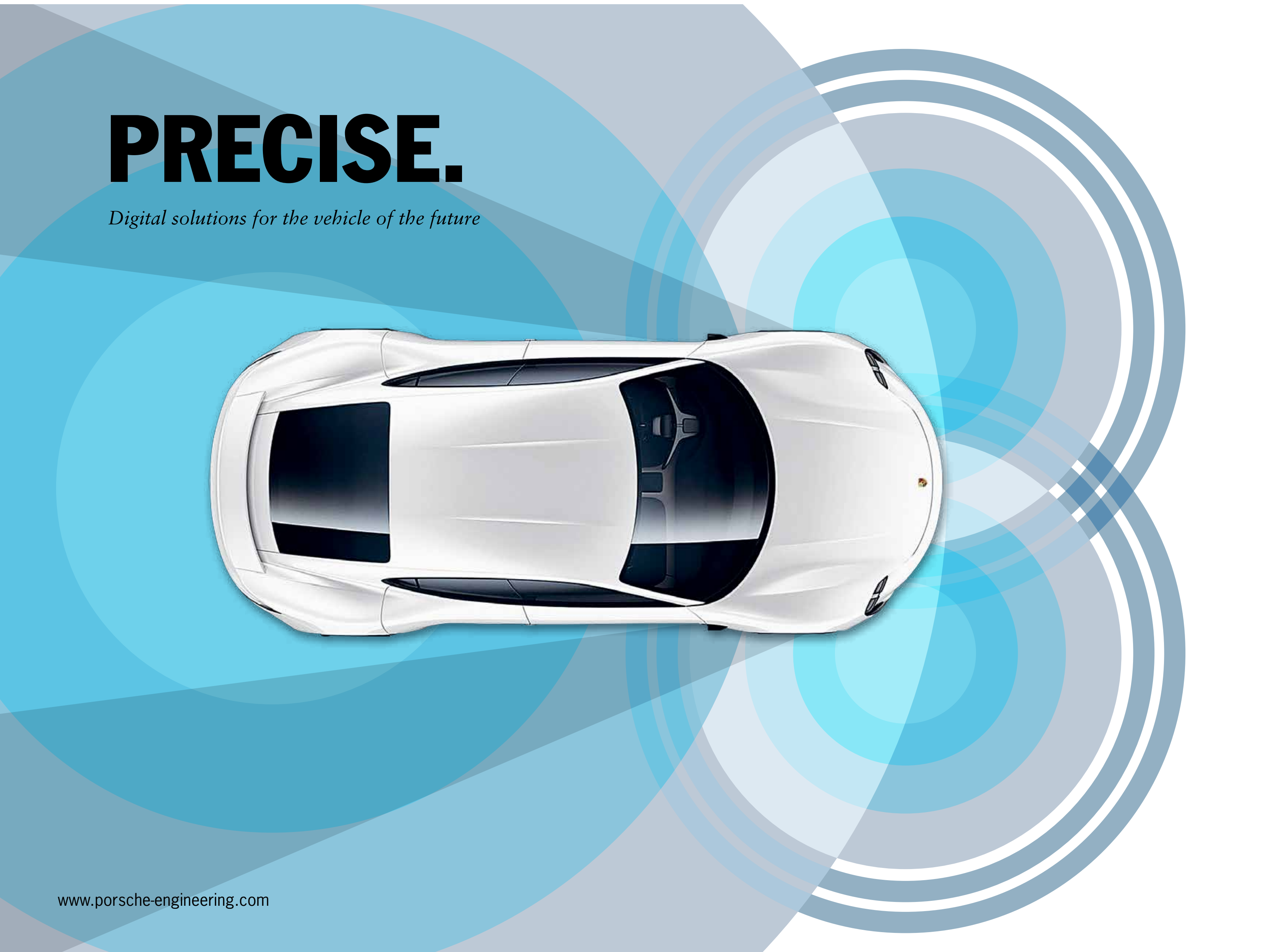
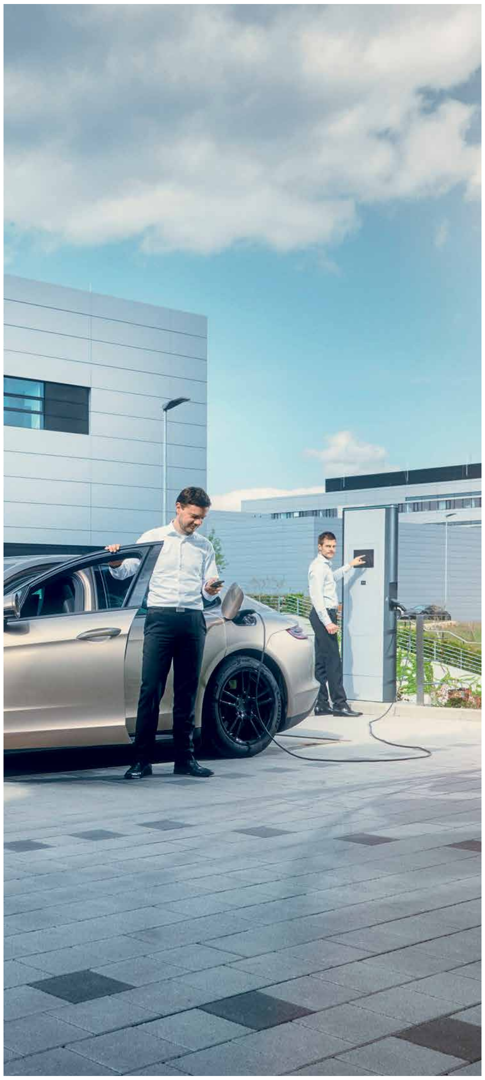
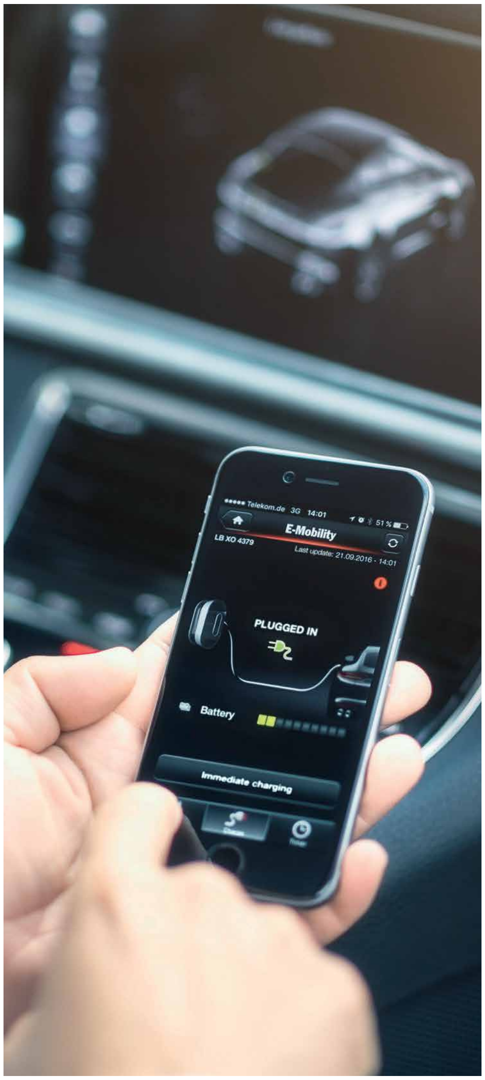
Porsche Engineering
MAGAZINE

