02
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Porsche Engineering Magazine

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ACCELERATING DEVELOPMENT

How data-driven and real-life methods work together

As unique as you and your dreams.

DRIVEN BY DREAMS

75
1948
2023

PORSCHE

Markus-Christian Eberl
CEO of Porsche Engineering

Dear Reader,

Whether it's software for new driving functions, the integration of components into an overall system, or the ever-rising connectivity of our vehicles: In automotive development, we are increasingly moving away from complicated problems and toward complex ones. This has consequences for our work. A single engineer or a small group of highly specialized developers can no longer adequately solve today's complex requirements on their own. Instead, joint, integrative work in larger networks is increasingly becoming an essential ingredient for success. A suitably capable system continues to use the intelligence, creativity and proficiency of each individual person, while getting more out of them than the sum of the parts and contributing to shaping the overall solution through its organizational form. We are familiar with the basic principle from team sports; yet to achieve technically complex goals, it is not five, six or eleven players who need to be enabled to collaborate in this way, but hundreds or even thousands of software specialists, engineers and other experts.

Managing this task places high demands on the management culture. While in the past a charismatic manager often led from the front, in the future leadership will increasingly be required from the side: Managers will have to empower teams for their own development tasks rather than laying out the exact path to success. This changes the entire organization of companies. With agile methods and new organizational principles, managers today can structure their problem-solving differently and operationalize the above-mentioned leadership principle. One significant advantage of such methods is that there are fewer closed specifications; rather, a higher degree of openness to solutions is inherent in the method. This accelerates the implementation of highly complex tasks in particular, and promotes solutions. At the same time, greater responsibility is assigned to employees. At Porsche Engineering, we have established exactly these structures and processes in recent years.

Our goal: A customized technical solution for our customers, the optimal result in time and in quality. We see our role as that of an equal partner. In a complex world, continuous dialog with our clients is, after all, essential—a closed loop in which ideas are bounced back and forth. This is how we enlarge the solution spaces and find the right answers to current challenges.

The cover story of the current issue illustrates our own methodical evolution in this regard. New opportunities for development arise in particular from the intelligent use of a wide range of data. Whereas technically limited volumes of data limited us in the past, at this point we can easily fill large data lakes. This is due to extensive technological development on the part of the data sources, such as simulations and sensors in the vehicles, as well as in the areas of data transmission and storage. The challenge now is to use intelligent algorithms—including artificial intelligence—to identify and interpret the relevant information. At the same time, however, real-life testing on test tracks such as those at Nardò Technical Center will remain indispensable. Ultimately, it is people and not algorithms that will end up evaluating and approving the final result of a development.

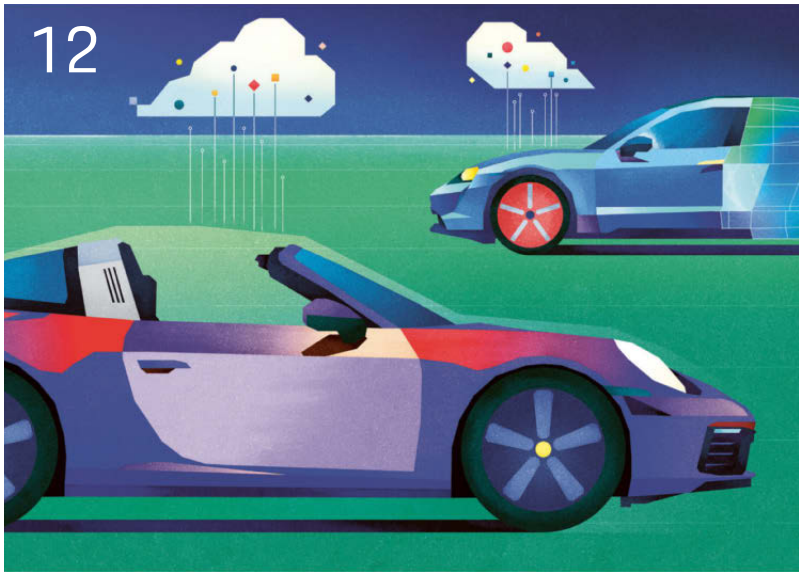
From services for complicated issues to turnkey solutions for ever changing, highly complex problems: That's the expectation of the road ahead. And I am very much looking forward to going down that road together with you in my new role as Chairman of the Executive Board of Porsche Engineering.

I hope you enjoy reading this issue of the magazine.

Markus-Christian Eberl

→ **ABOUT PORSCHE ENGINEERING:** Porsche Engineering Group GmbH is an international technology partner to the automotive industry. The subsidiary of Dr. Ing. h.c. F. Porsche AG is developing the intelligent and connected vehicle of the future for its customers—including functions and software. Some 1,700 engineers and software developers are dedicated to the latest technologies, for example in the fields of highly automated driving functions, e-mobility and high-voltage systems, connectivity, and artificial intelligence. They are carrying the tradition of Ferdinand Porsche's design office, founded in 1931, into the future and developing the digital vehicle technologies of tomorrow. In doing so, they combine in-depth vehicle expertise with digital and software expertise.

On cloud nine: Data-driven development works with huge volumes of data, using the cloud as a hub.



On the road worldwide: For international validation, vehicles are tested in the US and other countries.

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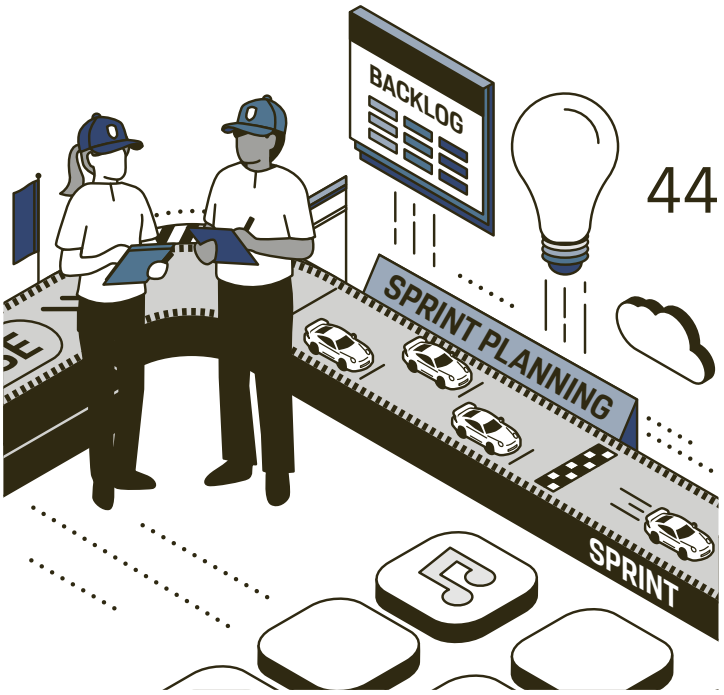
COVER STORY DEVELOPMENT METHODS OF THE FUTURE

Experts in conversation: Dr. Michael Steiner and Markus-Christian Eberl take a look at the future of the automobile.



Quick turnaround: Agile software development focuses on flexibility and speed.

PERFORMANCE AND EXPERTISE

TRENDS AND TECHNOLOGIES

PORSCHE AND PRODUCT

ESSAY

SECTIONS

CONTRIBUTORS

Marc-Stefan Andres writes features, reports, interviews and portraits. And is interested in almost everything.

Andreas Reeg is a photographer from Darmstadt, Germany, who specializes in portraits. He is also the author of three books.

Andrew Timmins led the infographic team at stern for ten years. Today he is a freelancer based in Hamburg.

NEWS 02/2023

Panamera GTS

Fuel consumption (combined): 13.1–12.1 l/100 km
CO_2 emissions (combined): 296–275 g/km

All consumption figures according to WLTP; as of 05/2023

On course for growth: Marius Mihailovici (above) heads Porsche Engineering Romania and places the emphasis on a modern working environment (below).

Activities in Timişoara

NEW OFFICE AND CONTINUED EXPANSION IN ROMANIA

Porsche Engineering has opened a new location in Timișoara and is pursuing long-term growth plans in Romania: The company, which has another R&D office in Cluj-Napoca, aims to recruit more than 100 employees in Romania in 2023, out of which 50 software developers and engineers are planned to be hired in Timișoara. The focus is being directed at issues such as AI, big data, cloud, infotainment, ADAS, connectivity, and other areas affecting the future of the automotive IT era. The new office in Timișoara is located in the heart of the city, in the United Business Center building in Iulius Town Timișoara. It covers 2,110 square meters and is a modern, digitalized space where employees can experience the new era of hybrid working. "Porsche Engineering is a company that relies on a spirit of innovation—with the individual as the driving force," says Marius Mihailovici, Managing Director of Porsche Engineering Romania. The company intends to contribute to the growth of the local automotive software industry, to train the current and next generation of technical talents, and to give something back to society.

"Porsche Engineering is a company that relies on a spirit of innovation—with the individual as the driving force."

Marius Mihailovici
Managing Director
Porsche Engineering Romania

New Executive Board:
Markus-Christian Eberl (top left) succeeds Peter Schäfer (top right). Dirk Philipp (center) was appointed to the Executive Board as CFO/COO; Dirk Lappe (bottom) remains Managing Director of Technology (CTO).

Retirement of Peter Schäfer

CHANGES IN THE EXECUTIVE BOARD AT PORSCHE ENGINEERING

Markus-Christian Eberl (49) has been Chairman of the Executive Board of Porsche Engineering since June 2023. Following his position as Vice President Technical Conformity at Porsche AG, he succeeds **Peter Schäfer** (63), who retired at the end of May. In addition, **Dirk Philipp** (53) was appointed to the Executive Board at the beginning of 2023, where he assumed the position of Managing Director of Commerce/Chief Operating Officer (CFO/COO). **Dirk Lappe** (59) remains Managing Director of Technology (CTO); he has held this position since 2009. Markus-Christian Eberl has been with Porsche for 23 years. Prior to his appointment as CEO of Porsche Engineering, he headed Technical Conformity in the R&D department of Porsche AG. Before that still, he held various positions in Internal Auditing and Engine Development, and has held management positions since 2014. Before joining Porsche in 2000, Eberl gained experience in the field of engineering services with a focus on software development. "Porsche Engineering combines comprehensive vehicle know-how with digital and software expertise. I am convinced that Markus-Christian Eberl will provide important impulses for the targeted development of Porsche Engineering at this crucial interface," says Michael Steiner, Member of the Executive Board for Research and Development at Porsche AG and Chairman of the Shareholders' Committee of Porsche Engineering. He also took the opportunity to thank Peter Schäfer: "We owe Peter Schäfer a great deal of gratitude. He made a significant contribution to the company's success story—with a clear strategic direction and a consistent international orientation. He has always put special emphasis on corporate culture." Dirk Philipp has been Director of Finance and Administration at Porsche Engineering since 2011 and has held various positions within the Porsche Group since 1995, including Director of Finance Controlling of Development.

1,700

employees now work for Porsche Engineering worldwide.

12

locations in five countries guarantee that developers are always close to their customers.

Wave hunter: Sebastian Steudtner's new surfboard will help to take surfing to a new level.

Collaboration in surfing

READY FOR THE NEXT LEVEL IN SURFING WITH AN OPTIMIZED BOARD

Over the past two years, Porsche Engineering has worked with Sebastian Steudtner, the big-wave world-record-holder with a wave height of 26.21 meters, and Porsche AG to scientifically analyze and optimize Steudtner's surfboard. Experience from vehicle development was translated to the world of surfing: Using the latest simulation methods and wind tunnel validation, the team improved the surfboard's handling in the water (hydrodynamics) as well as the aerodynamics of both the board and the surfer—always with the goal in mind of reducing drag in both the water and the air. This should enable Steudtner to reach higher speeds. 70 to 80 km/h is currently possible.

A high speed is necessary to ride bigger waves—because the higher a wave is, the faster the surfer has to be to keep it from crashing over him. The new board was presented to the public for the first time in Cascais, Portugal, in May. Optimization of the complete system of Sebastian's surfboard resulted in significantly reduced drag, which in turn could now potentially enable surfing speeds of up to 100 km/h. The new board was dubbed the "Caçador RS". The name is a combination of the Portuguese word "caçador" (hunter) and the classic Porsche designation "RS", which is reserved for the sportiest Porsche models.

Big data

Massive volumes of data in vehicles are opening up new possibilities in engineering.

Text: Christian Buck

Vehicles have long since become powerful computers on wheels, as more and more control units enable more and more functions. This is also evident in the volumes of data being processed in modern vehicles. The standard CAN bus used in vehicles, with its maximum data rate of one megabit per second (Mbps), has long become insufficient. But even Flexray, at ten Mbps, is reaching its limits. That's why automotive ethernet is now finding its way into vehicles, providing 100 or 1,000 Mbps depending on the variant. There is a flurry of activity on the various bus systems: "It's safe to assume that a fully equipped vehicle sends around 20 Gbit of data internally every second," reports Dietmar Luz, Senior Expert Electrics/Electronics at Porsche Engineering. "It is processed in dozens of control units. By comparison: The first vehicles with intelligence on board had exactly two control units—the engine and brake control units—networked via CAN bus."

In the future, highly automated driving functions in particular will result in ballooning data rates thanks to numerous cameras, radars and lidar sensors. This is already having an impact in engineering: "A test vehicle generates up to 44 terabytes of data per day during highly automated driving," says Dr. Joachim Schaper, Head of AI and Big Data at Porsche Engineering. "The data is saved to fast hard drives in the luggage compartments of the cars."

From there, it is sent to the cloud, where data from test drives and simulations accumulates during vehicle development. "Today, we are already in the petabyte range, with one petabyte corresponding to about 1,000 hard drives in modern computers," calculates Daniel Schumacher, who works as a cloud architecture specialist at Porsche Engineering. "Soon we will reach the exabyte range." Fortunately, hard drive manufacturers are still managing to set new storage records on a regular basis—so they are unlikely to be overtaken by vehicle developers in the foreseeable future.

Upon arrival in the cloud, the data is available to developers at all locations and can be analyzed—in some cases in real time. It can be used, for example, to train neural networks for highly automated driving functions, as well as to automatically analyze error messages from the control units. Increasingly, the algorithms also support the application engineers, who can find better solutions more quickly through data-driven development. The use of data in development is likely to continue to accelerate in the future, as growing volumes of data and new technologies such as quantum computers will open up new possibilities for engineers—and with them new driving experiences that are scarcely imaginable for customers today.

Flood of data: The volume of digital information in the vehicle has increased by a factor of ten due to the use of cloud technologies. When more modern driver assistance and safety systems are added, the data volume will once again increase—by a factor of 800.

DATA ON CLOUD NINE

Porsche Engineering uses the ever-increasing volumes of data from test benches, simulations and test vehicles to significantly accelerate development and place it on a broader empirical basis. Cloud technology plays a crucial role in this, while at the same time leading to more effective use of the IT infrastructure.

Text: Constantin Gillies
Illustrations: Dan Matutina

COVER STORY

DATA-DRIVEN DEVELOPMENT

Data suppliers: Today's test vehicles are full of sensors that supply ever larger volumes of data. They are evaluated in the cloud and sent to the developers.

911 Targa 4

Fuel consumption (combined): 10.9–10.5 l/100 km
CO_2 emissions (combined): 247–238 g/km

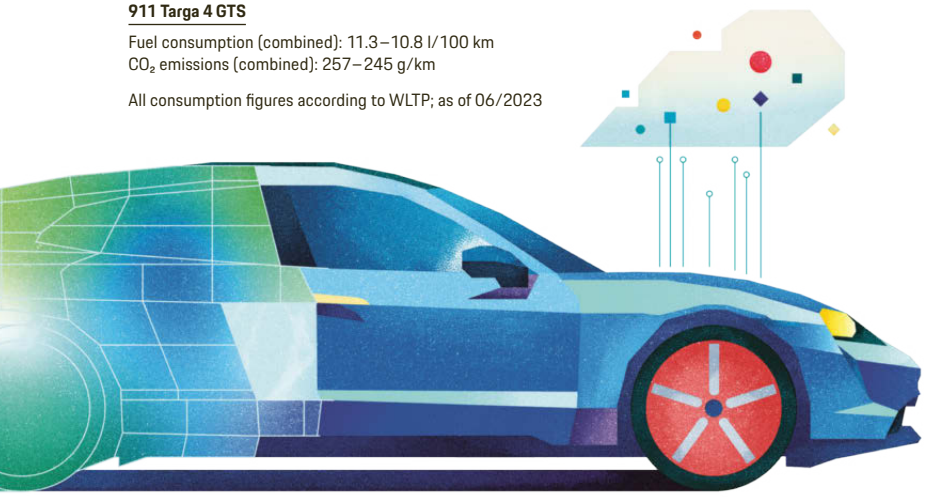
911 Targa 4S

Fuel consumption (combined): 11.1–10.4 l/100 km
CO_2 emissions (combined): 252–236 g/km

911 Targa 4 GTS

Fuel consumption (combined): 11.3–10.8 l/100 km
CO_2 emissions (combined): 257–245 g/km

All consumption figures according to WLTP; as of 06/2023



In the past, a test drive was over when the vehicle was parked in the garage. Today, it also continues well after this—for example, when testing the road-readiness of battery-electric models, which is also carried out at night and on weekends. This involves the vehicle automatically switching itself to start mode several hundred times: The temperature, voltage and capacity of the high-voltage battery are checked and the on-board systems are prepared to hit the road. Each time it is started, data loggers record all communication in the vehicle—up to three gigabytes of raw data per test, or roughly the equivalent of 40,000 emails without an attachment. The measurement data is then sent to the cloud via a mobile network or WiFi, where it is processed and analyzed. All of this proceeds automatically. "When the engineer arrives at the office in the morning, there is an email in their mailbox that indicates the availability of the data and results of the test," says Jonas Brandstetter, Development Engineer at Porsche Engineering.

BOOST THANKS TO THE CLOUD

This type of data-driven vehicle development is rapidly gaining in importance. For a growing number of technical issues, extensive data analyses can provide a broader empirical basis and complement the experience of the engineers. Data-driven development is given an additional boost by the cloud, as much more test data can be evaluated with the help of online processing capacity. This accelerates development work and, at the same time, leads to more effective use of IT infrastructure. "The cloud can deliver added value in almost all areas," says Brandstetter. Experts estimate that the amount of digital information in the vehicle has increased by a factor of ten in recent years. If modern driver assistance, ADAS and safety systems are added to this, the data volume increases again by a factor of 800 (also see the article on page 10). "What customer and test vehicles will deliver in the future can no longer be processed manually," says Daniel Schumacher, Specialist for Cloud Architecture at Porsche Engineering. In concrete terms: In its original version, the bus technology CAN (Controller Area Network) was designed for one million bits per second. Its successor, automotive ethernet, can transmit ten thousand times that amount—ten gigabits per second. In other words, as much data flows through the vehicle in 3.5 seconds as is required for a complete feature film on DVD.

The data also originates from more and more sources. Porsche Engineering has fully equipped its latest test vehicles with the JUPITER system (Joint User Personalized Integrated Testing and Engineering Resource) with laser scanners that record 1.5 million measuring points every second. With the help of the ComBox, which can be installed in the vehicle in just a few steps, this and other information can be transferred to the cloud in real time. Another data source is hardware-in-the-loop (HiL) systems, in which parts of the vehicle are simulated, for example the cockpit with the instrument cluster and operating elements. This allows the infotainment system for a new model to be tested before the actual vehicle is available.

