in the very innovative environment of ADAS/HAD, it is necessary to observe the performance and solution approaches of competitor vehicles to learn from the good and to avoid the bad. Even in the age of ADAS/HAD, it is important for Porsche to design the product in a way that it can be experienced as typical of the brand and to differentiate itself from others. This requires clearly recognizable driving characteristics that are associated with the Porsche brand and can be compared to the benchmark. Familiar brand attributes such as driving pleasure, performance, precision,

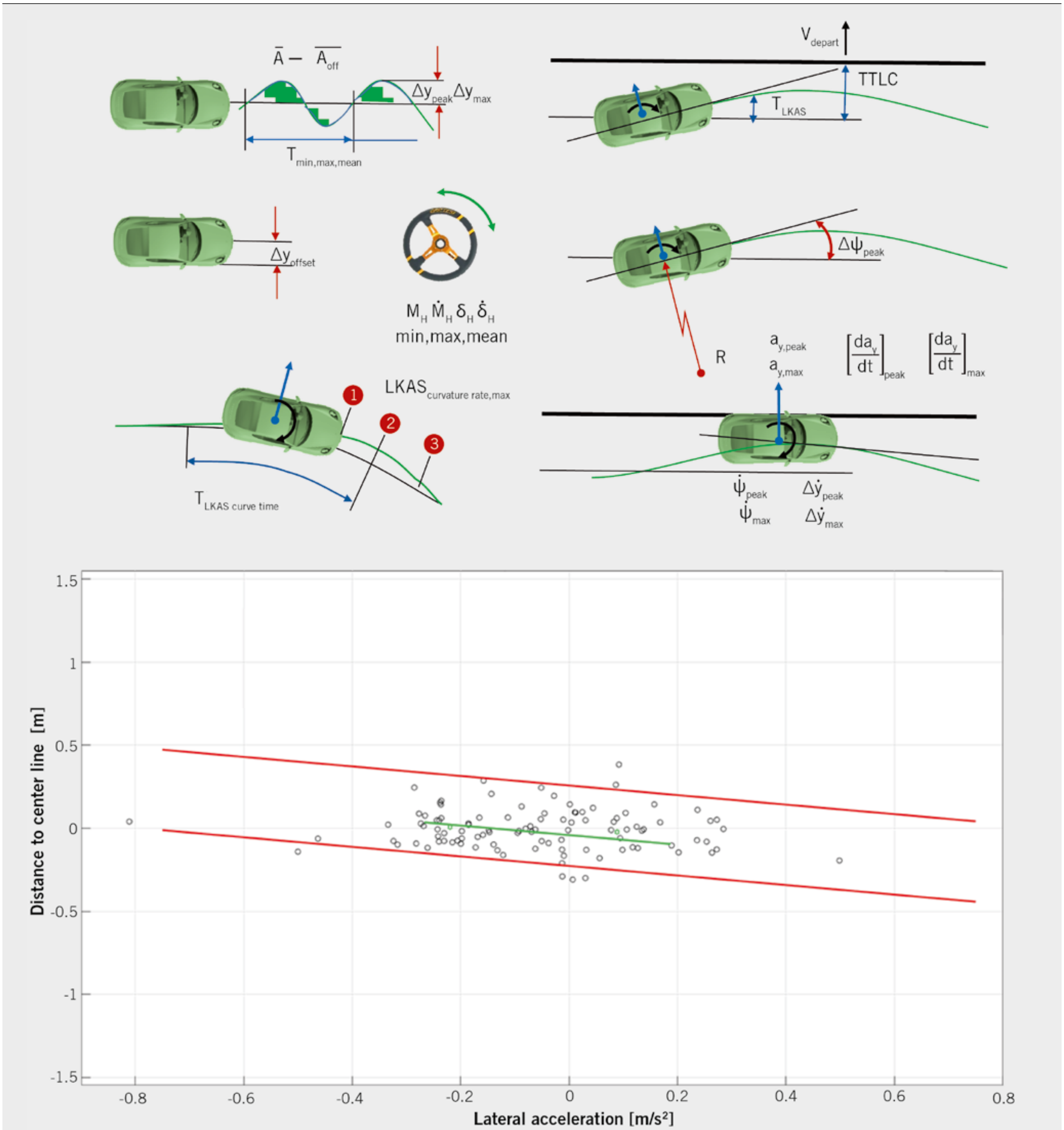

FIGURE 5 Concept of objective criteria (top) and side offset for straight and curved driving (bottom) (© University of Applied Sciences Kempten)

driver feedback, transparency and reliability are to be addressed here as well, with a high degree of suitability for everyday use. Customers would expect a Porsche, for example, to follow a harmonic driving line very precisely and always provide the driver with pleasant but not disturbing feedback on the driving condition. For this purpose, the desired brand attributes were linked to the criteria in the level model, **FIGURE 2**. This makes it possible to define objective targets for a typical Porsche characteristic and validate them at all times in all phases of development - from simulation to road tests.

4.1 SIMULATION-BASED DEVELOPMENT PROCESS

In order to be able to validate the characteristic objectives in all phases of the development at the overall vehicle level, a modular simulation environment consisting of the environment simulation Vires VTD, Porsche driving dynamics model and a control system network including lane keeping control was set up. The co-simulation platform AVL Model.Connect represents the networking of the individual simulations/models and offers corresponding functions for their consistent use in the proceedings Model-in-the-Loop (MiL), Software-

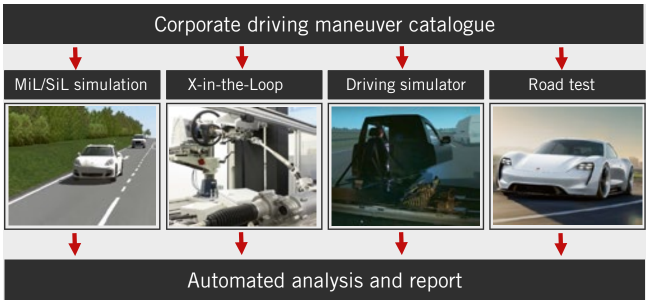

FIGURE 6 Simulation-based development process
(© University of Applied Sciences Kempten)

in-the-Loop (SiL) and Hardware-in-the-Loop (HiL), **FIGURE 6**. A good steering model with effects in the on-center area is required in order to evaluate the track guidance quality, vehicle reaction and driver-vehicle interaction realistically. For this purpose, the Pfeffer steering model of MdynamiX was integrated into the Porsche driving dynamics model. The Ground Truth maps of the route and maneuvers catalogue were implemented analogously to the road tests. In order to obtain comparable results for the evaluation of development progress in all phases, the evaluation and evaluation algorithms were integrated into the Porsche post-processing tool Veda Post. This can be used throughout, from the simulation to the road test, and always guarantees comparable results, **FIGURE 6**. Efficient calibrations for uniform driving characteristics across all model series and vehicle variants can thus be achieved.

5 SUMMARY AND OUTLOOK

ADAS/HAD are becoming very important for the Porsche brand. Using the example of assisted lateral guidance, a procedure model was successfully established to show how a typical Porsche characteristic can be effectively achieved in an attribute-based development. The procedure model is currently being transferred to assisted longitudinal guidance and to driving functions with higher automation levels as well as to country-specific calibrations, for example China.

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