Cloud-based Calibration Suite © ETAS

Vehicle development

Efficient, automated calibration via cloud-based toolchain

The calibration of vehicle electronics influences the vehicle's performance, efficiency, and safety more than ever before. However, traditional PC-based calibration is reaching its limits in the face of ever-increasing data volumes and the complexity of software-defined vehicles. On the other hand, calibration via a cloud-based toolchain increases agility and enables engineers to work in a data-driven and efficient manner.

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The automotive industry is undergoing an unprecedented transformation, driven by electrification, automated driving, and the shift towards software-defined vehicles (SDVs). Economic pressures and shortened development cycles are increasingly forcing OEMs to optimize and automate their development processes. Vehicle calibration is also facing a fundamental upheaval: The explosive growth in data volumes, for example from test fleets and customer vehicles, which are increasingly stored in the cloud, opens up new opportunities. However, it also requires new processing strategies and cloud-based tools that—moving beyond time-consuming local downloads and manual data preparation—enable a standardized and largely automated calibration process.

The current standard practice is still predominantly a conventional PC-based calibration of the ECU software: Here, the development engineer downloads measurement data from various sources in different formats to the local computer, where it is prepared and preprocessed. The data is then evaluated using an analysis and reporting tool and reconfigured or adjusted based on an existing configuration—all while potentially reducing the amount of data to shorten the computation time. This is followed by a manual evaluation of the results and preparation of the relevant measurements. Finally, the project is configured for model-based calibration by importing the measurement data and initial parameter set. This allows for the optimization of an existing ECU model, such as the exhaust gas temperature model, in the form of a Functional Mock-up Unit (FMU).

during which time it cannot be shut down or used for any other purpose. Scaling up computing power using local approaches, however, is difficult and expensive.

Furthermore, the various software tools required are often not seamlessly integrated. For example, after data preprocessing, the user must manually analyze the results, prepare relevant measurements, and import them into the respective simulation or calibration tool. This is not only time-consuming but also increases the likelihood of human error. In addition, many calibration tools are designed as isolated, stand-alone solutions. This prevents automated, seamless information exchange between data acquisition, analysis, and optimization, resulting in data silos and redundant tasks.