In the past, data was usually analyzed on-premises. Development engineers transferred measured values from the test drives to local computers and evalu-

"In the morning, there is an email in the inbox that indicates the availability of the data and results of the test."

Jonas Brandstetter
Development Engineer at Porsche Engineering

ated them there. The drawbacks of this procedure: A lot of manual work is required; only people in the respective department have access to the data; and a separate IT infrastructure must be set up for each task, the capacity of which might not be optimally utilized later on. These drawbacks can be eliminated by using the cloud. If data is uploaded to a central data lake, any number of developers can access it—whether they work in Czechia, Romania, China, Italy or Germany. "This is the ideal platform for allowing specialists from all over the world to participate," says Daniel Meissner, Senior IT Specialist at Porsche Engineering. What's more, the external computer capacities are adaptable. Entire systems or computing nodes can be added or removed as required depending on the task.

UNIFIED DATA STRUCTURE

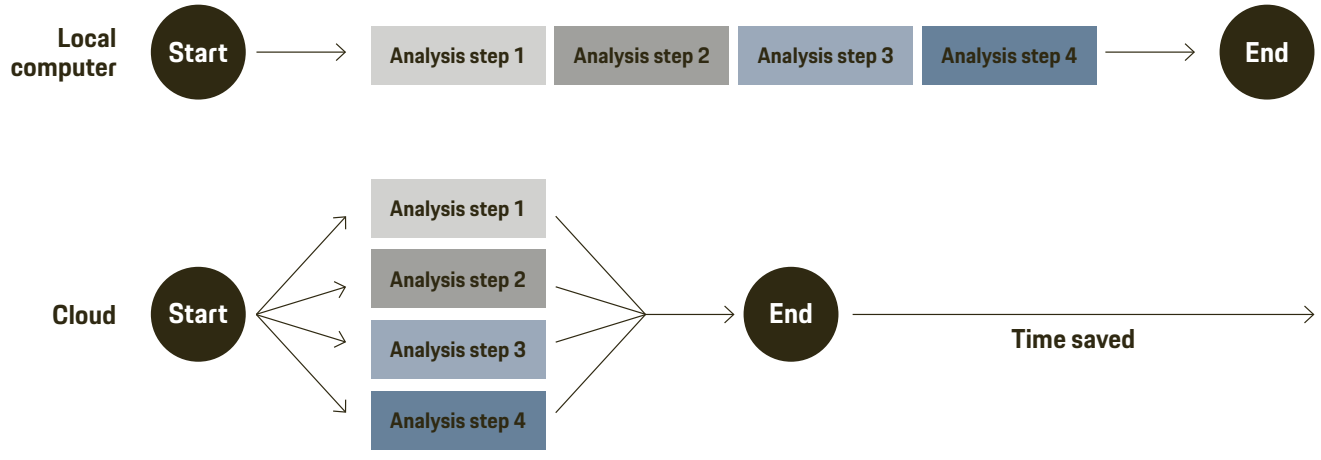
Preliminary work is, however, required to take advantage of the benefits of the cloud. "We need to make all the data available in a uniform structure," explains Schumacher. The format in which a measuring instrument or sensor delivers its data depends on the specific manufacturer and the software used internally. There are also several standards for internal vehicle communication (CAN, FlexRay, automotive ethernet). In order to view the data separately from the respective hardware, Porsche Engineering uses a kind of intermediate layer—the Robot Operating System (ROS). This programming framework, which was originally developed for industrial robots, provides a uniform data format and tools for evaluation.

"What customer and test vehicles will deliver in the future can no longer be processed manually."

Daniel Schumacher
Specialist for Cloud Architecture at Porsche Engineering

Unlike on-premises work, the evaluation of a test drive can begin today while a vehicle is still on the track—anywhere in the world. JUPITER vehicles, for example, are directly connected to the cloud via 5G. This means that the first work step can be carried out while the vehicle is still driving—a step known as pre-processing: The data that was compressed for transport is reverted to its initial state. A selection is then made, as not every piece of digital information is

SIMULTANEOUS, NOT SEQUENTIAL:
ANALYTICS IN THE CLOUD INSTEAD OF ON-PREMISES



ACCELERATED DEVELOPMENT: DATA AND THE CLOUD MAKE IT POSSIBLE

3
gigabytes of raw data can be generated when testing the starting process by electric vehicles.

200
processes can be initiated simultaneously in the cloud to process tasks more quickly.

30
times more test cases are processed in development now than in the past.

1.5
million points are measured per second with laser scanners in JUPITER test vehicles.

10
gigabits per second is how much automotive ethernet can transmit in the vehicle.

5G
enables JUPITER test vehicles to be connected to the cloud.

relevant for the development of a driving function. In the road-readiness tests mentioned above, for example, an algorithm selects those tests in which a control unit on the vehicle bus did not react quickly enough—for example, if it did not start up within the required 200 milliseconds but required 400 milliseconds.

"I only see the one or two cases out of 100 where something didn't proceed optimally," says Adalbert Rosinski, an expert for networking and bus systems at Porsche AG. In the past, he would have had to carry out this time-consuming pre-selection process himself. Moreover, much more data is available since the tests are carried out automatically and are pre-evaluated. "The number of test cases has increased by a factor of 20 to 30," Rosinski estimates. This increases the chance of discovering optimization potential.

EVALUATION WITH MACHINE LEARNING

In addition to the data, the analysis tools that the developers have previously worked with locally must also be transferred to the cloud. This is the step usually associated with the greatest amount of work. "We work intensively with the respective department when converting into code," reports Schumacher. A typical example of automotive development is a threshold or characteristic curve analysis, in which software examines a time series and marks areas in which the data has reached a critical level. In addition, evaluation using machine learning is becoming more and more widespread: An algorithm is fed large sets of real data and autonomously learns to recognize critical moments. Both analysis methods can be transferred to the cloud without any problems.

In order to perform an analysis on multiple computers in parallel, the work must be divided into small packages—experts talk about making it cloud-enabled. An eight-hour test drive, for example, is divided into segments of one hour each. The measurement data is combined with the analysis code to form packages (see box); these containers, as they are called, can then be distributed to virtual machines in the network. "In the cloud, up to 200 processes can be started in parallel," adds

"I only see the one or two cases out of 100 where something didn't proceed optimally."

Adalbert Rosinski
Expert for networking and bus systems at Porsche AG

“Software is the engine of the future—this is underscored by the close partnership we have entered into with the Volkswagen Group.”

Dr. Markus Stinner
Automotive expert at Microsoft Germany

Brandstetter; “in the past, you would have had to have 200 computers available locally for that.”

The developers receive the results of the cloud evaluation in the HyDA format (hybrid data and analysis), this being a mix of measurement data and evaluation. “This enables the engineer to carry out an analysis at every level,” explains Brandstetter. They can, for example, have a complete true/false evaluation displayed for a data series—or, if necessary, take a deep dive into the analysis of 300 individual signals.

NO ALTERNATIVE IN THE LONG RUN

The advantages of working in the cloud are obvious: More speed, more data and a broader data basis for decision-making processes. Moving to the cloud is challenging, however. “It means a completely new way of working,” as Meissner concedes. To make it easier to get started, the cloud experts at Porsche Engineering work intensively with the specialist departments. “We don’t want to take over the work, but take our colleagues along for the ride,” as Meissner describes the approach. In small workshops and accompanied by consultants, the specialist departments bring their processes to the cloud themselves.

The experts agree on one point: in the long run, there is no alternative to data-driven development. “In the future, it will be a matter of validating software before it even reaches the control unit in the vehicle,” explains networking expert Rosinski. Trials will increasingly take place in virtual test environments, he continues. At the same time, significantly more validation cycles will be run in the same amount of time. Without the new architecture in the cloud, he says, this pace would not be feasible.

SUMMARY

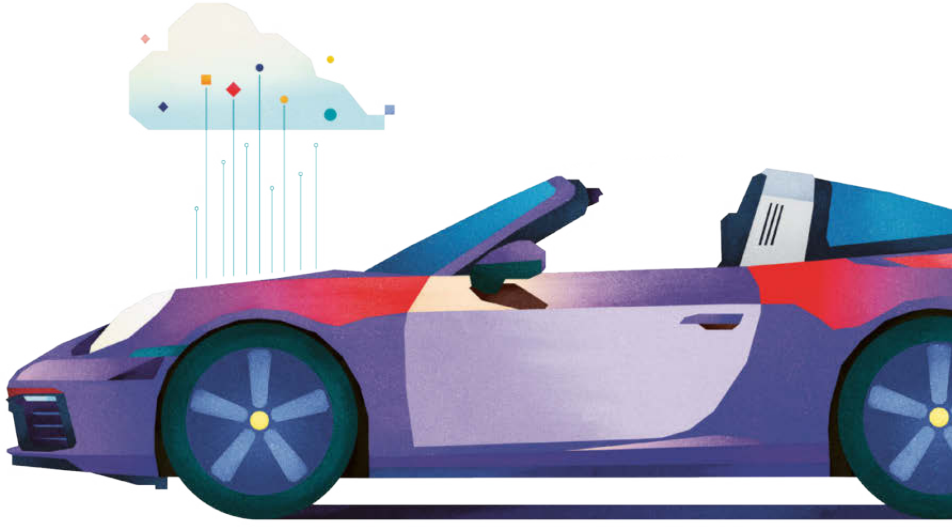
Data-driven development is rapidly gaining importance. The cloud provides an additional boost, as much more test data can be evaluated there in a short time. Porsche Engineering uses data-driven development and is applying the method in more and more technical fields.

ANALYZING DATA DURING THE DRIVE —WITH MAXIMUM SECURITY

Porsche Engineering uses the Microsoft Azure Cloud as a platform for processing development data. The so-called zero-trust model ensures maximum security for sensitive data. The initial assumption is that all devices are insecure, including those connected via a virtual private network (VPN). “Every access must be authenticated, authorized and encrypted,” explains Dr. Markus Stinner, automotive expert at Microsoft Germany. A development vehicle is approached as an Internet of Things device with its own security certificates. Data uploads can be individually authenticated and authorized. “Using this architecture, we can also stream development data from the vehicle with a minimum of delay,” says Stinner.

The actual analysis takes place in a Kubernetes cluster in the cloud. A Kubernetes cluster is a group of virtual machines that can perform many tasks in parallel. The prerequisite for this is that the tasks were first made parallelizable—i.e. divided into small packages. This is done using docker containers, which contain everything the virtual machine needs to be able to work: Operating system (parts), program code and data to be processed. An eight-hour test drive, for example, is divided into segments of one hour each and is then saved together with the respective analysis tool in a container. This means that several hundred hours of test drives can be evaluated in parallel in the cloud.

For cloud provider Microsoft, the automotive sector plays an extremely important role. “Software is the engine of the future—this is underscored by the close partnership we have entered into with the Volkswagen Group.” Autonomous driving will increase the complexity of software even further. “We want to tackle this challenge together with Porsche Engineering.”



Focus on the essentials

Intelligent verification: A newly developed functionality is tested on the HiL test bench (top). The intense testing process ensures that the integration of new features into the vehicle system proceeds smoothly.

A new concept from Porsche Engineering enables complete automation of bench tests for new digital functions. Continuous integration automates not only the tests, but also the accompanying processes. This increases the efficiency of functional testing for Porsche Connect services.

Text: Richard Backhaus

Upgrading the equipment in a Porsche and easily adding optional functions via software—this is possible thanks to the digital services of Porsche Connect. This gives drivers access to a wealth of additional functions that support them before, during, and after their journey. For example, if drivers so choose, they can easily add active lane guidance for even safer driving or an intelligent management function that adjusts the climate and speed settings to the electric vehicle's remaining range.

To ensure that the features are integrated smoothly into the vehicle system and that the many different services work seamlessly together, an international test team of around 110 employees at Porsche Engineering verifies the software for all Porsche model lines and individual models before it enters the vehicle. "The ecosystem formed by modern connectivity solutions such as Porsche Connect is particularly complex, as different software worlds—automotive, infrastructure, and smartphone—are integrated. In addition, there is a wealth of individual software functions that must be tested in all combinations," as Dr. Fabian Hinder, who is a specialist project engineer at Porsche Engineering, explains. The test steps in the laboratory and on the road which the software must be put through are therefore just as extensive as you would expect.

Porsche Engineering has set up 30 special HiL (hardware-in-the-loop) test benches at its locations in Shanghai, Cluj, Prague, Ostrava, and Weissach for bench testing of Porsche Connect services. Only the four core control units installed in the vehicle for the Porsche Connect services are integrated as hardware; the other vehicle systems are reproduced in a virtual real-time environment. "This residual bus simulation, as it is known, is primarily used to generate the communication data for the various bus systems, meaning that we can test the Porsche Connect services under realistic conditions on the test bench," says Daniel Klauber, a development engineer at Porsche Engineering. During the tests, it is examined whether the software reacts as specified to various situations generated by the simulation. "Based on the results of these basic functional tests, known as smoke tests, the experts at Porsche Engineering decide how the further test sequences should be structured," explains Klauber. These examinations are conducted at different locations around the world to test market-specific functions.

Even though the residual bus simulation and the implementation of the HiL test have been largely automated for a long time, the preparation of the test bench before and the processing of the results after the test were largely conducted manually. For example, the test bench engineers had to manually select the latest Connect software from the data management system and load it onto the control units in the test environment.

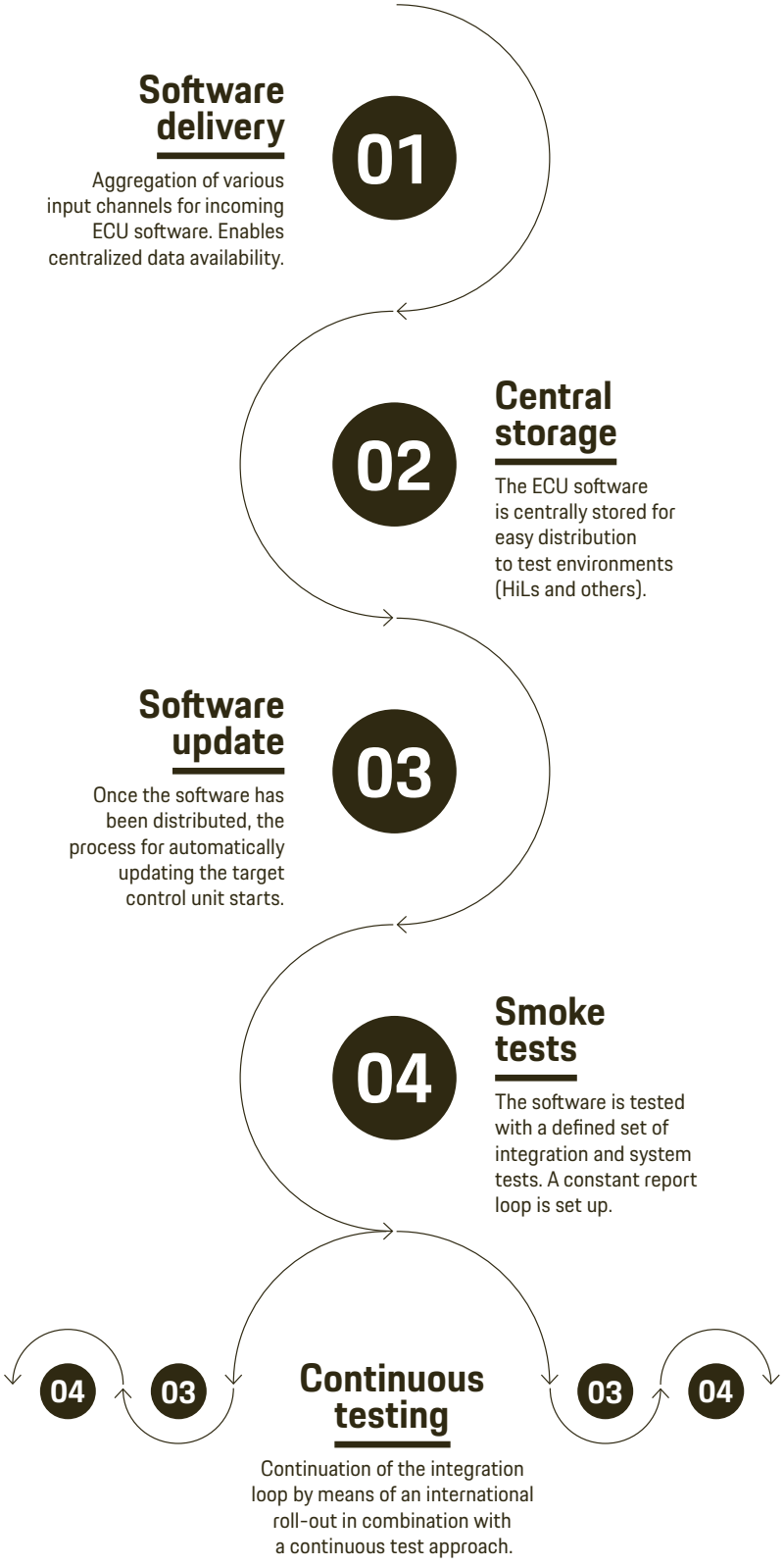
COMPLETE AUTOMATION

A new Porsche Engineering concept now ensures complete process automation of the test bench tests. Not only are the tests themselves being automated, so are the accompanying processes. The system manages the software for the Connect services independently, and also uploads it to the test control units. The control unit parameterization and the start, execution, and analysis of the bench tests are also

"The ecosystem formed by modern connectivity solutions is particularly complex, as different software worlds are integrated."

Dr. Fabian Hinder
Specialist Project Engineer at Porsche Engineering

CONTINUOUS INTEGRATION
AUTOMATED TEST PROCESS CHAIN



automated. "This reduces the test engineers' workload and speeds up the tests, as there is no need to carry out manual tasks between the process steps. The time required for manual work to prepare the test benches is thus reduced by around 90 percent. The system also actively alerts the test team to critical test results. The team can therefore concentrate fully on error analysis," says Hinder.

INTERDISCIPLINARY TEAM

In addition, extensive expert knowledge is no longer required for some activities on the test bench, as was the case, for example, for the manual update of new software to the test control units. "In the Connect environment, there is an extremely high variance due to the number of services, the number of vehicle model lines to be served, and the number of markets. In order to be able to cover these variants with tests when there are weekly software deliveries, it is imperative that the HiL test bench be fully automated," says Carsten Weigt, Team Lead Shared Test & Integration at Porsche AG.

Full automation was implemented with in-house know-how by an interdisciplinary project team at Porsche Engineering. Experts from the areas of software development, process automation, test automation, residual bus simulation, and test infrastructure design worked together at various locations worldwide. Part of the teams' work involved supplementing the existing building blocks with interfaces it had developed itself to allow a more far-reaching automation of the process chain. "To reduce complexity, we defined automatic routines that make it easier for us to trigger processes," explains David Karimi, a development engineer at Porsche Engineering.

"It is imperative that the HiL test bench be fully automated."

Carsten Weigt
Team Lead Shared Test & Integration
at Porsche AG

The experts used in-house developments to compensate for any lack of full-automation building blocks. This allowed, for example, a local client to be created for controlling the test benches, as well as what is known as a software crawler, which automatically downloads software from suppliers' servers. Other examples include generic control logic and reporting tools for documenting all results of the individual automated process steps.

MODULAR DESIGN

The methodology used to fully automate the test benches is also referred to as continuous integration. At its core, the methodology is based on the open-source software system Jenkins, which allows ongoing assembly of software components to form an application. "Porsche Connect services continue to be developed fast and dynamically. In order to be able to safeguard the new services and changes in good time—despite the pace of development—we have pushed ahead with the introduction of HiL automation. With continuous integration, we can now automatically download new control unit software, and flash and code the control units very efficiently," explains Dickson Ng, Product Owner Automation Platform & Continuous Integration at Porsche AG.

With its modular design, the continuous integration methodology offers a high degree of flexibility for adaptations and extensions, because different modules can be integrated into a new overall process depending on the use case. "This makes our approach suitable for automating all bench tests for all domains," says Hinder. "We have already received the first requests from other departments." For the time being, however, the project team is focusing on integrating full automation into all Connect HiL test rigs from Porsche Engineering worldwide. Following the successful initial implementation, all other test rigs in Germany, China, and the Czech Republic are now to be retrofitted. It is planned that all HiL test rigs for Porsche Connect services will be in fully automated operation by the end of 2023.

"To reduce complexity, we defined automatic routines that make it easier for us to trigger processes."

David Karimi
Development Engineer at Porsche Engineering

SOFTWARE TESTING PIPELINE

From the delivery of new software versions to the report: The test process in Jenkins follows a precisely defined workflow (a concrete example is shown below, which took around three-and-a-half hours—and includes the exact times for the individual steps). Manual intervention is no longer necessary.

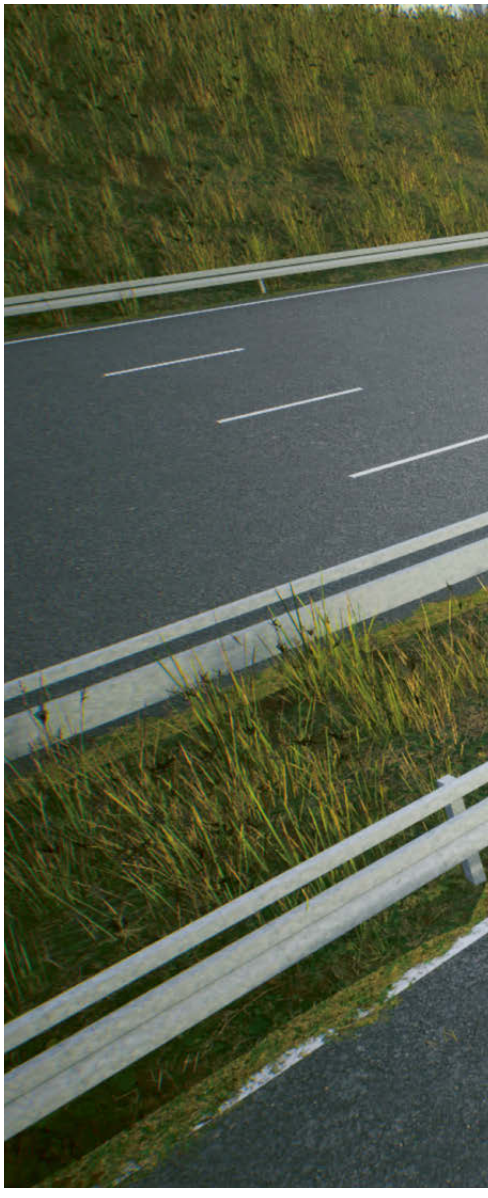
Software checkout	ECU update	Smart vehicle testing	Infotainment testing	Report generation
1 min 1 sec	33 min 0 sec	2 h 0 min	49 min 5 sec	6 min 2 sec
New ECU software is identified, processed, and distributed to the selected HiL environment.	A special component handles automatic flashing and coding as well as additional ECU-specific checks.	Different types of test tools are triggered with a predefined set of automated test cases. The results are evaluated.		Each step from previous actions is collected and reported to team-specific endpoints.

01 REAL TEST DRIVES

Automatic detection: JUPITER test vehicles from Porsche Engineering provide video, radar, and lidar data of real traffic situations.

Automatic analysis

Algorithms record the course of the road, the position of road users, and the road users' behavior. Critical situations such as sudden braking are detected.



Simulated. Automated. Varied.

Functions for highly automated driving must be intensively validated by means of simulations. In the AVEAS research project, Porsche Engineering is working on automated detection of critical traffic situations from sensor data using AI and storing the situations in a database. The route models and traffic situations generated in this way are also varied in order to generate more test cases for virtual validation.

Text: Constantin Gillies

“We are currently developing a method that will continue to recognize road users even when that category of road user has not been seen for a long time.”

Leon Eisemann
Doctoral candidate and specialist in image recognition at Porsche Engineering

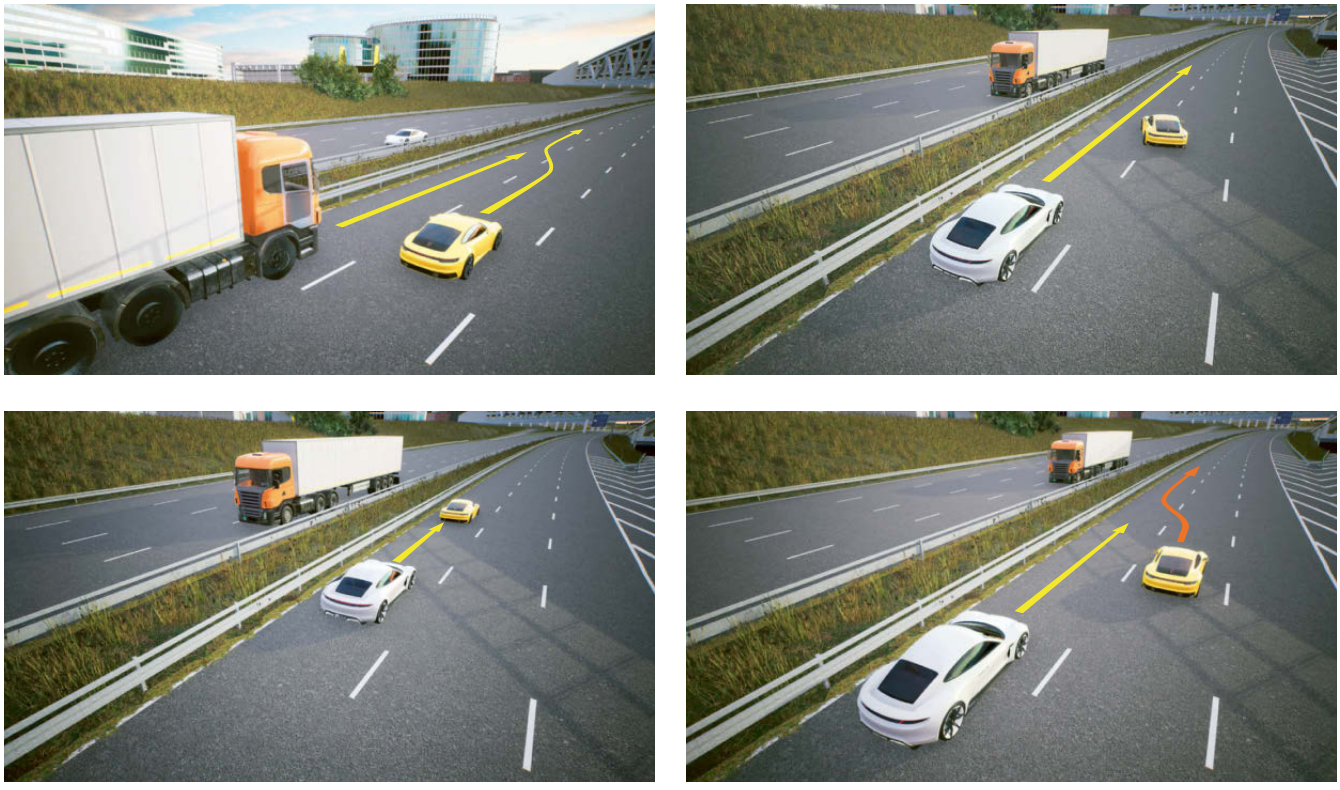
Abstract description

Meta-processes are derived from the individual trajectories, for example, ‘the vehicle stops at the intersection and then moves off again’. These meta-processes can be varied later in the simulation.

DATA EXTRACTION, SITUATION IDENTIFICATION AND ROUTE MODELING 02

Virtual test drives: Developers can recreate real-world journeys in the PEVATeC simulation framework.

03 GENERATING SCENARIO VARIATIONS



Endless possibilities: Critical situations such as a cut-in process can be simulated thousands of times with different parameters.

"We are building a complete catalog of critical scenarios that will enable us to validate driver assistance systems and functions for highly automated driving."

Dr. Joachim Schaper
Head of AI and Big Data at Porsche Engineering

Tille Karoline Rupp
Responsible for Simulation at Porsche Engineering

A **vehicle overtakes** and pulls in again leaving too little distance in front of the car behind—at such moments, accidents are often only narrowly avoided. Today, the driver usually prevents the worst by braking or evading. The autonomously driving vehicle of tomorrow must also be able to react safely at critical moments, which is why Porsche Engineering is already playing through such scenarios intensively in simulations today.

When doing so, the engineers specifically increase criticality, for example by reducing the distance between vehicles. "We are building a complete catalog of critical scenarios that enable us to validate driver assistance systems and functions for highly automated driving," explain Dr. Joachim Schaper, Head of AI and Big Data at Porsche Engineering and Tille Karoline Rupp, Responsible for Simulation at Porsche Engineering.

The virtual tests are part of the AVEAS research project (the acronym comes from the German phrase *Absicherungsrelevante Verkehrssituationen erheben, analysieren, simulieren*, which means 'collecting, analyzing, simulating traffic situations relevant to validation'), in which, in addition to Porsche Engineering, a further 20 partners are involved, including several Fraunhofer institutes and the Karlsruhe company understand.ai.

SIMULATABLE SCENARIOS

AVEAS aims to eliminate a major hurdle in the path of autonomous driving: lack of data. In order to validate functions for highly automated driving, billions of test kilometers would theoretically have to be driven. Because this would involve an

enormous amount of time and money, real journeys are supplemented by journeys in the simulation. However, this is particularly difficult in critical traffic situations, as there is a lack of real basic data for the simulation—after all, in normal traffic situations, marginal situations rarely occur. AVEAS is intended to fill this gap. The aim of the project is to evaluate test drives automatically and to prepare the critical traffic situations as simulated scenarios.

Porsche Engineering is contributing a number of key components to this. For example, a JUPITER test vehicle (Joint User Personalized Integrated Testing and Engineering Resource) is being provided for the test drives. It is equipped with cameras, radar, and lidar sensors and sends the data it measures to the cloud. Porsche Engineering also handles the evaluation: Algorithms automatically record the course of the road, the position of other road users, and the road users' behavior.

The machine learning methods used are constantly being refined. "We are currently developing a method that continues to recognize road users even when that category of road user has not been seen for a long time, for example because they have been hidden behind a truck," says Leon Eisemann, a doctoral candidate and specialist in image recognition at Porsche Engineering. The recorded traffic events are stored in standardized file formats such as ASAM OpenDRIVE (logical description of the road network) or ASAM OpenLABEL (objects and the dynamics thereof). AVEAS can therefore also provide input for other projects, such as route modeling (see box).

In a second step, algorithms select the critical traffic situations by focusing, for example, on short clearances or unusually intense deceleration forces. "The relevant degree of criticality always depends on the driving function to be tested later," emphasizes Nicole Neis, a doctoral candidate in the field of simulation at Porsche Engineering. For example, if Adaptive Cruise Control (ACC) is to be validated, the need for sudden braking before hitting the tail end of a traffic jam would be a relevant critical scenario.

Environmental factors can also trigger critical scenarios. For example, when the vehicle approaches the exit from a tunnel, the glare may dazzle the on-board cameras. The selection algorithm also highlights those kinds of traffic situations so that they can be used to safeguard driving functions—after all, the autonomous vehicle should react as calmly as a human driver, for example by reducing speed or prioritizing other sensors.

First, the (simulatable) driving scenarios consist of position data gleaned from road users over time; experts call this a 'trajectory-based' description. In order to be able to vary a driving scenario later on in the simulation, it must be described in abstract terms—i.e. as 'based on maneuvers'. To this end, meta-processes are derived from the individual trajectories, for example, 'the vehicle stops at the intersection and then moves off again'. This scenario can then be added to any starting point in a virtual course and can be modified later.

EXTENSION OF THE TEST SPACE

The virtual test drives take place in the internally developed simulation environment known as PEVATeC SimFramework (Porsche Engineering Virtual ADAS Testing Center Simulation Framework). The real journey can be reconstructed (simulated) and then be played through after specific modifications have been made, all within the digital world. "In what is known as scenario sampling, the real critical situations are systematically modified, which artificially extends the virtual validation test space," explains Rupp.

A cut-in maneuver, for example, can be repeated thousands of times with different parameters: with a higher cut-in speed, a shorter clearance (time headway), or adverse environmental conditions such as a wet road. This targeted variation of parameters also allows test scenarios to be created that cannot be driven in real terms for safety reasons alone—such as emergency braking to avoid hitting the tail end of a traffic jam.

In the last step, synthetic marginal scenarios are used to validate and optimize the driving function in question. To this end, Porsche Engineering is constructing a digital twin of the JUPITER test vehicle. "The 'Digital JUPITER' contains the same interfaces and sensors as the real vehicle," explains David Hermann, a doctoral candidate and specialist project engineer in the field of simulation at Porsche Engineering. "All functions can be tested on a one-to-one basis." Porsche Engineering will use the Digital JUPITER to evaluate and optimize an

Testing the driving function

The synthetic scenarios are used in the simulation to validate and optimize the driving function in question. To this end, Porsche Engineering is constructing a digital twin of the JUPITER test vehicle.

"The relevant degree of criticality always depends on the driving function to be tested later."

Nicole Neis
Doctoral candidate in the field of simulation at Porsche Engineering

"The 'Digital JUPITER' contains the same interfaces and sensors as the real car."

David Herrmann
Doctoral candidate and specialist project engineer in the field of simulation at Porsche Engineering

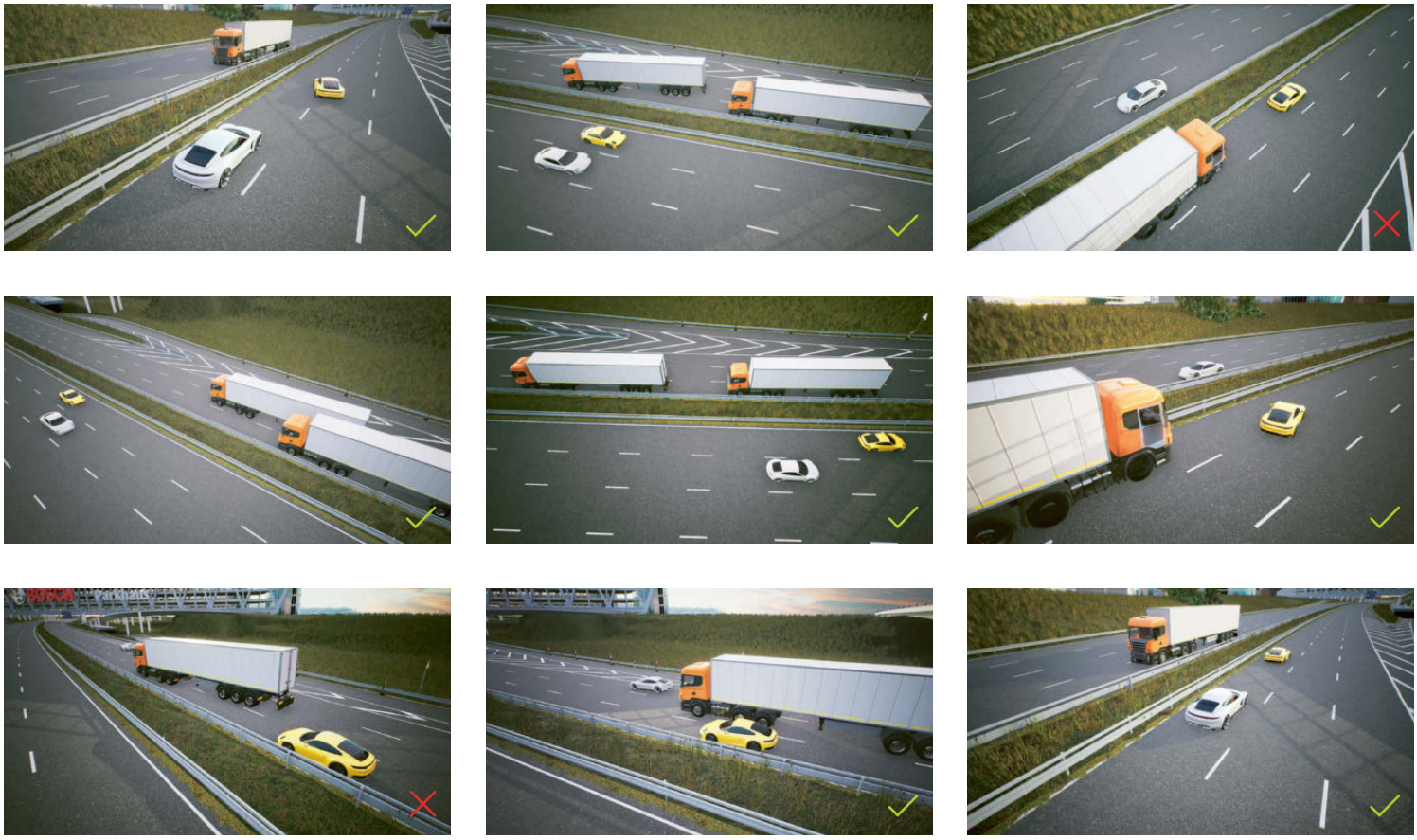
Adaptive Cruise Control function and a parking function (Reverse Assist) within the framework of AVEAS.

FIRST PATENTS FILED

In order for real and virtual test drives to be congruent, a lot of experience is required—much of which must be gained in the analog world. "What is needed is a deep understanding of how real technology and simulations are related," Schaper emphasizes. A virtual vehicle, for example, has to react to different road surfaces just like the analog model.

The project, which was launched in December 2021, has already delivered its first results. "There are many links in the process chain, test drives are underway, and some patents have already been filed," says Michael Strobelt, who coordinates Porsche Engineering's participation in AVEAS. However, the fundamental work has also brought challenges. "Mapping reality with its high degree of variability is exacting," as doctoral candidate Eisemann underscores. Detection algorithms, for example, must be able to identify vehicles from all over the world—not just German ones. "Interface management also plays a major role," adds Neis, who is also pursuing a doctorate. Since AVEAS partners contribute data from different sources, the exchange of information requires accurate coordination. The Karlsruhe Institute of

04 SIMULATION & EVALUATION



A simulated endurance test: The virtual test environment shows whether the driving function reacts as desired (green checkmark) or whether it needs to be improved (red X).