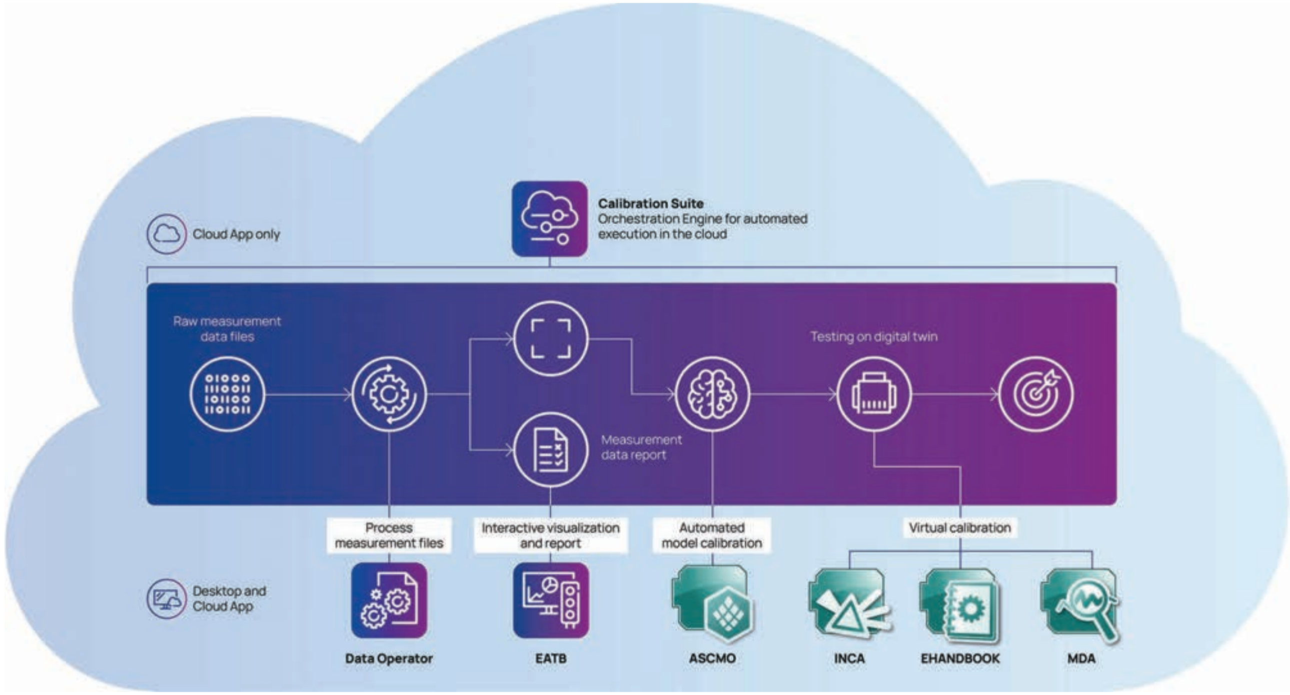

Figure 1: The cloud-based toolchain enables optimized data preprocessing, analysis of large datasets, and the creation of data-driven models for virtual sensors using advanced machine learning algorithms in an automated workflow. © ETAS

Conventional calibration is often time-consuming and tedious.

In principle, this sequential approach remains effective. However, conventional vehicle calibration is plagued by a number of inefficiencies and limitations that are becoming increasingly problematic in light of new vehicle architectures and accelerated development processes. For example, often downloading the vast amounts of measurement data from test fleets or trial drives, frequently originating from external sources, requires significant time, bandwidth, and storage space. Furthermore, processing and analyzing these large datasets, as well as complex calibration and optimization tasks, consume considerable computing power. A typical workstation can be tied up for many hours or even days,

Impending loss of knowledge and low standardization

Moreover, traditional calibration expertise is often closely tied to specific vehicle programs and the engineers involved. This poses a significant risk for OEMs: if key personnel leaves, knowledge loss is imminent. Furthermore, standardized processes across different projects and teams are often lacking, which also impairs knowledge reusability and efficiency. Additionally, initial calibrations often lack an integrated feedback loop that uses test data to refine the models. This results in optimization potential remaining untapped and hinders a continuous improvement process.

Vehicle calibration process with cloud-based, automated toolchain

What is needed, therefore, is an integrated software solution (e.g., ETAS Calibration Suite) that streamlines the calibration process through an intelligent, automated, and cloud-based toolchain. The core objective is to fully leverage the vast wealth of raw measurement data from vehicle fleets or test bench runs and transform it into optimized calibration data for the ECUs – in a seamless process that eliminates the previously mentioned drawbacks of conventional calibration.