Technology, for example, provides aerial photographs of roads, and these are also incorporated into the construction of the digital scenarios.

AVEAS will be running until the end of 2024, by which time a scalable pipeline for the evaluation of driving scenarios should be in place—as well as a catalog with many hundreds of thousands of critical scenarios. Both could greatly accelerate development work in the future. Rupp describes the long-term vision as follows: "Scenarios are generated during the test run and used immediately in the simulation to optimize the driving function." After validation, an over-the-air update could then be used to add the scenarios to the vehicle.

Optimization and validation

By simulating thousands of critical traffic situations, the new driving function can be efficiently optimized and validated.

SUMMARY

In the AVEAS research project, Porsche Engineering and its partners are working on automated detection of critical traffic situations in sensor data with the help of AI and storing the situations in a database. They are also varied to generate more test cases. The scenarios are then translated into a simulation, where they are used to validate driver assistance systems and functions for highly automated driving.

ROUTE MODELING
PRECISE MAPPING OF THE WORLD

Simulations require a world in which road users can move, and with which they can interact. "These route models are a fundamental component of every ADAS/AD simulation—no route model, no virtual test drive," says Tille Karoline Rupp, Responsible for Simulation at Porsche Engineering. Route models, referred to in technical jargon as the 'scene', describe both the driving area (road, parking space) and the surrounding area. They consist of a mathematical model of the road network in OpenDRIVE format and a 3D model that describes the exact appearance and material of the objects.

Digital maps, such as those used by commercial navigation systems, are not precise or detailed enough for this. "For example, there is a lack of information about the width of the lanes and road markings," explains Tobias Watzl, a development engineer in the field of simulation with responsibility for route modeling. Depending on the task, high-resolution maps, freely available OpenStreetMap material, elevation models, and much more can be combined. "In order to be able to virtually map the large number of test kilometers required in an appropriate time frame, we are working on our own, highly automated route modeling process," adds Rupp. The degree of automation in the creation process is constantly increased.

As part of the AVEAS project, the JUPITER test vehicles that are used feed measurement data into the route modeling process. They use their lidar sensors to scan the surroundings and transfer the resulting point clouds into the cloud. Since road markings reflect differently from asphalt, they can be easily identified in the lidar data. Special algorithms calculate a continuous overall line from the individual markers (this process even works if individual markers are missing). The result is a precise geo-referenced image of a real street in OpenDRIVE format. This is contrasted with generic route models that are not based on a specific real road (example: ten kilometers of a two-lane freeway).

Line modeling requires high precision. The road geometry determined must be accurate down to the centimeter, otherwise, for example, the vehicle distances would not be correct later on when lane changes are simulated. One challenge is that, since roads in OpenDRIVE format are described as mathematical functions, discontinuities can arise that would appear in the simulation as a 'sharp bend' in the road. Such discontinuities must be interpolated. "The digital twin often drives a route several hundred thousand times—every detail must be right," stresses Watzl.

"Data-driven development is essential to make increasing complexity manageable."

Dr. Michael Steiner
Member of the Executive Board for Research and Development at Porsche AG

Experts in innovation: Dr. Michael Steiner (left) and Markus-Christian Eberl look back on a successful collaboration—and see a lot of potential for the future.

“We unite virtual, algorithmic and data-driven development with the real world.”

Markus-Christian Eberl
Chairman of the Executive Board
of Porsche Engineering

Sustainability, artificial intelligence, and the new partnership between OEMs and technology service providers: In this interview, **Dr. Michael Steiner**, Member of the Executive Board for Research and Development at Porsche AG, and **Markus-Christian Eberl**, Chairman of the Executive Board of Porsche Engineering, discuss the most important topics in automotive development.

Interview: Christian Buck
Photos: Andreas Reeg

"Our aspiration is to be a technology partner for the intelligent and connected vehicle."

Markus-Christian Eberl

Which trends will most shape automotive development in the future?

— **STEINER:** Electrification will soon become ubiquitous in the automotive industry, though it will not entirely dominate it. After all, the pace of transformation is likely to vary in different market segments and regions of the world. Moreover, thanks to higher data transmission rates and data availability, as well as connection to backends in the cloud, more and more functions will be available in the car. Conversely, functions could then also shift from the vehicle to the backend. In this respect, the 'software-defined vehicle' will increasingly influence the automotive industry. Development, in turn, will increasingly involve software methods and simulation vehicles due to the increasing complexity alone.

Mr. Eberl, what is your view of the most important trends?

— **EBERL:** I would like to address the increasing heterogeneity of the world. We are observing changing expectations of vehicles. In many regions, we are seeing the emergence of new customer expectations influenced by independent, local ecosystems, among other factors. We have to respond to this on the vehicle side. There is also rising heterogeneity with regard to technical regulations: The requirements for vehicles and therefore our service products as well are becoming more diverse and increasingly demanding. We have to adapt to these developments and act in a manner that is specific to different regions of the world. Another megatrend I would like to mention here is the topic of ecological sustainability: Actually, the term 'trend' does not really do justice to this topic area, because it is more a widely recognized and accepted need for action—this is much more than a mere trend. The realization that humankind must respond to the CO_2 problem and also to other environmental issues has become increasingly widespread in recent years. For us, this means that the importance of sustainable engineering continues to grow.

— **STEINER:** Of course, this is particularly true for a manufacturer of luxury products like Porsche. We want to and must also be a role model in the area of sustainability—not only when it comes to operation of the vehicle, but also in its manufacture and recyclability. Admittedly, the latter does not play such a major role at Porsche because most of the vehicles we produce are never really taken out of service. And yet: Anyone who wants to credibly exemplify luxury today cannot do so only through high-tech, quality and brand. It also requires being a leader in terms of sustainability.

Markus-Christian Eberl
has been the Chairman of the Executive Board of Porsche Engineering since June 2023. He was previously Vice President Technical Conformity at Porsche AG. He holds a Diploma of Engineering, having studied aerospace engineering at the University of Stuttgart.

We haven't heard much about highly automated driving lately. What can we expect here in the future?

— **STEINER:** Technically, a lot is already happening today. I think that in two or three years, Level 4 driving will be technically possible, in principle. But that's not an issue at Porsche at the moment. Since people always want to drive a Porsche themselves, Porsche cars will always have a steering wheel and pedals. But that doesn't mean that we won't offer our customers automated driving functions up to Level 3 in the future, for example to lighten the strain on drivers when parking or in traffic jams on the highway. When it comes to automated driving functions, our aim is not to be first to

Dr. Michael Steiner
has been the Member of the Executive Board for Research and Development at Porsche AG since 2016. He previously served as Vice President Complete Vehicle Engineering/Quality Management. The mechanical engineer obtained his doctorate from the Technical University of Munich in 1995.

market. Rather, the focus of development for Porsche is on the highest possible utility and high reliability. Overall, however, highly automated driving at Level 4 or even Level 5 has to be approvable and make economic sense. In some cities—including Phoenix and San Francisco—test fleets are already on the road, in some cases in semi-commercial operation and without drivers. This works, but only with extreme technological outlays. It's not yet economically viable. Another challenge is that to a large extent, many of the vehicles work with AI methods. One major challenge in this context is to provide the required proof of safety in a deterministic sense, because these systems learn. Performing test drives over millions of kilometers is no longer sufficient for this purpose. Instead, we need complementary methods—for example, through limiting driving strategies of a more deterministic nature, in the context of which the vehicle can develop a detailed strategy using AI methods.

"The 'software-defined vehicle' will increasingly influence the automotive industry."

Dr. Michael Steiner

— **EBERL:** At Porsche Engineering, we are consistently investing in methods and capabilities for the intelligent and connected vehicles of the future. After all, we are certain that significant progress will be made in this area in the near future. I would like to touch on the following factors here: First, enhanced connectivity and driving assistance functions can turn lost time directly into useful time, for example in a traffic jam situation. This reduces waste of one of our most valuable resources—our time. This suggests that assisted driving functions will continue to increase, until reaching the point of automated driving. The second factor is a technical enabler: geometrically miniaturized computing power that is decreasing in price and increasing in performance. Today, this enables real-time processing of large quantities of sensor data in the vehicle. This is precisely the area in which we have built up extensive expertise and capacity. And we have the great advantage of being able to combine the virtual, algorithmic, and data-driven development of corresponding functions at our test site in Nardò with the real world—thus representing true end-to-end engineering.

— **STEINER:** That's an important point. Every manufacturer wants to work in a secure and reproducible environment so that they can efficiently test new functions in a wide range of variations, and train vehicles and networks.

What other issues are you currently focusing on?

— **EBERL:** The topic of innovation competence is a major issue for me, because innovation cycles are becoming shorter and shorter nowadays. It is crucial for us to maintain or even enhance our innovative capability. That sounds straightforward, but it is difficult. Innovation competence means that innovations have to make it through the entire funnel to the end product. Our employees come up with innovative ideas, both small and large, almost every day. A key challenge that this involves is to pave the way for good ideas and not let them fall victim to everyday operational obligations or formalities. Culture plays a major role in being able to achieve that—even for a service provider. If I want to be a technology partner today, I have to deliver more to my customers than just a simple answer to the question they posed.

“We need an open culture of innovation—including from the partner to us.”

Dr. Michael Steiner

What does that mean in concrete terms?

— **EBERL:** Our aspiration at Porsche Engineering is to be a technology partner for the intelligent and connected vehicle. What that means is that we have the ability to think outside the box and provide our customers with an answer that extends beyond a potentially restrictive question—in other words, to think along with them, to open up the solution space, to participate in the design of the solution in a creative sense, and thereby deliver added value. To do this, we need appropriately designed interfaces to and collaboration models with our clients: Our approach with clients is to bring our own ideas to the table without losing sight of the original task, of course. This leads to added value for both sides: For the customer and for the service provider and its employees.

— **STEINER:** I can only second that. Not all of tomorrow's innovations will come from Weissach, but also from partners and certainly to some extent from completely different industries. That's why we need an open culture of innovation—including from the partner to us. And that's also why Porsche Engineering is so popular, not only with us. The engineers and software developers bring their own ideas to the table, yet remain customer-focused. It doesn't make sense to try to make something palatable to customers which they don't even want. Porsche Engineering also has the ability to provide input as a suggestion during the course of a project which wasn't part of the specifications but adds value. We then have to listen and not close things down right away. That's what I mean by innovation permeability.

What distinguishes Porsche Engineering in its role in a partnership of equals?

— **EBERL:** To be successful, you need knowledge, for starters. But you also need experience, which is something you can't just conjure out of thin air, because it accrues over a long period of time and is a kind of cumulative knowledge from continuous activity. As a subsidiary of a manufacturer, we have been active in automotive development for decades and understand not only the new topics, but also their interconnectedness with the traditional disciplines as well as their integration into the overall vehicle. So we not only have specific knowledge, but also experience—a lot of experience! The third ingredient is culture: We create framework conditions that unleash creativity and promote our capacity for implementation. We structure our services on the basis of these three pillars—knowledge, experience and culture—to meet the specific needs of our customers. With this Porsche Engineering triad, we generate added value for our clients.

Mr. Steiner, cars are becoming increasingly complex. Is this shifting the division of labor between OEMs and development partners?

— **STEINER:** There will be a tendency for more development to be carried out by third parties in the future. This has to do with several factors: First, many development service providers have specialized—from integrating a new radar sensor into an existing vehicle system to developing a complete vehicle variant. As a manufacturer, we formulate a strategy for in-house and third-party services. There has long been a trend for technical value creation to increasingly be done by development service providers. Secondly, we face the major challenge of finding qualified personnel in Germany and Central Europe. The existing shortage of experts means that we must increasingly head to places where well-trained employees can be found. This includes China, where there are many computer scientists, electrical engineers and mechanical engineers. India is very strong in terms of software expertise, as are parts of Eastern Europe. There are limitations on the ability to bring all these talented people to Central Europe. Instead, companies have to go where the talent is available. And this can also involve going through tech partners like Porsche Engineering.

Can the use of AI and data-driven development help alleviate this shortage of experts?

— **STEINER:** Data-driven development is essential to make increasing complexity manageable. Because computers are much better than humans at pattern recognition, we also need to use this approach. This has a positive side-effect:

If we develop in a more data-driven way and use AI methods to find errors and anomalies, we might also be able to optimize solutions in an automated way—in other words, carry out development activities with computer support. And in the future, we might be able to work in a more geographically distributed way in a network of development hubs around the world. Not everything will become data-driven and virtual overnight, but we will presumably see more and more of it.

— **EBERL:** To enable precisely that, we are investing in our own methodological capabilities not only with a view to specific customer demand, but out of conviction. Take the JUPITER test vehicles, for example, in which we can integrate and test new sensor technology for automated driving very quickly on the basis of standardized middleware such as ROS and DDS. Using code libraries, we can quickly access these sensors or their data, for example, to create and test new algorithms. We are doing this because we believe that data-driven development will play a decisive role in the complete pipeline from collection to storage and control of data. That is why we are also continuing to upgrade the testing grounds in Nardò, where a high-performance 5G network is already available today. With this technology in place, we can, for example, offer support to our customers with cloud-based data services, so that their developers can access newly generated data directly and quickly, not just on site, but worldwide.

— **STEINER:** Being able to access data from vehicles on a test track like the one in Nardò here in Weissach in real time, with high bandwidth, is something we've dreamed about for a long time. And that dream is now coming true.

Mr. Steiner, let's look 20 years into the future. What will be different in a Porsche compared to today? And what will remain the same?

— **STEINER:** Some things will remain the same or continue to improve step by step: For example, we will continue to work on ensuring that the vehicle implements all the driver's wishes even more precisely and responsively—whether on the steering wheel, the brakes, or the accelerator pedal. But some things will also change fundamentally, such as the interaction with the vehicle: It will be done more through natural language, with which the driver can call up comfort or office functions. Video conferencing will probably also become a matter of course. This will be made possible by connectivity to the outside world that is at least double-redundant. It is likely that vehicles will also communicate with each other, perhaps via 6G or 7G networks. Vehicles will also store and use energy more intelligently. Advances in cell chemistry will mean that batteries will become smaller and cheaper. Their initial CO_2 footprint is also likely to shrink—as will plastics and aluminum and steel. Green steel, for example, is likely to become the state of the art in the future, and hopefully green aluminum as well. Just a few weeks ago, we entered into a new partnership with the Norwegian company Hydro, which will work with us to further reduce the CO_2 footprint of our vehicles with regard to the use of aluminum. And of course, in 20 years' time, a Porsche will also be able to drive itself, at least in the vast majority of situations. At the same time, however, driving should be at least as much fun as it is today, because we want to bring the performance of today's super sports cars to normal Porsche vehicles.

"We create framework conditions that unleash creativity and promote our capacity for implementation."

Markus-Christian Eberl

911 Carrera S Cabriolet

Fuel consumption (combined): 11.0–10.3 l/100 km;
CO_2 emissions (combined): 250–233 g/km

Taycan

Power consumption (combined): 23.9–19.6 kWh/100 km
CO_2 emissions (combined): 0 g/km
Range (combined): 371–503 km
Electric range (city): 440–566 km

Cayenne E-Hybrid

Fuel consumption weighted (PHEV model range): 1.8–1.5 l/100 km
Power consumption combined (weighted) (model range): 30.8–28.7 kWh/100 km
CO_2 emissions (combined): 42–33 g/km
Electric range (EAER) (model range): 66–74 km
Electric range (EAER City) (model range): 77–90 km

All consumption figures according to WLTP; as of 05/2023

On roads around the world: To validate new vehicles, Porsche Engineering teams take their work to Norway (top left), the US (bottom left) and China, among other locations around the world.

Real-world endurance testing

In international validation, development engineers and testing and quality staff ensure that the entire vehicle meets expectations in real-world operation in the context of market-specific function validation. They combine their in-depth technical understanding with detailed knowledge of the respective markets to deliver a high quality and first-class customer experience.

Text: Marc-Stefan Andres, Christian Buck (Interview)
Photos: Anthony Dias, Luca Santini

Shanghai, China: Public-road validation in Shanghai is used to test, for example, the handshake of a hybrid vehicle and the customer's charging experience. The aim is to ensure that the Porsche meets the brand's high quality standards.

The Porsche Cayenne has been driving through urban canyons of Shanghai for several hours now. The drive seems directionless, yet the driver is following a well-thought-out plan. He stops several times to recharge the battery of the plug-in hybrid—for example in supermarket parking lots or in parking garages where there are public charging stations. At the different stops, he tests different payment methods such as credit cards and apps. The frequent recharging processes have a special purpose: The new vehicle is on the road as part of its international validation before the start of series production, with a local test driver at the wheel. This process is used to ensure that the Porsche satisfies the high expectations of customers and delivers on the brand's promise of quality later on. Both the 'handshake' with the charging station and the charging experience for the customer are tested.

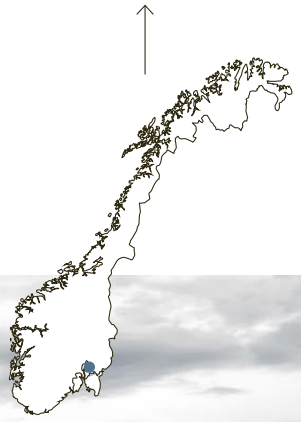
"When we start international validation, the development of the model is already so far advanced that we have basic testing, maturity tests, and release tests behind us," explains Alexander Kopp, who together with Fabian Wörner is responsible for coordinating complete vehicle validation at Porsche Engineering in the 'Complete Vehicle Validation & Analysis' team. "Quality assurance therefore has a particular significance: It is important to drive the models in real-world situations in the same way that customers do—under what are sometimes changing conditions, since the world doesn't stand still. Things

are always changing—laws are often amended, for example." Differentiated, detailed validation in a wide variety of markets is therefore extremely important for the customer experience. There's no other way for a Porsche to reach production maturity, because the functional, visual and emotional quality of the product is revealed by the details.

VALIDATION IN TWO SHIFTS

It is important for the validation drives to be conducted at many different locations in order to obtain as complete a picture as possible. Market-specific circumstances such as local traffic conditions or specific infrastructure for online services can only be validated in that particular location. This is why Porsche Engineering has development engineers as well as testing and quality staff working all around the world. Local validation drivers work with them in two shifts a day, with each driver spending a third of the driving time in the city, on country roads and motorways, respectively, in order to get as realistic a picture as possible. "It is precisely this combination of high evaluation expertise and local understanding that sets Porsche Engineering apart," says Dr. Nazif Mehmet Yazici, who is responsible for complete vehicle quality and validation in the Corporate Quality department at Porsche AG (see also the interview on page 38). "That's why we have been working closely and successfully together for years."

With the introduction of comprehensive Connect services, the importance of market-specific function validation has increased immensely. Experiencing vehicle functions and services in real-world operation under country- and market-specific conditions, with a focus on local functionality and interoperability, provides early insights that can help improve product quality and customer satisfaction. For certain purposes, such as validating the charging functions of electric vehicles, intensive validation procedures called special programs are also conducted. This trend is likely to continue in the future: "Due to technological advances, we are being confronted with an explosion of potential vehicle functions,"



Oslo, Norway:
Norway is a pioneer in the field of electrification. That's why vehicle interoperability with charging infrastructure is particularly important in this market.

"It is important to drive the models in real-world situations in the same way that customers do—under what are sometimes changing conditions, since the world doesn't stand still."

Alexander Kopp
Responsible for coordinating complete vehicle validation at Porsche Engineering

Los Angeles, US:
Functional development must also take into account special factors in the US, such as non-uniform lane markings.
Christian Friedl, Dr. Peter Schäfer, Dirk Lappe and Dr. Nazif Mehmet Yazici (from left to right) went to see things for themselves.

Taycan GTS
Power consumption (combined): 23.3–20.4 kWh/100 km
CO_2 emissions (combined): 0 g/km
Range (combined): 439–502 km
Electric range (city): 539–621 km

911 Dakar
Fuel consumption (combined): 11.3 l/100 km
CO_2 emissions (combined): 256 g/km

All consumption figures according to WLTP; as of 05/2023

says Christian Friedl, Vice President Corporate Quality at Porsche AG. "This is why we have to consider which features are relevant to our customers at an early stage. This also varies hugely from market to market, which is why it will be all the more imperative for us to be on the ground in the future."

Conditions during the validation drives are highly variable. While in Shanghai they are primarily conducted in urban areas, in Norway the driver might not see another person for hours. "The country is a pioneer in electrification in many respects," says Fabian Wörner. "That's why vehicle interoperability with the charging infrastructure is particularly important for Porsche in this market."

VALIDATION IN OSLO

Porsche Engineering carried out validation of the Taycan there, for example, prior to its market launch. While the model was subjected to continuous subzero temperatures during cold-country testing, international validation takes a different approach. "In the urban validation cluster, the vehicle is road-tested in Oslo, where it is exposed to changing temperature influences during the day and at night. The driver must be able to open and start it again the next morning without any functional impairments. Another focus is on comfort functions as well as preconditioning, for example on the departure

"The local teams' validation of functional and emotional aspects plays a key role in ensuring the quality of the Porsche brand."

Fabian Wörner
Responsible for coordinating complete vehicle validation at Porsche Engineering

timer set using the app or the engine-independent heating," says Wörner, describing one use case. Another example: Whereas in Germany salt is used on roads during snow and ice conditions in winter, the Norwegians spread grit. "For our vehicles, this means that the bodywork and add-on parts are subjected to greater stress due to grit exposure," explains Wörner. Such market-specific feedback can lead to corrections and improvements—or inform requirements for future optimization measures.

SENSORS FOR MARKET TRENDS

Alexander Kopp mentions another example from the US. For driver assistance systems, the vehicle uses copious sensor data and stored predictive map data. The interpretation of lane markings is made more difficult, because they are not uniform in American states—sometimes white as in Germany, but also yellow in some cases, which in Germany is only used for construction sites. "Market-specific peculiarities like this have to be taken into account and safely

Nardò, Italy:
Test vehicles can be put through their paces under sometimes extreme conditions on a number of the more than 20 test tracks in Nardò.

implemented by the function development team in Weissach," says Kopp. The local teams quickly identify such cases and pass on their observations to the developers. At the same time, they also have another important function. "Our teams act as sensors for market currents and trends that can be incorporated into development and marketing," states Kopp. He also points out how different the drivers are in the markets: "This allows us to learn what users in the respective markets require in terms of systems and functions—in contrast to the view from a German engineer's perspective."

International validation drives are conducted not only on public roads, but also at the Nardò Technical Center in Italy. At the proving ground in Apulia, the vehicles are driven on a number of the more than 20 test tracks to test them under sometimes extreme conditions. "This is important for Porsche, because many of our buyers want to experience their vehicles as sports cars at trackdays on the race track," says Wörner. "Everything has to work then, of course—just as it does in a motorsport environment, where Porsche has racked up countless victories on the world's race tracks."

FEEDBACK DURING THE DRIVE

No matter where in the world the validation takes place, the findings gained in the process always find their way back to the developers, who then use the information to further improve the quality of the new models. The vehicles are equipped with measurement technology from Porsche that continuously records data and transmits it to a database. The ComBox developed by Porsche Engineering is used for efficient data utilization. The ComBox uses WiFi or a mobile network to transmit all data from the international validation vehicle to a database while the drive is still ongoing—including the observations of the people behind the wheel: Drivers can document noteworthy occurrences by pressing a button in the vehicle that starts a measurement and voice recording. The local experts can then compare this information to the measurement data and the camera images.

During the subsequent evaluation, the Porsche analysts can get to the bottom of any anomalies. This makes it possible to translate what the drivers subjectively perceived and described into objective terms. The events collected can be retraced exactly thanks to the preliminary analysis and objectification, which means that any malfunctions can be reproduced very easily. "The local expert teams can then recreate the situation and check whether the event occurs again," says Wörner. Their mission is clear: "The local teams' validation of functional and emotional aspects plays a key role in ensuring the quality of the Porsche brand—always taking into account the demands of our international clientele." ●

INTERVIEW:
"COMBINING TECHNICAL EXPERTISE WITH KNOWLEDGE OF THE MARKET"

Real public-road (quality) validation will remain indispensable for the foreseeable future—even if virtual methods are becoming increasingly important. In this interview, Christian Friedl, Vice President Corporate Quality at Porsche AG., and Dr. Nazif Mehmet Yazici, Director Complete Vehicle Quality and Validation in Friedl's team, talk about different customer expectations and future challenges.

Why is international validation so important?

— **FRIEDL:** We have a very international clientele with very specific requirements—and a high quality standard, the Porsche quality standard. About one third of our customers come from each of the world regions of Europe, North America, and Asia, the latter with a main focus on China. That's why we test product quality under real conditions on location. This is the only way we can ensure that our vehicles meet customers' expectations. The vehicles also have to be able to allow for local laws and special factors. For example, traffic signs in China look different from those in Europe or the US. Nevertheless, our vehicles must be able to recognize them reliably—at any time of day or night, in sunshine, fog or a monsoonal downpour.

— **YAZICI:** Added to this are the different ways in which customers in different markets use the vehicles. Through our local drivers, we learn about the paradigms and needs in each place. In China, the expectations of displays, fans and fragrance systems, for example, are completely different from ours.

"You can't validate functions for China through Swabian-colored glasses. We need local experts who understand and represent our customers."

Christian Friedl
Vice President Corporate Quality at Porsche AG

What is most important when it comes to validation?

— **FRIEDL:** In the simplest terms: You can't validate functions for China through Swabian-colored glasses. We need local experts who understand and represent our customers. It's the only way we can offer a product tailored to the respective market. In terms of methodology, we distinguish between the breadth and the depth of the validation. In the context of validation breadth, we focus on emotional validation in addition to the visual and functional qualities—our products, after all, are experienced to a large extent through emotions. When it comes to new features such as assisted or piloted driving, the interaction between the experts on location and the Swabian engineer then comes back into focus. Together, they form a team that combines deep-reaching technical expertise with knowledge of the local market.

— **YAZICI:** That's also one of the reasons why we work with Porsche Engineering on international validation. The experts know the local market and, at the same time, have the technological expertise to assess functions technically. This is the basis for solid feedback, which then leads to corrections and improvements—or informs requirements for future functions.

You have already noted that vehicle functions are becoming increasingly complex. What does this mean for international validation going forward?

— **YAZICI:** Connectivity, digitalization, and functions with a high degree of automation are increasingly coming to the fore—and this with great variation in the world's different regions. This is why we have to ask ourselves: What does this mean for highly automated driving systems? What might automated valet parking look like? We are also observing another trend: Validation focuses less and less on kilometers driven and more on functionality, hours of operation, and the accessibility of vehicles in the local ecosystem. Or in other words: The focus is increasingly being directed at the overall package.

— **FRIEDL:** I would like to add one more aspect. Today, validation is at the end of the development process. In the future, we intend to describe new customer requirements even more precisely at the beginning of development, and start thinking even earlier about how we can validate them later on. The end result could be a control loop that forms a continuous link between customer requirements and validation. That would make it much easier to factor in improvements while development is still in progress.

— **YAZICI:** It is becoming increasingly important to make intelligent use of vehicle data to identify usage behavior and errors. This data holds great potential for collaboration between validation and development in early phases. This is a challenge for us as a group, including our partner Porsche Engineering. We have to make the best possible use of this treasure trove of data.

Let's conclude by looking to the future. Which trends will be important—virtual validation, for example?

— **FRIEDL:** We will invest heavily in virtual validation, for example to ensure basic functionality. But in my view, adaptation to market-specific customer expectations will have to be done in real life for the foreseeable future. In addition, there will always be new functions in the car that we cannot yet validate virtually. The level of virtual validation will continue to rise, but without completely replacing real validation. So we will have to do the one without neglecting the other.

— **YAZICI:** There are now, in fact, very impressive simulation methods—Porsche Engineering's EMC lab in Bietigheim, for example, where my cell phone thought it was in New York and had to connect to the US network. So we can use simulations to test certain interactions in advance. Nevertheless, the combination of virtual and real validation will remain indispensable over the next two decades.

— **FRIEDL:** To put a bit of a spin on it: Validation is very much a question of 'emotional quality assurance'. And I very much hope that 20 years from now, we will still not be able to map emotional quality virtually. ●

"Validation focuses more on functionality, hours of operation, and the accessibility of vehicles in the local ecosystem."

Dr. Nazif Mehmet Yazici
Director Complete Vehicle and Analysis in Christian Friedl's team

SUMMARY

The requirements of different markets for the quality and operation of new vehicles can only be verified on location. Porsche Engineering therefore deploys mixed teams consisting of local drivers and engineers around the world. The knowledge gained in the process is immediately fed back to the developers. The aim is to consistently ensure the high quality standards of the Porsche brand.

ANY QUESTIONS?

Some questions just have to be asked. We have the answers—delivered with an amusing twist. This time:

Will cars soon be developed in the metaverse?

Text: Christian Buck
Illustration: Julien Pacaud

If a number of visionaries from Silicon Valley were to have their way, we will soon be spending a large part of our lives in the metaverse. Equipped with VR glasses, in the future we might just live in virtual worlds, moving around as avatars, and communicating with the avatars of other people. The metaverse opens up entirely new possibilities for brand manufacturers: Why not sell digital twins of exclusive products in virtual stores, for example? The avatars of metaverse users could adorn themselves with sophisticated handbags, classy watches, or the latest sneakers to impress their avatar friends.

Automotive development too could also increasingly shift to the virtual world in the future. US chip manufacturer Nvidia, for example, is pushing its own metaverse under the name 'Omniverse'. The Omniverse is touted to enable digital twins of factories, the training of robots in simulated environments, and live collaborations between developers across locations. This would make it possible to carry out—in full or in part—vehicle developments in the metaverse. Interior designers, for example, could design and test different interior variants in a virtual vehicle. Potential customers could say what they think of these ideas long before production starts. And development could keep progressing all the while. For example, vehicle development could be transferred entirely to a team of digital bots working in virtual development departments on innovations for the vehicles of the medium-term future.

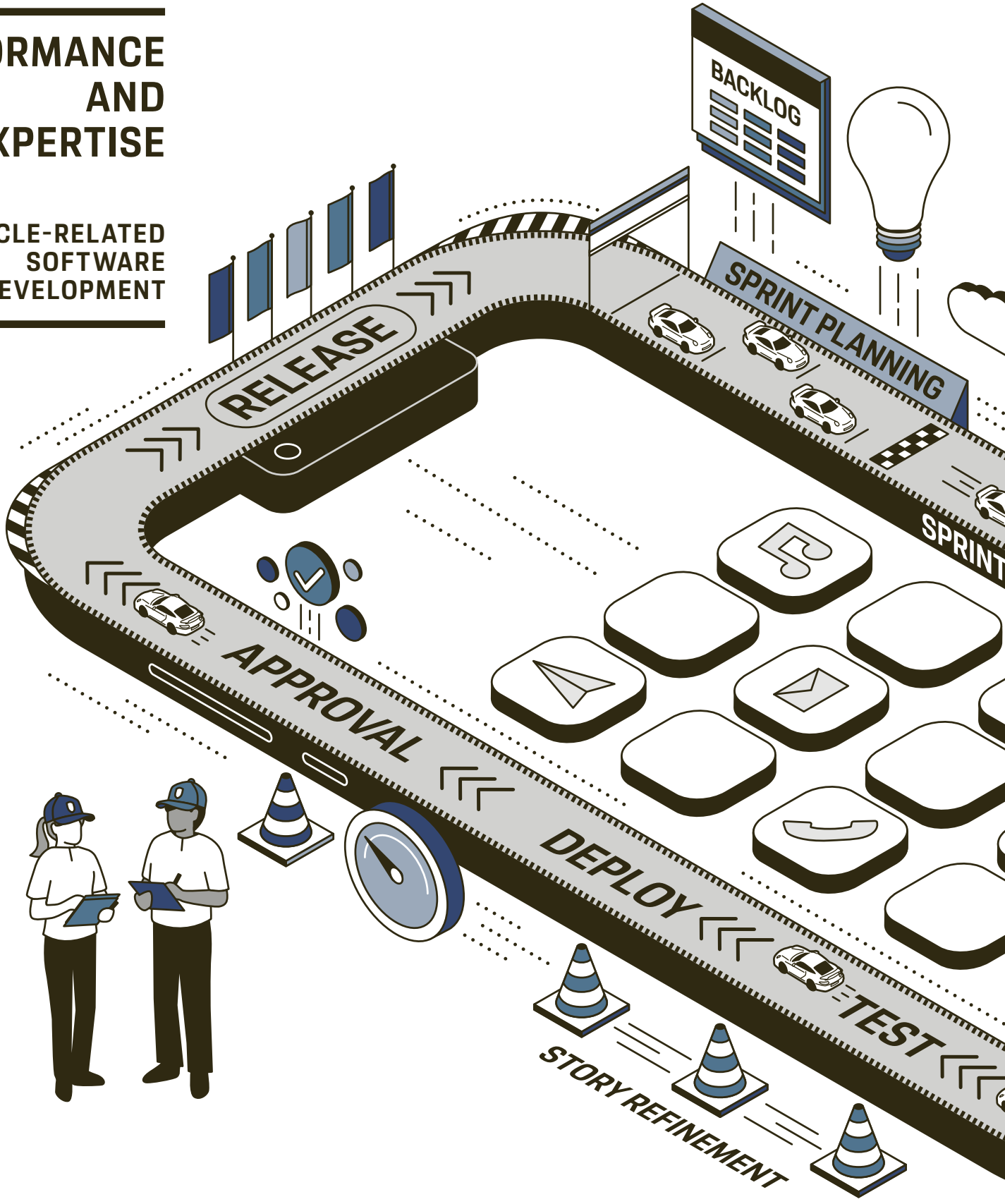
One thing is certain: Work in the metaverse will always require detailed digital twins with which simulated test drives, among other things, can be carried out during development. Moreover, to simulate real environments for testing highly automated driving functions, Porsche Engineering has technologies and models that can be used to enrich the metaverse with realistic scenarios. These models could also be used to take virtual rides in the metaverse—for example, in a metaverse sports car that customers' avatars could buy at the metaverse dealership. Thanks to blockchain technology, the vehicles would be non-fungible tokens (NFTs) that are every bit as exclusive as their real-world counterparts. In a few years' time, Porsche enthusiasts might meet virtually for 'Cars & Coffee' to admire their respective digital sports cars and philosophize about life.

If things will ever come to that? That will depend on how well consumers take to the virtual setting. For all their fidelity to reality, virtual environments are always models and answer questions that were posed in advance. Dynamic, physical, real-world experiences feel different. However, the fun that can be experienced in a virtual environment could certainly be real.

Reimagined: Not only could new cars be developed in the metaverse, but virtual vehicles and other goods could be sold as digital status symbols.

PERFORMANCE AND EXPERTISE

VEHICLE-RELATED SOFTWARE DEVELOPMENT

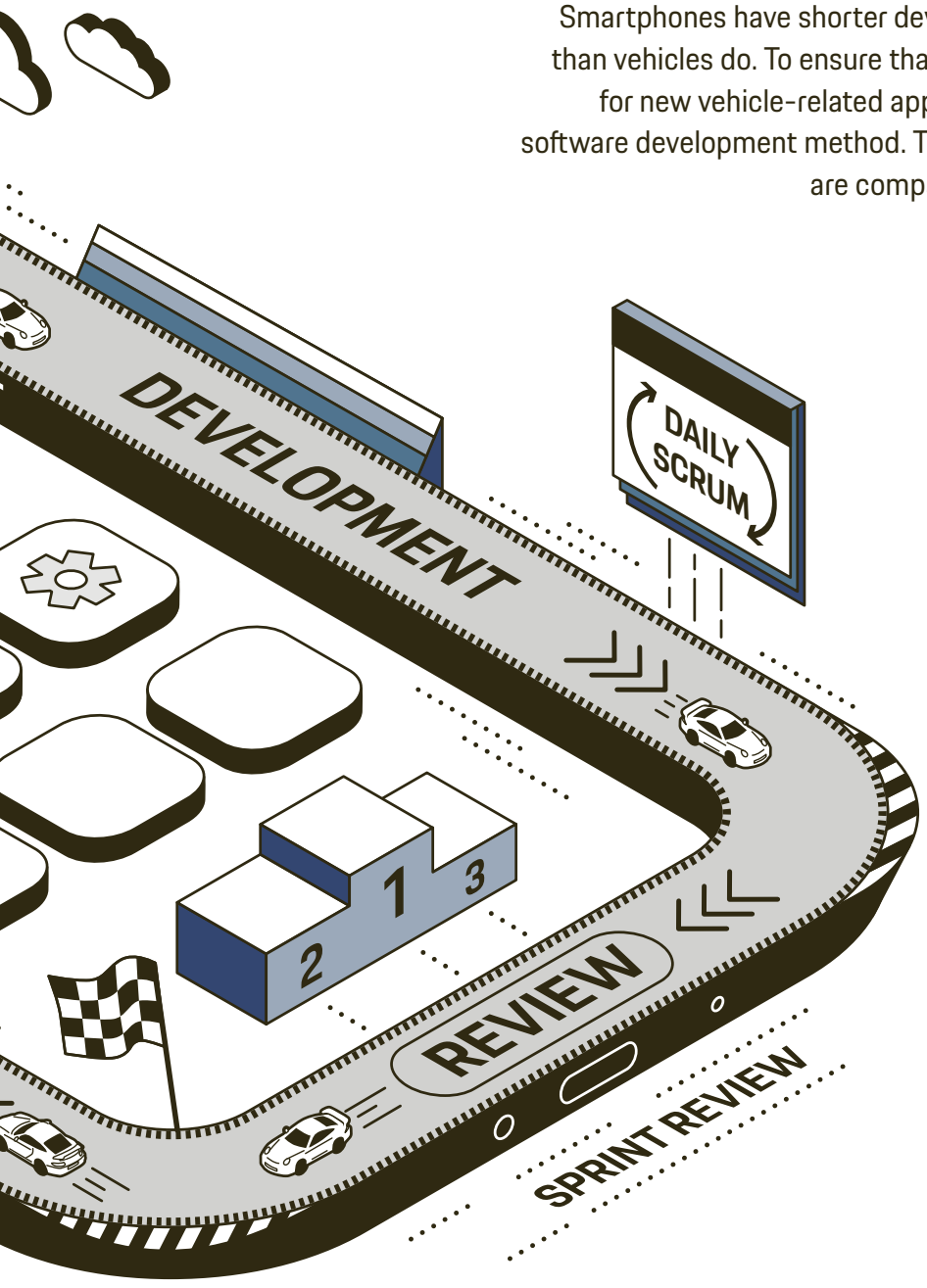


Fast and flexible: Agile software development takes place in two-week cycles known as sprints.