In practice, the known calibration steps are linked to an automated work-

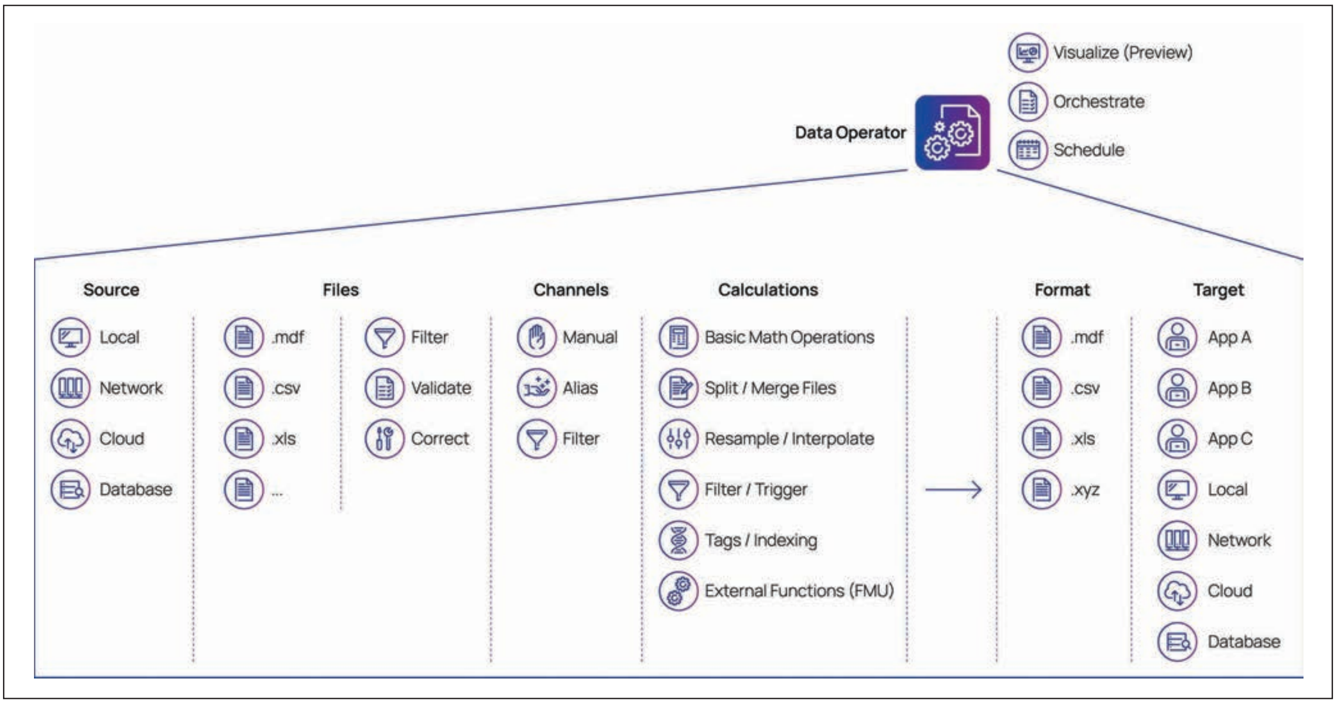

Figure 2: In the first process step, the raw data is taken from the various sources by the Data Operator, merged, standardized, and prepared for subsequent analysis. © ETAS

flow across different software tools and largely moved to the cloud—from automated data preprocessing to event-based analysis and report generation to automated optimization **(Figure 1)**.

1 *Automated data preprocessing*
As soon as new, relevant measurement data becomes available in the cloud environment, it is automatically imported and prepared by data preprocessing software (e.g., ETAS Data Operator) directly in the cloud. The software's main task is to consolidate and standardize the raw data from various sources and prepare it for subsequent analysis. This includes reading the measurement data, adjusting sample rates, and filtering out irrelevant channels or time segments. To ensure consistent analysis, signal names are standardized, and the data is converted into a standard format such as MF4. This initial process step creates a clean and robust data foundation. Time-consuming downloads and lengthy processing times on local PCs are eliminated, while simultaneously ensuring data completeness and the reliability of the subsequent analysis (**Figure 2**).

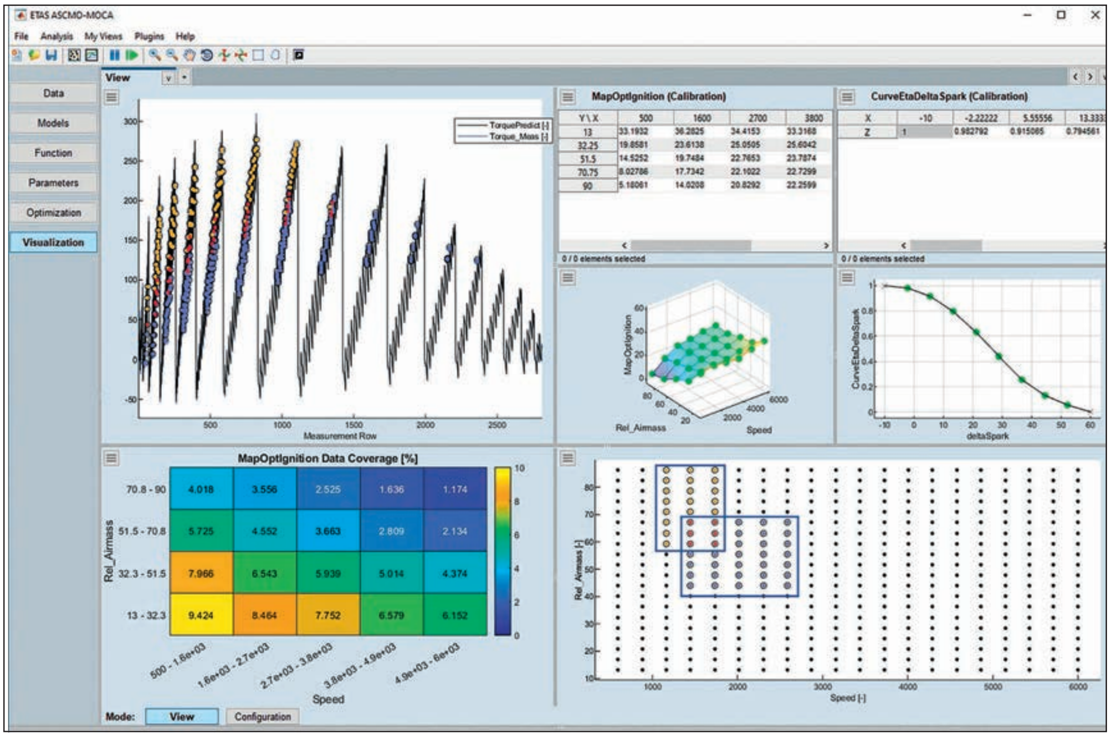

Figure 3: As part of the toolchain, ETAS ASCMO-MOCA enables the efficient optimization of parameters in physical models and offers a variety of interactive visualizations. © ETAS