SPRINTING TO THE APP

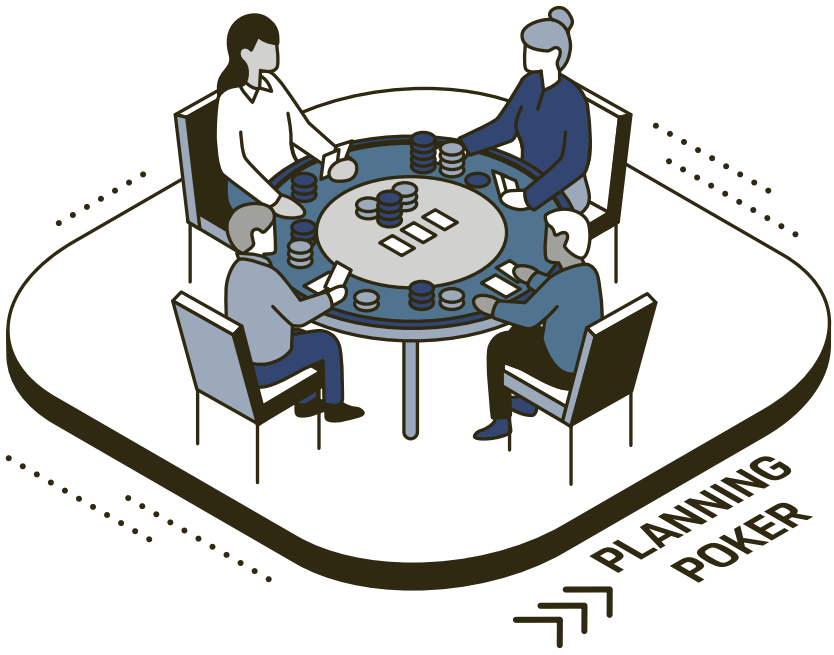
Smartphones have shorter development and update cycles for their software than vehicles do. To ensure that both ecosystems nevertheless work together for new vehicle-related app functions, Porsche Engineering uses the agile software development method. This ensures that a wide variety of smartphones are compatible with the vehicle in all sorts of conditions.

Text: Richard Backhaus
Illustrations: Pia Bublies



The networking of smartphones and vehicle electronics enables new functions that further enhance the driving experience. One example is features that use a smartphone camera to record videos from the windshield and link them to live vehicle information. "One of the major challenges in implementing app functions based on the interaction between the two ecosystems, smartphone and vehicle, is the many strands that come together during development," explains Thomas Pretsch, Director Infotainment, Connect & E/E at Porsche Engineering.

To achieve the desired range of functions, the apps often access and read ECU information such as vehicle position, speed, engine speed, braking force, steering angle, as well as longitudinal and lateral acceleration via the in-vehicle WiFi connection of the vehicle infotainment system. The software link between the app and vehicle electronics required for this is complicated by the different product lifecycles of the two ecosystems: The development team has to integrate



Cards face down: The aim of 'planning poker' is to obtain an independent estimate of the effort for a ticket.

fast-moving smartphone technology into vehicles with much longer development intervals. At the same time, it must ensure that the app runs reliably under all conditions on the different smartphones and is also compatible with older vehicle systems.

ALWAYS UP TO DATE

For the development of apps for vehicle applications, Porsche Engineering uses agile software development methods with which an app is continuously kept up to date. Individual work packages that can be implemented within a short period of two weeks are defined for processing the software. As a result, developers are no longer bound to the cycles of vehicle model updates, but have the option of creating a new software version at any time, which is then delivered to customers via the app store.

Using agile software development, Porsche Engineering can ensure full implementation of an app for Apple and Android smartphones, from programming and testing to generating the release version for end customers. "Porsche Engineering's development advantage in this regard is the combination of extensive software expertise and comprehensive knowledge of vehicle technology. Added to this is our expertise in vehicle dynamics development, which enables us to predict exactly which vehicle parameters we need to implement a particular function," says Pretsch. Just as agile as the software development is the adaptation of the development methodology to new requirements or conditions. One aspect that plays a much greater role in the vehicle than in other app application areas is the testing of the software. At Porsche Engineering, these tests are carried out during development so that the software code can be adapted quickly if errors arise: When defining the sprints, the development team sets milestones for the programming. Once the milestones have been reached, a specially trained test engineer checks the software maturity.

To ensure that the high requirements for functional reliability can be implemented even more efficiently in the future, Porsche Engineering is broadening the test program for the apps in successive steps. "Additional tests during development do cost time, but the effort required to make changes for debugging is much lower the earlier you identify an error," says Johannes Hubert, Development Engineer Infotainment & Connect at Porsche Engineering. Depending on the scope of the update, functional tests by simulation and in the vehicle itself are already an integral part of the development process. "The simulations are carried out by internal routines within the software," as Hubert explains. Fabian Breisig, Specialist Project Engineer Infotainment & Connect at Porsche, adds: "These tests provide information about basic functions of the app. The in-vehicle tests, on the other hand, cover connectivity with the infotainment system and app functions while driving." In the future, the driving tests will be supplemented and, in part, replaced by more far-reaching simulations and tests on the HiL (hard-

"Additional tests do cost time, but the effort to make changes for debugging is much lower the earlier you identify an error."

Johannes Hubert
Development Engineer Infotainment & Connect at Porsche Engineering

"Agile methods are ideal for software development projects that are subject to a continuous change process."

Thomas Pretsch
Director Infotainment, Connect & E/E at Porsche Engineering

ware-in-the-loop) test bench. During the simulation tests, the smartphone is integrated into a racing simulation. "For the app, this creates a situation similar to that in the vehicle. This brings us closer to the real scenario and allows us to replicate extensive functional tests without a vehicle," says Breisig.

HIGH FLEXIBILITY THROUGH SIMULATION

The HiL test bench allows the app to be integrated into the vehicle system even when no test vehicle is available. Instead of the complete vehicle, only the infotainment module of the vehicle is required as hardware, and the incoming and outgoing data streams to and from the other control units are reproduced by the test system as a simulation. This leads to a high degree of flexibility in app development—for example, functions for new vehicle model series can be integrated into the app at an early stage so that they are already available when the vehicle is launched, and customers can use them right away.

Agile software development methods can also be used for tasks other than the app application. Porsche Engineering also uses agile methods, for example, in the development of battery systems and operating strategies for electric vehicles, but interest is also growing in other areas. "Agile methods are ideal for software development projects that are subject to a continuous change process," says Pretsch. "Due to the ever-increasing importance of networking and software in vehicles, I am assuming the use of this approach will increase in all vehicle areas."

AGILE SOFTWARE DEVELOPMENT

Agile software development is a project management approach widely used in consumer electronics, for example, which is characterized by the incremental creation of software in frequent iteration cycles (sprints). One advantage of the agile approach: It's possible to react quickly to changes, as the development can be flexibly adapted to evolving requirements. Since the intermediate goals are always just software portions, the final objective of a development does not have to be clearly outlined or known. The definition of the scope of work (ticket) to be completed in the sprint takes place in a coordination meeting with all team members. In this context, they use a method known as planning poker (see glossary).

Glossary

Sprint

Agile development takes place in short cycles (usually two weeks) to ensure quick feedback. An iteration cycle is also called a sprint.

Daily stand-up

The daily stand-up is a short daily meeting where developers update each other on the status of their sprint.

Ticket

A ticket is a software development task (bugs, stories, tasks) that is transferred to one or more sprints in the story refinement.

Backlog

The backlog is the list of all tickets that are to be implemented.

Story refinement

The maintenance of the backlog is called story refinement. In a continuous process, the tickets are elaborated and made ready for implementation in a sprint.

Planning poker

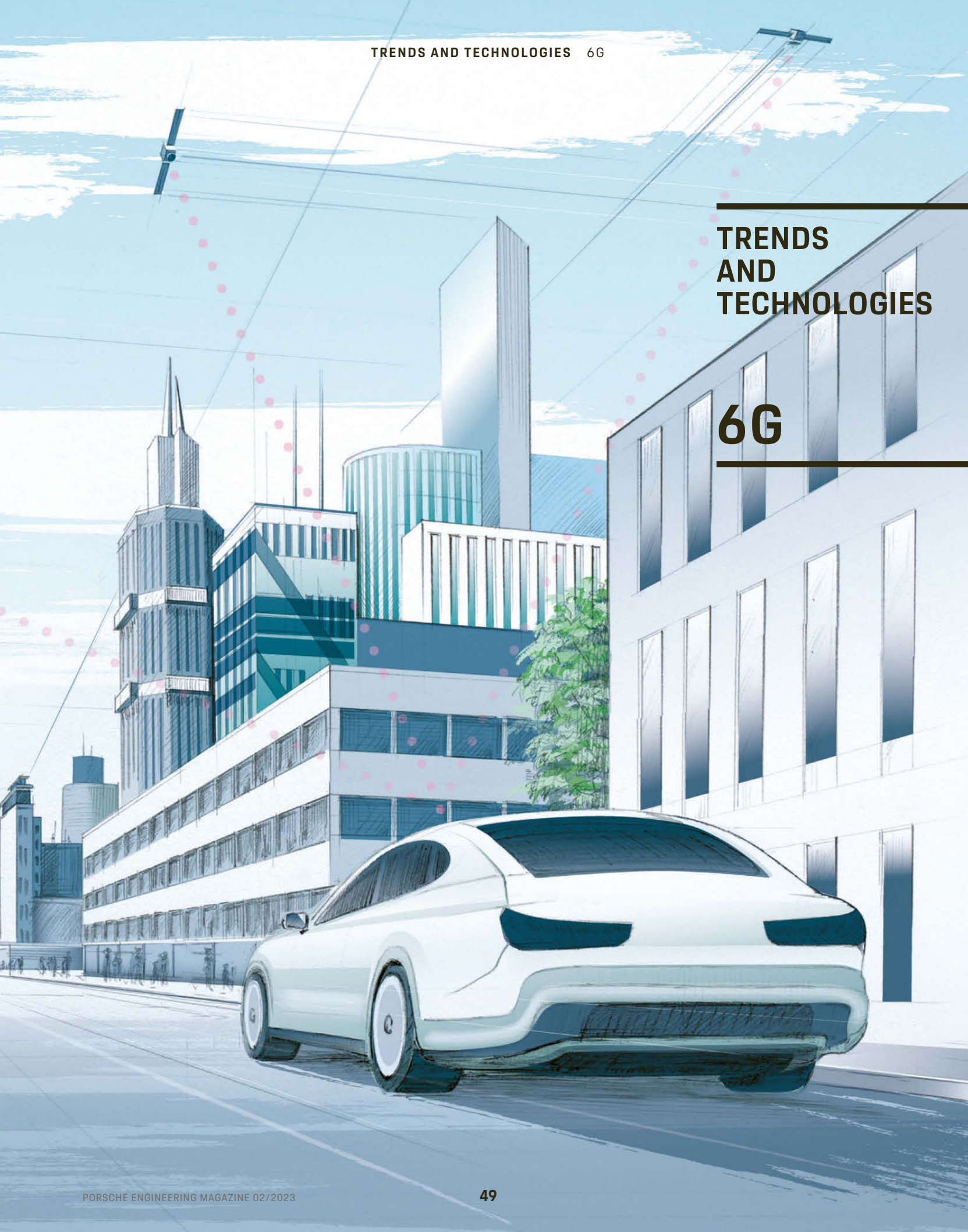
Planning poker is an agile method for estimating the effort for a ticket. This requires each developer to make a forecast with hidden poker cards. If there are discrepancies between the estimates, this is an indication of ambiguity—for example, an imprecise formulation of the ticket. The goal of planning poker is to ensure that all developers give the same forecast for the effort required for each ticket, meaning that they have a common understanding of the task.

SIXTH SENSE

Researchers and engineers around the world are already working hard on the next generation of mobile communications, 6G, which should be available by around 2030. Vehicles in particular could benefit from the high data rates and from the fusion of communications and environment detection.

Text: Christian Buck
Illustrations: Andrew Timmins

An ideal partner: Vehicles in particular will benefit from 6G, for example through fast data exchange and the combination of communication and environment detection.



TRENDS AND TECHNOLOGIES

6G

"With 6G, satellites will for the first time be integrated into the network right from the start."

Bernhard Niemann
Head of the Broadband and Broadcast Department, Fraunhofer IIS

Network operators are currently rolling out 5G networks at full speed, which is enabling them to introduce a large number of new applications in the process—not least in the automotive sector, as demonstrated by the development of intelligent and connected vehicles at Porsche Engineering's Nardò Technical Center. But research institutions and companies are thinking even further ahead and have already started the race to develop the next generation of mobile communications. Toward the end of the decade, the new 6G standard is expected to deliver even higher data rates, lower latency, and improved reliability, among other things. "There is intense activity in this area in the US, China and Europe," reports Andreas Müller, head of all 6G projects at Bosch. "It has been understood in all regions of the world that next-generation mobile communications is an issue of strategic importance."

Researchers do, however, still have a lot of ground to cover before 6G can make its way into the everyday lives of private and commercial users, as future 6G networks will require a significant shift in the boundaries of what is technically feasible. For example, developers have discovered the third dimension to ensure uninterrupted data exchange worldwide. "Until now, mobile communications have primarily been limited to the earth's surface," says Bernhard Niemann, Head of the Broadband and Broadcast Department at the Fraunhofer Institute for Integrated Circuits IIS. "With 6G, on the other hand, satellites will for the first time be integrated into the network right from the start."

HANDOVER FROM SATELLITE TO SATELLITE

The satellites could be stationary ones in geostationary orbit (GEO) at an altitude of 36,000 kilometers, or their lower-orbiting counterparts, for example in low Earth orbit (LEO), which is 200 to 2,000 kilometers above the Earth's surface. Even balloons could be used as high-altitude platforms for 6G base stations at altitudes of 15 to 20 kilometers. At higher frequencies of 10 GHz or more, the antennas of the 6G devices must point in the direction of the satellites or balloons. LEO satellites present an additional challenge: Because they move rapidly across the sky, the connection must be regularly handed off from one satellite to the next—without the user noticing.

The performance of 6G is also expected to be enhanced with the aid of artificial intelligence (AI). AI algorithms could, for example, give mobile networks the flexibility to adapt to current conditions and thereby optimize their operation. "Machine learning can be used to identify typical usage over the course of a day," explains Fraunhofer researcher Niemann. "This information could be used to operate 6G networks with a minimum of energy input." Bosch expert Müller can also imagine basic AI-supported services that the mobile network makes available to its users: "It would be conceivable for the 6G network to offer services such as object classification in video recordings."

Müller even believes it is possible that data transmission will no longer be standardized the conventional way by precisely specifying the manner in which a signal is generated, and that the neural networks on the transmitter and receiver ends will instead be left to select the best method in each case under the current circumstances. Rohde & Schwarz and chip manufacturer NVIDIA have already taken the first steps toward AI-supported hardware: In February, they unveiled a neural receiver in which an AI model exhibits a significantly better performance than a powerful standard algorithm. "This method can also be integrated into future 6G smartphones," explains Taro Eichler, technology manager for wireless communication and photonics at Rohde & Schwarz.

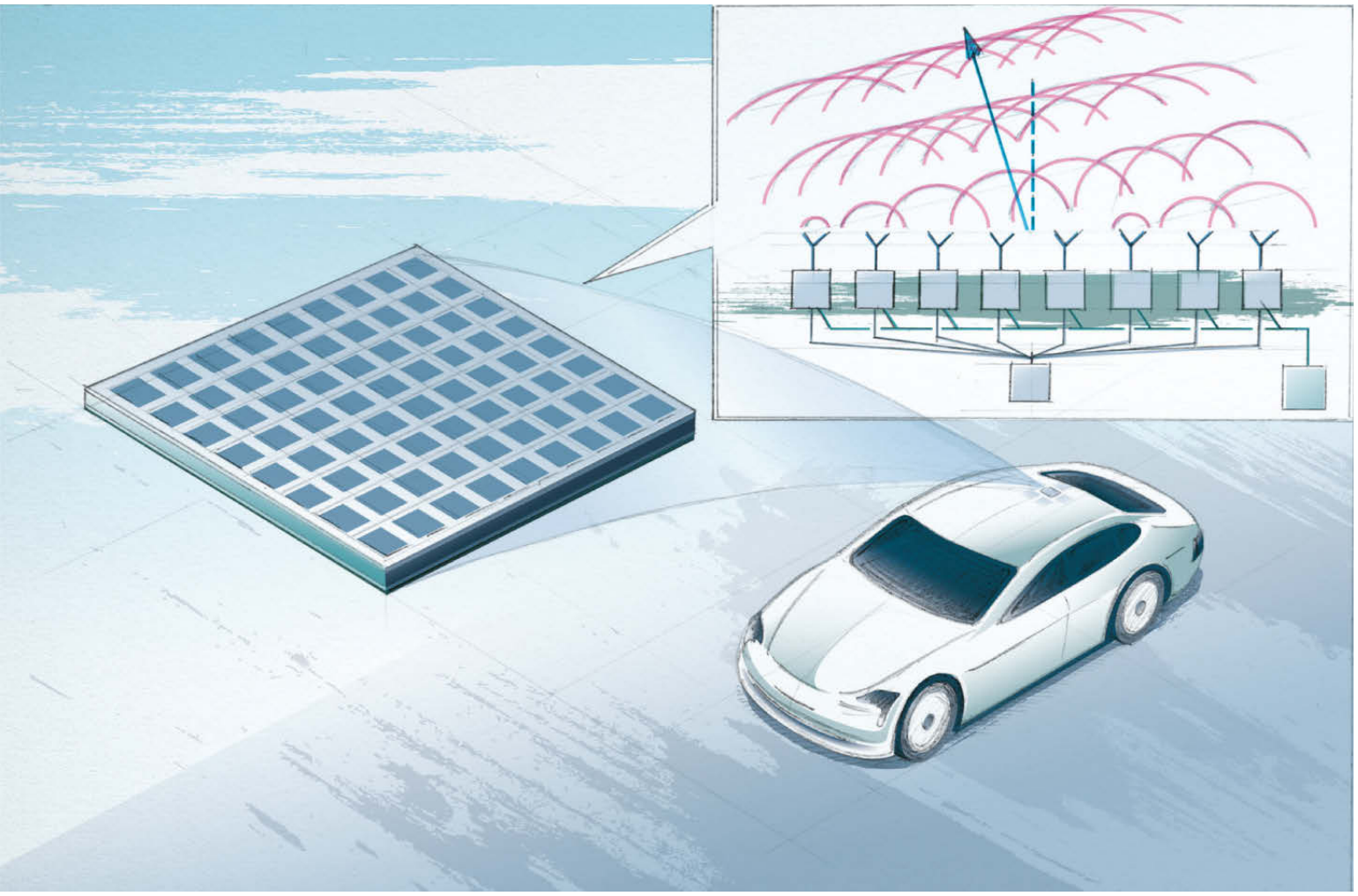
ADVANCING INTO THE TERAHERTZ RANGE

Many innovations are also needed to attain the planned high data rates: "Up to one terabit per second should be possible in the future," as Niemann says. "To do that, you have to tap into higher frequency ranges, because that's the only place where the necessary bandwidths for fast data transmission are available." The plan is therefore to use frequencies in the sub-terahertz range between 90 and 300 gigahertz and, potentially, ones in the terahertz range above 300 gigahertz as well. By comparison: 4G operates below six gigahertz, and while 5G theoretically provides for data transmission at up to 71 gigahertz, it is currently seldom used for mobile broadband services.

300

gigahertz and more: 6G is advancing into whole new dimensions in radio frequencies. This places high demands on chips, connection technology and antennas.

Optimizing range: To extend range even at high frequencies, antenna arrays will be used for beamforming. Intelligent surfaces that specifically reflect the radio waves are new.



"It has been understood in all regions of the world that next-generation mobile communications is an issue of strategic importance."

Andreas Müller
Head of 6G Projects at Bosch

Frequencies in the triple-digit gigahertz range offer a lot of bandwidth, but the physics there makes life difficult for 6G developers. Radio waves rapidly lose their energy in the air and therefore only travel a few meters. To increase the range, researchers are relying on 'Massive MIMO' (massive multiple-input multiple-output): Hundreds of tiny antennas are interconnected and software is used to align the wireless beam between the transmitter and receiver. "This beamforming process using 512 or 1,024 antennas, for example, makes it possible to significantly increase the range of radio waves even at such high frequencies," explains Prof. Ivan Ndip, who heads the RF & Smart Sensor Systems Department at the Fraunhofer Institute for Reliability and Microintegration. "Beamforming enables high mobility and flexibility in communication, but also increases hardware complexity, as numerous transceiver channels are required.

It also increases energy consumption and costs. For point-to-point communications, lens antennas offer an alternative solution. They can enable ranges of up to several hundred meters at 6G frequencies above 100 GHz. To ensure a cost-effective and energy-efficient 6G solution, the transceiver architecture, antenna configurations, and the number of antennas

Data rates of up to

1,000

gigabits per second are expected to be possible with 6G. Latency is said to be around 0.1 milliseconds.

Third dimension: Instead of limiting themselves to the earth's surface, 6G developers are also utilizing satellites and balloons from the outset.

7G

could use quantum-based processes and algorithms for encryption—but this is presumably years off.

should therefore be determined according to the application."

Another method of increasing the range is also expected to be used for the first time in 6G: Reconfigurable smart surfaces. "Until now, the propagation characteristics and channel for the radio waves have been considered immutable, predetermined by the walls inside buildings, for example," Eichler explains. "In the future, however, the signals could be reflected off surfaces in order to guide them in a specific direction and thereby achieve better coverage. That's a completely new approach." Reconfigurable smart surfaces are flat structures with integrated electronic circuits, for example special diodes or liquid crystal structures combined with tiny antenna elements. They can be programmed to redirect the incoming radio waves in a targeted way and thus reroute them precisely to the intended receiver. The advantage of the new technology: It is said to be significantly more energy-efficient and less expensive than classic radio repeaters, each of which contains a complete transmitter and receiver. However, a great deal of research is still needed in this area.

Designers of high-frequency chips and systems are also facing major challenges. On the one hand,

"Beamforming using 512 or 1,024 antennas makes it possible to significantly increase the range of radio waves, even at high frequencies."

Prof. Ivan Ndip
Head of the RF & Smart Sensor Systems Department at Fraunhofer IZM

"In the future, however, the signals could be reflected off surfaces in order to guide them in a specific direction and thereby achieve better coverage."

Taro Eichler
Technology Manager for Wireless Communication and Photonics at Rohde & Schwarz

they have to use special semiconductors such as silicon-germanium or gallium nitride at frequencies in the high gigahertz range; on the other hand, the integration of all components into one system also plays a key role. "You have to rethink everything here," Ndip said. "It's very difficult to get the energy from the transmitter to the antenna with as little loss as possible and at the same time dissipate the heat from the chips." Again, new materials, together with assembly and connection technology, are the key to success: Substrates made of polymers, glasses or ceramics could be the basis for integrated of 6G chip and antenna packages.

In addition to high data rates, the use of high frequencies opens up another new possibility: the fusion of communication and environment detection. In the future, 6G radio waves could also be used to detect nearby objects, surfaces, and motion using reflected radiation, as in radar technology. "Vehicles could use 6G to exchange data with each other, for example, and at the same time pick up the resulting reflections to get an idea of their surroundings," explains Bosch expert Müller. "While communication and radar are still completely separate today, in a few years we could use the same frequencies, chips and antennas for both." In the 6G-ICAS4Mobility research project, Bosch is working with partners to more closely integrate what are currently separate communications and radar systems into a single 6G system. To this end, real-time sensor data from various mobile vehicles will be coordinated and combined via 6G technology to provide a more accurate picture of the vehicle's surroundings. The goal is to increase road safety and efficiency.

Expert Ndip also sees many potential 6G applications in the automotive sector, such as autonomous driving: "An autonomous vehicle needs to be able to communicate its position to other road users in real time, measure distances precisely, and get a 360° view of its surroundings at the same time." Also needed, he said, are downloads of large volumes of data, such as high-resolution city maps, video images from other vehicles, and high-definition movies for entertainment while driving. Thanks to the high 6G data rates, this would not be a problem—4K videos or extensive map updates, for example, could be downloaded to the vehicle in a short time via a base station at an intersection or gas station. Fraunhofer researcher Niemann calls this process a data shower.

In addition to the automotive sector, 6G is also expected to enable new applications in fields such as industrial manufacturing, telemedicine and robotics. Government support for this versatile technology is correspondingly high: In Germany alone, the Research Ministry is funding the mobile communications technology of the future with around 700 million euros until 2025. "5G was a bit neglected in this country," says Eichler. "In order to be technologically self-sufficient, not least in view of the current geopolitical situation, long-term we want to become more independent with 6G and build our own wireless ecosystem in Germany or Europe." Four '6G hubs' made up of universities and research institutes, among other measures, each receiving funding of 70 million euros for three years, will be part of this effort. There have also been roughly 20 industrial projects supported by the Research Ministry and launched in collaboration with various partners from the 6G hubs.

NO END TO DEVELOPMENT IN SIGHT

The first iterations of 6G networks could be in operation by the end of the decade, but probably still with a reduced range of functions. After 2030, all new functions should then be introduced gradually. But even then, Fraunhofer expert Niemann says, 6G will not be the end of the road for mobile technology. "I'm sure that something new will come along again in the future," he says. "Just as AI is making its way into mobile communications for the first time today, quantum-based processes and algorithms could play an important role in the next generation, for example for encryption." He also believes the use of blockchain is possible to secure transactions and create trust. It could be used, for example, to log messages between vehicles in a tamper-proof manner. "Every data exchange in vehicle-2-vehicle communication—notification of an obstacle on the roadway, for example—would be stored in the blockchain," Niemann says. "Even these few examples show: 7G will incorporate new trends and enable innovative services that are still unimaginable today."

SUMMARY

Researchers and companies are already working on the next wireless standard, 6G. It is expected to be available around 2030 and will enable new applications in addition to performance improvements. For example, the same frequencies can be used for communications and radar, enabling data exchange and environment detection to be performed simultaneously. The basis for the new 6G applications is advanced semiconductors and smart antenna arrays for beamforming.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Information technology is the basis for innovations in a wide range of industries. At the same time, however, IT energy consumption could lead to major challenges in the future. That's why computer scientists aim to use green coding to significantly reduce the CO_2 emissions of IT.

Text: Christian Buck

Whether it's the internet, data centers or artificial intelligence: Wherever intensive computing is carried out, energy consumption and the associated greenhouse gas emissions are high. According to a report by the Association for Computing Machinery (ACM), information and communication technologies (ICT) and global air traffic are now roughly on a par in terms of their climate impact: Depending on the study quoted, the ICT industry accounts for 1.8 to 2.8 percent of annual greenhouse gas emissions. If the effects of hardware production are also factored in, its share is almost four percent. Air traffic is estimated to account for around 2.5 percent.

ICT energy demand is likely to continue to increase significantly in the future: According to the ACM, if current trends continue, it could be responsible for one-third of all global greenhouse gas emissions in 2050. "Computing-intensive processes such as Big Data, the Internet of Things, and artificial intelligence are, in some cases, very energy-hungry," as Prof. Volker Wohlgemuth of the Berlin University of Applied Sciences reports. "While they can make a major contribution to sustainable development,

they must themselves be developed in the most resource-efficient way possible." More energy-efficient hardware and a climate-neutral power supply are likely to lead to improvements in this regard. Yet software development can also make a noticeable contribution—through green coding. Green coding is a software development approach that aims to reduce the resources and energy required to design, create, process and publish a software project. It has been an issue in vehicle development for some time: ECUs exhibit extreme limitations in terms of memory and computing power, and therefore need to be programmed very efficiently. But even in this case, it could be possible to save energy—by intelligently distributing the computing operations: energy-saving ones in the vehicle and more computationally intensive ones in the cloud.

PROBLEMS WITH BLOATWARE

There are studies that attest how great the impact of software is on the energy consumption and greenhouse gas emissions of information technologies. For example, a study commissioned by the German Federal Environment Agency shows how differently two word processing programs utilize the resources of a computer: In a standard usage scenario, one software consumed 3.6 watt-hours of energy, while a competing product came in at just 0.93 watt-hours. "Although both programs perform the same tasks, program two requires only about a quarter of electrical energy and is therefore significantly more energy efficient," the authors of the study found. A comparison of three internet browsers revealed a similar picture: Under comparable conditions, the energy consumption during use was 1.95, 0.91 and 0.66 watt-hours, respectively. When idle, their processor utilization actually fluctuated between 0.8 and 12 percent.

One reason for the poor values is bloatware, this being software that is encumbered with a multitude of—often little used—functions and which is therefore not very energy efficient. The utilized programming languages also result in significant differences: C, for example, which was developed in the early 1970s, and the relatively new language Rust perform best in terms of energy consumption, while the widely used languages Ruby and Python result in significant increases in power consumption. In a comparative test, they required 70 and 76 times more power than C, respectively, for the same tasks—not least because both are recompiled (interpreted) during each program runtime, whereas with C or Rust this process occurs only once before the software is started (compilation). "However, some programming languages offer much better support through specific libraries for a problem that may not exist in others," Wohlgemuth points out. "So you always have to look at the individual case."

To minimize the impact of software development on the environment, green coding applies a range of approaches. "These include software architecture, implementation, methodology and platforms," Wohlgemuth says. "There is a multitude of different ways to program power-saving mechanisms." For example, if you don't write a mathematical function (calculating the factorial of a natural number) yourself

"Green coding can be applied in any industry or used as a criterion for awarding contracts."

Prof. Volker Wohlgemuth
Berlin University of Applied Sciences

> **"Unwanted advertising causes as much greenhouse gas emissions annually in the EU alone as a city the size of Turin."**
>
> **Joseph De Veaugh-Geiss**
> Project and Community Manager at KDE e.V.

in Python, but instead use the predefined variant from a function library written in C, you can reduce the energy consumption by over 90 percent. A similar reduction was also measured for the calculation of random numbers.

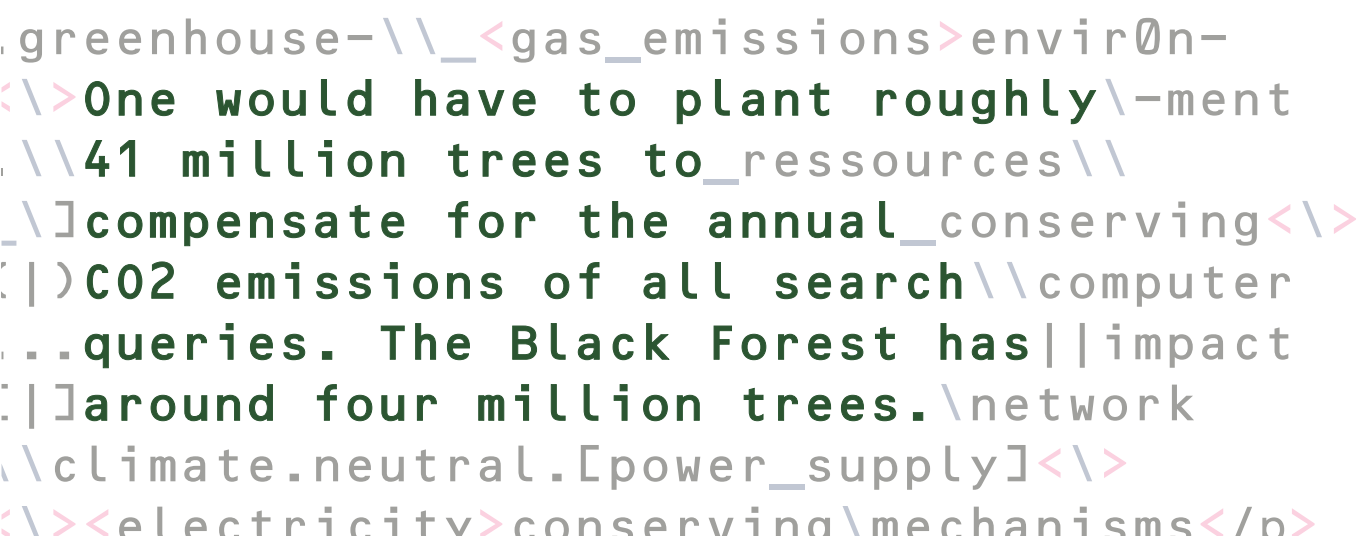
AVOIDING UNNECESSARY CODE

There is also potential for optimization when it comes to the use of open source software libraries: Many contain code that is never used and leads to unnecessary energy consumption during compilation. Savings can also be achieved by keeping network traffic to a minimum in distributed software applications. "This can be achieved, for example, by using fewer high-resolution images or by using binary rather than text-based file formats," Wohlgemuth said. "In addition, running computations as locally as possible instead of deep in the cloud can be worthwhile—but there is still a need for research in this area." Software also has implications for the service life of IT hardware. "If resource requirements keep increasing, for example due to bloatware, computers have to be replaced at an unnecessarily early stage, which leads to additional consumption of energy and raw materials," Wohlgemuth says. "Programmers should also think about this when they write software."

To take account of these and various other requirements for the sustainability of code, and to recognize particularly green products, the German Federal Ministry for the Environment has extended its Blue Angel eco-label to software. "This covers various aspects of sustainability," explains Joseph De Veaugh-Geiss, who works on the Blue Angel for Free and Open Source Software project for the software community KDE. "In addition to energy consumption, it's about the service life of the hardware, but also the autonomy of the user. Among the criteria is the ability to remain free of unwanted advertising—which in the EU alone produces as much greenhouse gas emissions annually as a city the size of Turin."

GROWING INTEREST

So far, only one piece of software has been awarded the Blue Angel. "Politicians should use the Blue Angel as an award criterion for public contracts," says Wohlgemuth, who has the impression that green coding is only slowly gaining traction among businesses. In research and teaching, on the other hand, the topic is already receiving much more attention, he says, because computer science has also recognized that programs and hardware can have a major impact on the environment and the climate—in both a positive and negative sense. "Green coding can be applied in any industry or used as a criterion for awarding contracts, and there is particularly great potential in areas such as IT, finance, automotive or online retail," Wohlgemuth says. "That's why it's important for us to create awareness among developers about the immense leverage they have for more climate protection in their work." ●



PORSCHE AND PRODUCT

THE NEW CAYENNE

Future success assured: The new Cayenne combines on-road and off-road performance with everyday luxury and comfort.

Cayenne

Fuel consumption (combined): 12.1–10.8 l/100 km
CO_2 emissions (combined): 275–246 g/km

Cayenne E-Hybrid

Fuel consumption (combined): 1.8–1.5 l/100 km
CO_2 emissions (combined): 42–33 g/km
Power consumption (combined): 30.8–28.7 kWh/100 km
Electric range (combined): 66–74 km
Electric range (city): 77–90 km

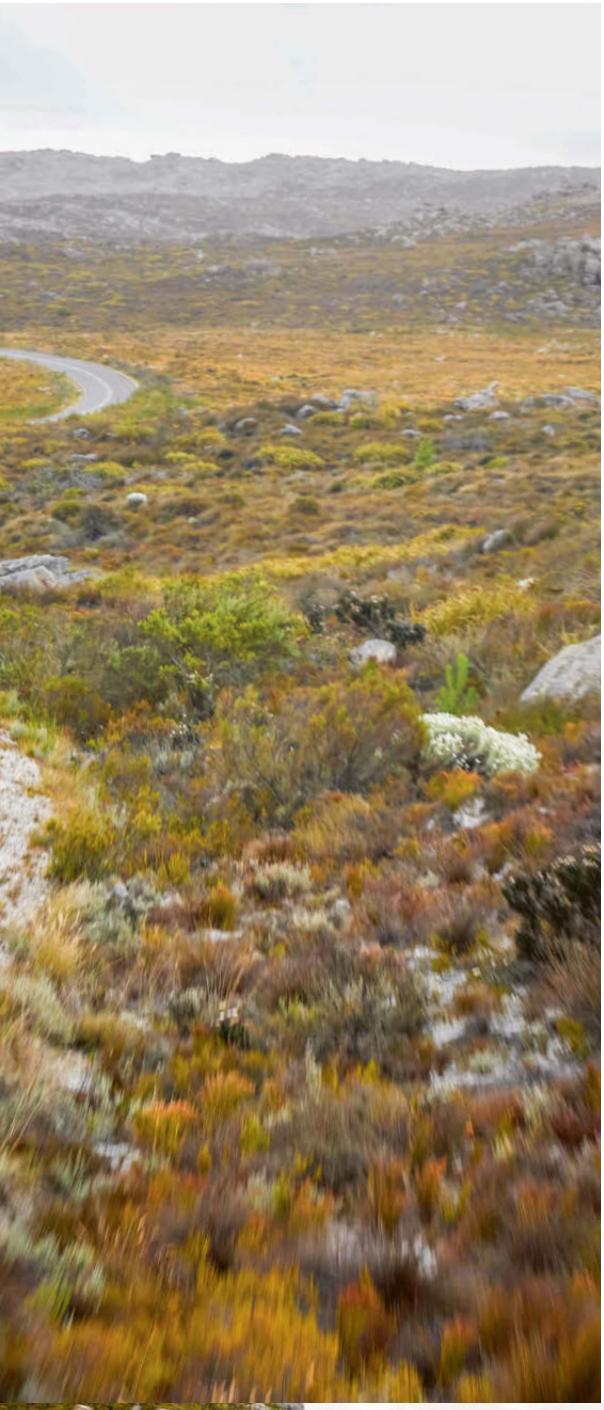
Cayenne S/Cayenne S Coupé

Fuel consumption (combined): 13.4–12.4 l/100 km
CO_2 emissions (combined): 304–282 g/km

Cayenne E-Hybrid Coupé

Fuel consumption (combined): 1.8–1.5 l/100 km
CO_2 emissions (combined): 42–33 g/km
Power consumption (combined): 30.8–28.6 kWh/100 km
Electric range (combined): 66–74 km
Electric range (city): 78–90 km

All consumption figures according to WLTP; as of 05/2023



MORE LUXURY, MORE PERFORMANCE

Porsche has fundamentally overhauled the third generation of the Cayenne with extensive changes to the powertrain, chassis, design and equipment. This has further extended not only on-road and off-road performance, but also luxurious everyday comfort.