2 *Event-based analysis and reporting*
Following data preparation, the analysis and reporting tool (e.g., ETAS Analytics Toolbox EATB) takes over and systematically searches the large datasets of the data lake for relevant events and specific conditions. Data analysis is performed automatically via freely programmable configurations. This method is perfectly suited for a wide range of relevant use cases, such as identifying time intervals in which the limit value of an engine function is exceeded under specific conditions (ambient temperature, engine speed, etc.). The data segments identified in this way are then used for the subsequent optimization of the ECU function.
Extremely helpful in this context: The tool automatically generates a standardized report that clearly documents the results obtained. Process reliability and traceability are thus guaranteed at all times.
3 *Automated, ML-supported calibration optimization*
Finally, the measurement sections marked as relevant in the analysis are transferred to the tool for data-driven system modeling and optimization (e.g., ETAS ASCMO-MOCA). With the goal of optimal calibration, the software loads the relevant sections of the measurement data and the associated ECU function, usually as a Functional Mock-up Unit (FMU).
Using the current calibration data, the tool then initiates an automated optimization process. Optimization algorithms are used to calculate a new, improved parameter set for the function, and the result is saved as a new calibration data set in a DCM file.
Special machine learning (ML) algorithms also enable the software to create a precise virtual model of the vehicle system from a few, but meaningful, measurement data points. On this digital representation, the software can then quickly test countless calibration settings and automatically find the optimal configuration [1]. Instead of having to perform complex and time-consuming tests on real test benches or in vehicles, the development process is significantly accelerated in this way. At the same time, the data-driven approach improves the quality of the calibration (**Figure 3**).
The newly created calibration dataset can then be validated directly in a virtual environment. Using specific tools (e.g., EHANDBOOK or Measure Data Analyzer MDA from ETAS), the function is simulated with the new data. This test on the „digital twin" makes it possible to verify the effects of the changes without relying on physical hardware or vehicles. The entire process, from data availability to optimized and verified calibration, can be fully automated, for example, by running it overnight on a timer. The calibration engineer receives a notification the following morning with the results and a link to the new data.

Performance, time and efficiency gains

The end-to-end cloud-based toolchain offers a number of compelling advantages over traditional PC-based vehicle calibration. For example, the sometimes enormous datasets from multiple sources are combined, cleaned, and prepared for analysis directly in the cloud—without lengthy loading and processing times on the local PC.

The solution then automatically initiates an advanced data lake analysis to quickly uncover relevant patterns and insights within the vast sea of data. The results are summarized in consistent and clear reports, which can then be directly integrated into corresponding data-driven modeling within the cloud. Using machine learning algorithms, the optimal calibration of the vehicle systems can then be determined and intelligently adapted to the ECU functions based on real-world operating data. This allows development teams to work faster and more efficiently while still fully utilizing the available data.

Strategic advantage for SDV development

The presented toolchain fundamentally improves the calibration of vehicle electronics for the SDV. It enables flexible workflow orchestration, ensuring a seamless transition from offline desktop processing to scaled cloud execution. This not only promotes efficient collaboration among globally distributed teams but also allows for adaptation to specific infrastructure requirements by offering a choice between cloud environments (e.g., ETAS Calibration Suite on Microsoft Azure) and on-premise operation. Furthermore, the use of simulation and digital twins significantly reduces a dependency on physical hardware.

The toolchain's "fail fast, fix fast" approach results in improved calibration quality, faster development cycles, and a reduced time-to-market. The apparent dilemma of rapidly growing data volumes can thus be transformed into a strategic advantage for the development of software-defined vehicles during the calibration process. ■

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Literature & Links

[1] Thorsten Huber, Abhik Dey, Henner Schmidt: How to deploy machine learning models to series ECUs – A hands-on guide for integrating advanced AI into automotive ECUs without in-depth AI knowledge. Whitepaper, Etas GmbH 2026.

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