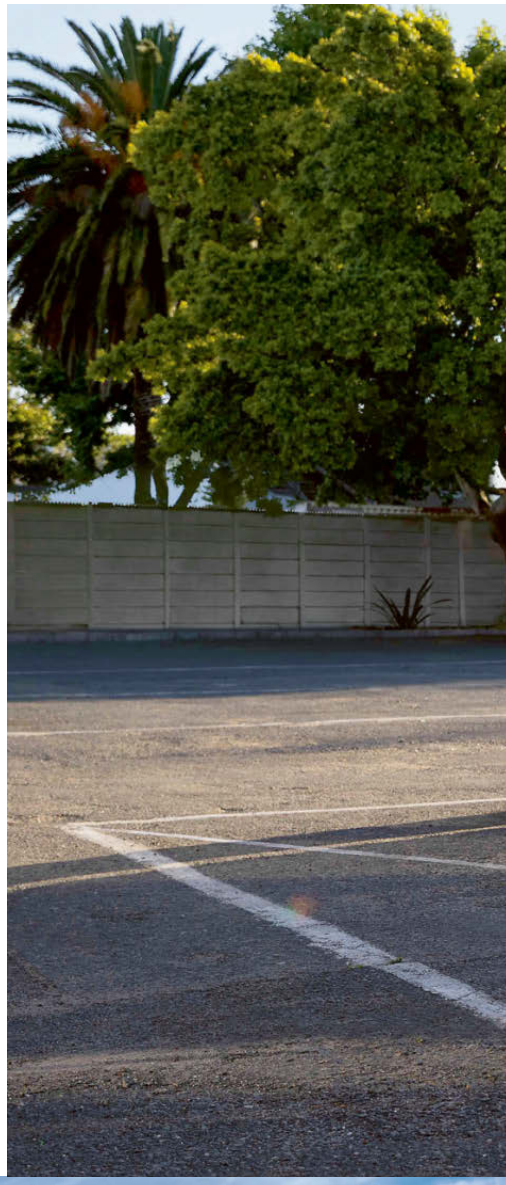
Text and photos: Dr. Ing. h.c. F. Porsche AG

Porsche has thoroughly refined its successful luxury SUV: The new Cayenne debuts with a highly digitalized display and control concept, new chassis technology and innovative high-tech features. "It's one of the most extensive product upgrades in the history of Porsche," says Michael Schätzle, Vice President Product Line Cayenne.

High-definition HD Matrix LED Headlights provide road illumination tailored to every driving situation, an air quality system filters pollutants from the air in the interior, and for the first time in the Cayenne, front passengers have their own infotainment display—for streaming videos during the trip, for example. With its extensively upgraded design and more powerful engine range, the Cayenne emphasizes its claim to be the sportiest car in its segment. Porsche has integrated a completely revised display and control concept into the new Cayenne.

The new Porsche Driver Experience, first introduced in the Porsche Taycan, focuses on the user experience and optimizes operation. Functions that the driver uses frequently are located directly on or immediately next to the steering wheel. For example, the lever located on the left behind the steering wheel now has additional functions for operating the driver assistance systems. The automatic transmission selector lever in the new Cayenne is now on the dashboard. This creates room on the new center console for storage compartments and a large air conditioning controller in an elegant black panel design. Large, easily accessible

Fully digital: The curved instrument cluster offers variable display options.



Quick connection: A new onboard charger with an 11 kW output noticeably reduces charging time (right).

"It's one of the most extensive product upgrades in the history of Porsche"

Michael Schätzle
Vice President Product Line Cayenne at Porsche AG

controls combined with mechanical air conditioning switches and a haptic volume controller ensure optimum operability and a refined look.

DIGITALIZED AND DRIVER-FOCUSED: PORSCHE DRIVER EXPERIENCE

For the first time, the redesigned cockpit of the Cayenne includes a fully digital 12.6-inch instrument cluster with a curved and free-standing design and variable display options. An optimized head-up display is available as an option. The standard 12.3-inch central Porsche Communication Management (PCM) display integrates harmoniously into the new dashboard and provides access to all the relevant vehicle functions. Native apps such as Spotify® and Apple Music® are provided to optimize connectivity in the new Cayenne. A 10.9-inch display is now available for the first time for the passenger side. This enriches the front passenger's driving experience by displaying performance data, providing separate access to the infotainment system controls and, depending on the market, the option of streaming video content on the road. A special foil ensures that the driver cannot see this display.

12.6

inch instrument cluster in a curved design

10.9

inch display for the front passenger

The new Cayenne now has a particularly expressive appearance. A new front end combined with more strongly arched wings, a new bonnet and technically appealing headlights emphasizes the vehicle's width. Three-dimensionally designed tail lights, uncluttered surfaces beneath, and a new rear apron with integrated number plate holder characterize the rear end design of the new Cayenne. An expanded color palette with three new colors, lightweight sports packages saving up to 33 kilograms for the Cayenne Coupé, and a new extensive range of 20, 21, and 22-inch wheels make it possible to individually and dynamically configure the new Cayenne.

Striking looks: Three-dimensionally designed tail lights, uncluttered surfaces, and a new rear apron characterize the rear end design of the new Cayenne.

Matrix LED Headlights are now standard in the new Cayenne. HD Matrix LED Headlights are a new optional feature. With two high-definition modules and more than 32,000 pixels per headlamp, their innovative technology picks out other users and blocks out the light of the high beam to them with pixel accuracy so as not to dazzle them. The brightness of the modules can be regulated in more than 1,000 steps depending on the driving situation. Customized light modes increase safety and comfort in different driving situations.

REFINED DESIGN, INNOVATIVE LIGHTING TECHNOLOGY

Porsche has also introduced an air quality system in the new Cayenne. As standard, the vehicle uses predictive navigation data to detect approaching tunnel entrances and automatically activates air recirculation. Optionally, a sensor detects the level of fine dust particles in the air and passes it through the fine dust filter multiple times if necessary. Furthermore, an ionizer removes many germs and pollutants from the air, which is particularly beneficial for allergy sufferers.

More than

32,000

pixels per LED headlight

Up to

90

kilometers of range in hybrid mode

In addition, customers can use a comprehensive range of new and optimized assistance systems. These include the active speed limiter and the swerve assist, the cornering assist, and the improved Porsche InnoDrive as part of the adaptive cruise control. This means that the new Cayenne is even better at helping its driver in dangerous situations as well as in traffic jams on motorways and main roads.

Porsche now equips the Cayenne at the factory with a steel spring suspension including Porsche Active Suspension Management (PASM). New shock absorbers with 2-valve technology and thus separate rebound and compression stages allow

optimized performance in all driving situations. In particular, comfort at slow speeds, handling during dynamic cornering, and pitch and roll support have been noticeably improved.

INCREASED RANGE BETWEEN RIDE COMFORT AND PERFORMANCE

The driving experience can be additionally enhanced with the new adaptive air suspension with 2-chamber, 2-valve technology. This improves the driving experience with a soft suspension characteristic, stabilizes the vehicle and simplifies on-road and off-road handling—compared to both the standard suspension and the predecessor model. At the same time, the adaptive air suspension improves driving precision and performance, and reduces body movements in dynamic driving situations. The suspension also offers an even sharper differentiation between Normal, Sport and Sport Plus driving modes.

In Europe, the new Cayenne debuts with three different engine versions. An extensive refinement of the four-liter V8 biturbo engine developed by Porsche replaces the previous V6 engine in the new Cayenne S. With a maximum output of 349 kW (474 PS) and a torque of 600 Nm—25 kW (34 PS) and 50 Nm more than its predecessor—it accelerates both the SUV and the SUV Coupé to 100 km/h in 4.7 seconds. The top speed is 273 km/h. The entry into the world of the Cayenne comes with an optimized three-liter V6 turbo engine. It now generates 260 kW (353 PS) and 500 Nm, which is 10 kW (13 PS) and 50 Nm more than before.

HYBRID MODEL WITH MORE POWER AND UP TO 90 KILOMETERS OF ELECTRIC RANGE

The six-cylinder engine also forms the basis for the powertrain of the Cayenne E-Hybrid. In combination with a new electric motor that has been improved by 30 kW to 130 kW (176 PS), the combined output increases to 346 kW (470 PS). Equipped with a high-voltage battery with a capacity increased from 17.9 kWh to 25.9 kWh, depending on the equipment level, a purely electric range according to the WLTP of up to 90 kilometers is now possible. A new 11 kW on-board charger now shortens the charging time at an appropriate power source to less than two and a half hours despite the increased battery capacity. During the trip, the optimized e-hybrid driving modes increase the efficiency of the vehicle.

Easy to reach: Since the automatic transmission selector lever is located on the dashboard, space is freed up in the center console for storage compartments and for a large air conditioning controller.

Teamwork for the new Porsche Cayenne

Porsche has fundamentally overhauled the third generation of the Cayenne with comprehensive changes to the powertrain, chassis, design and equipment. The engineers from Porsche Engineering were involved in this in all different areas. In addition to the chassis, Porsche Engineering also worked on drive integration and the body system—always in close cooperation with Porsche experts from the Weissach Development Center.

Starting in 2019, the chassis specialists from Porsche Engineering worked on extensive chassis scopes within an international team with more than sixty colleagues from four locations. In addition to driver assistance systems, steering, brakes and wheels, they also worked on the spring and damper system. In addition to a wide range of technical content, Porsche Engineering was also responsible for leading the team. The high cybersecurity requirements in the new Cayenne, which new EU directives on protection from IT attacks, were also among the particular technical challenges. Even after unveiling the new Porsche Cayenne, the successful collaboration has not yet come to an end: The chassis experts are working on further projects for the model line.

In addition to the chassis, the engineers from Porsche Engineering also worked on the integration of the motors and motor peripherals, the revision of the intake and process air, the development of the standard and sports exhaust systems, and the cooling system integration in the front end. Last but not least, the team also worked on optimizing the tank venting system and the engine design cover.

From the concept decision to the start of production, the body system experts worked on the vehicle concept and package as well as the Digital Mock Up (DMU). In addition, various body development scopes were also worked on from the concept decision to the start of production—from exterior scopes to interior scopes and vehicle safety.

The result: A robustly upgraded Porsche Cayenne that further broadens the spectrum between on-road and off-road performance on the one hand and luxurious everyday comfort on the other.

Deeper knowledge

PODCAST

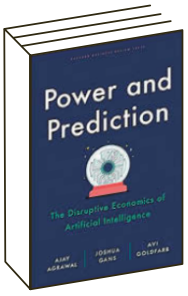
Every company has a story to tell

With an eye for detail, this popular podcast tells the stories of great companies. A number of episodes feature guest appearances by well-known founders and CEOs of companies such as Twitter, Atari, Zoom, Mozilla, and Electronic Arts.

Acquired
www.acquired.fm

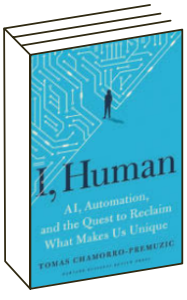
BOOK

Disruptive AI



The triumphal march of artificial intelligence has only just begun. This book explores how AI will fundamentally change decision-making.

Power and Prediction
Ajay Agrawal, Joshua Gans, Avi Goldfarb
Harvard Business Review Press



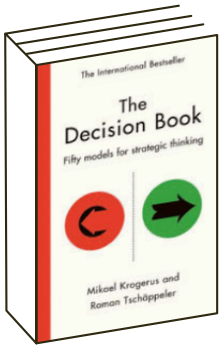
BOOK

A journey into the world of AI

Tomas Chamorro-Premuzic tackles a highly topical question: Will we use AI to improve the way we work and live? Or will we allow it to increase our alienation from each other?

I, Human
Tomas Chamorro-Premuzic
Harvard Business Review Press

The big picture



BOOK

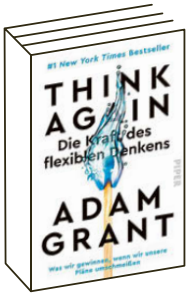
Making better decisions

What do I want? How can I achieve it? How can I be happier and work more efficiently? This book gives you 50 decision-making models for strategic thinking.

The Decision Book
Mikael Krogerus, Roman Tschäppeler
Profile Books

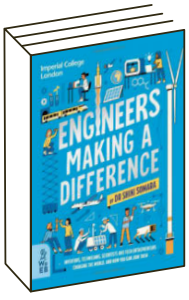
BOOK

The power of flexible thinking



In a rapidly changing world, there's one thing we need in particular: The ability to re-examine our thinking and liberate ourselves from what we have learned. This book demonstrates how to step out of your comfort zone.

Think Again
Adam Grant
Piper



BOOK

Engineers as superheroes

In this illustrated book, the author introduces 46 engineers and shows how their work is changing the world—for example, by fighting food shortages.

Engineers Making a Difference
Shini Somara
Bounce Marketing

For the child in all of us

GAME

Invitation to conversation

This set of 100 cards includes questions about hobbies, desires, fears, likes and dislikes, creativity, faith, and more. They're conversation-starters at the kitchen table, in the car, or wherever the desire for meaningful conversation happens to arise.

The Daily Question Conversation Card Set
www.amazon.de

GAME

Auditory memory game

This game consists of 20 sound squares equipped with an NFC chip. When you hold them up to your smartphone, the associated app plays a short sequence of sounds. This then raises the question: Does the sound sequence of the next square match it?

klang²
klang2.com

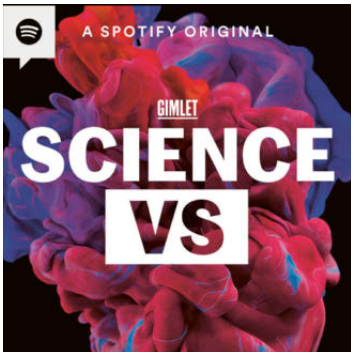
Intelligent entertainment

FILM

Father of the atomic bomb

In his latest film, director Christopher Nolan ("Tenet", "Interstellar") focuses on the American physicist J. Robert Oppenheimer, who is considered the 'father of the atomic bomb'. The film stars Cillian Murphy, Robert Downey Jr. and Matt Damon, among others.

Oppenheimer
Universal Pictures



PODCAST

Friendly fact-checkers

This podcast puts them all under the microscope: Fads, trends and persistent prejudices. How nasty are pit bulls, really? Can placebos cure diseases? Does hypnosis help? Science Vs provides the answers to these questions and many more.

Science Vs
gimletmedia.com/shows/science-vs

Vehicle development in the digital universe

High technical expertise, a clear strategy, and a culture of mutual respect: These are the essential prerequisites for success in the highly complex automotive world of today and beyond. Dr. Peter Schäfer takes a look at past and future revolutions.

When I look back today at my early days in the automotive industry, I realize: The industry is unrecognizable. As a young engineer, I grew up with pure mechanical engineering; the first computers came later. I was attracted to new technologies and interdisciplinary work, such as the use of computers for simulations in development, very early on. Because I understood: In engineering, there is no standing still.

Over the course of my professional life, I experienced one technological revolution after another. The first mechatronic systems—i.e. systems that contained electronics and software—were added to the mechanical engineering of the vehicles. The benefits of networking were quickly recognized. This made it possible to improve the interaction between the mechatronic systems. We all know what has happened in the meantime: The scope of digital functions has long since surpassed the mechanical scope.

But that's not all: Today, vehicles have onboard intelligence, but are also increasingly connected to a backend or to a cloud. In the future, the cloud will not only contain data—it will also enable completely new functions through the use of artificial intelligence. Being able to experience all these leaps in innovation was really something special. And to look ahead to the extensive changes that lie ahead.

Increasing networking also means that you have to think in a more and more networked way yourself—and you need employees who can do the same. As a result, not only technology, but also leadership and collaboration have undergone major changes. As a young engineer, I experienced even more pronounced hierarchies and more directive leadership. But even then, there were supervisors who promoted and practiced modern, collaborative leadership. I wanted to work in such an environment—and was lucky enough to be able to do so.

I learned that this form of collaboration with a high regard for the individual can function outstandingly in combination with demanding technical tasks and a clear strategic orientation. This then gave rise to my own understanding of leadership: For me, strategy and culture are elementary components of successful corporate management in a dynamic, complex environment. In my view, fair and equal treatment of people, openness and communication, and—very importantly—appreciation are absolutely essential. Even if you sometimes have to stand firm on the facts, it is important to always be fair in dealing with people—in other words, 'hard on facts, soft on people', or put another way: 'Separate the people from the problem'.

That alone is not, however, enough: In the networked world of today and beyond, we also need teams that are interdisciplinary in their composition. They must understand the traditional technologies, but at the same time also want to drive new innovations. For management, this means that you have to be able to assemble, lead, and inspire these teams. It is also important to take an integrative approach, because you're working with people with different backgrounds, cultures and skills.

This is how we understand leadership culture at Porsche Engineering today. We integrate people with different qualifications and backgrounds. Porsche Engineering is now an international company with 1,700 employees, in which more than half work outside Germany. This is precisely why we need a common culture that is universally valid and based on appreciation of the individual. It is the basis for our successful collaboration.

And we can't afford to stand still: Today, we are proficient in the development of complete vehicles and the technologies of the digital world. But the journey continues: The pace of change in the digital world is incredibly high, and leaps in innovation are happening ever more rapidly. In my vision, I see the intelligent vehicle of the future at the center of a digital universe that is expanding at an increasing rate. This expansion will spawn new galaxies—digital worlds—with new technologies. Vehicles could, for example, network with smart cities to share swarm intelligence.

This means that in the future, we will continue to need a pioneering spirit, as well as people with courage and a drive for change, who want to quickly familiarize themselves with new fields and strike out into new territory. At the same time, we need managers who can bring new thinking to the table and inspire digital natives. That's why we need to continue to develop our corporate culture and our strategy, because they are the foundation for our success.

One thing we must never lose along the way is the fun we have in our work. I always wanted to have that myself—and I am grateful that I have also been able to create an environment at Porsche Engineering in which our employees feel enthusiasm and joy.

Dr. Peter Schäfer

After 20 years with Porsche, Dr. Peter Schäfer, CEO of Porsche Engineering since 2019, is retiring. Schäfer has played a key role in shaping the strategic direction and successful growth of the international technology service provider: Under his leadership, Porsche Engineering has systematically advanced its positioning as a technology partner for the development of the intelligent and connected vehicle. In addition, new engineering offices were opened in Timișoara and Beijing. The number of employees in the group rose from 1,200 in 2019 to 1,700 today. During his time at Porsche Engineering, Schäfer not only made a significant contribution to the company's success story, but also consistently placed great importance on establishing a culture of mutual respect.

After studying mechanical engineering, Schäfer was a research assistant at the University of Stuttgart, where he also completed his doctorate. In 2003, he joined Porsche and became Head of Special Project Development. This was followed in 2004 by his appointment as general representative of Porsche Engineering Services GmbH, and in 2008 he became Managing Director of the company. Between 2009 and 2018, Schäfer worked at Porsche AG as Vice President Chassis Development and Vice President Complete Vehicle Development. In 2018, he returned to Porsche Engineering as CEO.

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