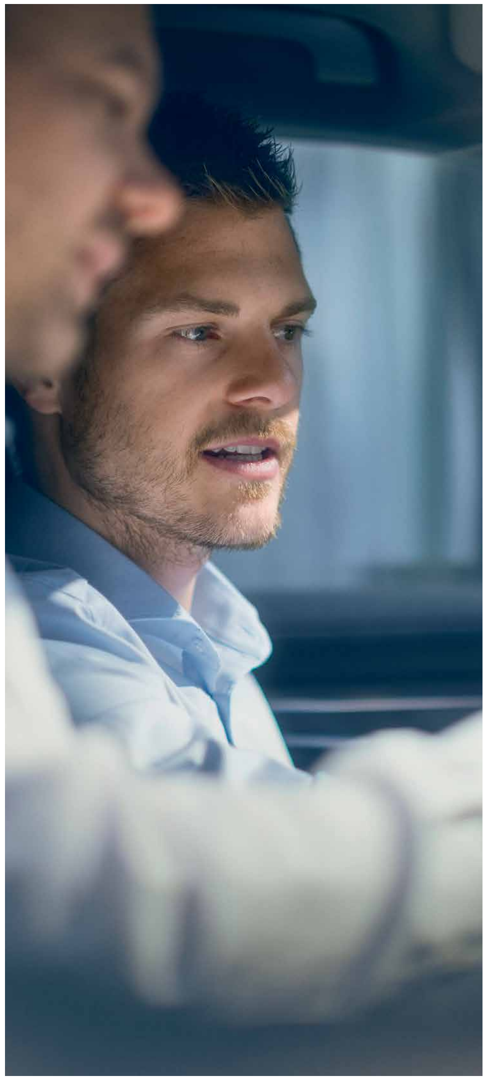
CUSTOMERS & MARKETS Driver cabins for Scania's new truck generation
TRENDS & TECHNOLOGIES Modular component for the battery system: the lithium-ion cell
ENGINEERING INSIGHTS Basics and success factors of the V8 engine

ISSUE 1/2017






E-Mobility
PLUGGED IN
Battery
Immediate charging



Dirk Lappe and Malte Radmann,
Managing Directors of Porsche Engineering

About Porsche Engineering

Creating forward-looking solutions was the standard set by Ferdinand Porsche when he started his design office in 1931. In doing so, he laid the foundation for today's Porsche customer developments. We renew our commitment to that example with each new project that we carry out for customers. The variety of services provided by Porsche Engineering ranges from the design of individual components to the planning and execution of complete vehicle developments and extends to industries beyond the automotive sector.

Dear Readers,

_____ This year's CES electronics tradeshow in Las Vegas was characterized by the rise of digital assistants in daily life. Siri, Alexa, Cortana and the like listen attentively to the goings-on around them and respond to the wishes of their users in fractions of a second. Orders from the internet are made with a simple voice command, the refrigerator is filled automatically and a central intelligence function reminds us that it's just about time to head to work—with traffic jams and delays already baked in. And we fill in the blanks that the artificial intelligence can't work out on its own with hand gestures and voice control.

What can we expect from this "user experience" in the future? How much automation, anticipation of our thoughts and needs, and convenience do we want? One thing is clear: much is possible. What is equally clear: not everything that is technologically feasible is necessarily a good idea. It would seem that the time has come to scrutinize some developments and not lose sight of what really counts: people.

As developers, we're at the forefront of making these themes a reality—particularly as concerns vehicles. That's why we feel such a strong responsibility to create sustainable solutions: developed with a purpose, and for people, rather than simply in pursuit of the technology for its own sake.

In a Porsche, it will remain possible to switch off the data connection; Privacy Mode must remain an option at all times. People need the space to spend time without the internet and constant connectivity. Music is the product of the rests between the notes. We want to advance technology in order to remain human.

We wish you an enjoyable read.

Sincerely,
Malte Radmann and Dirk Lappe

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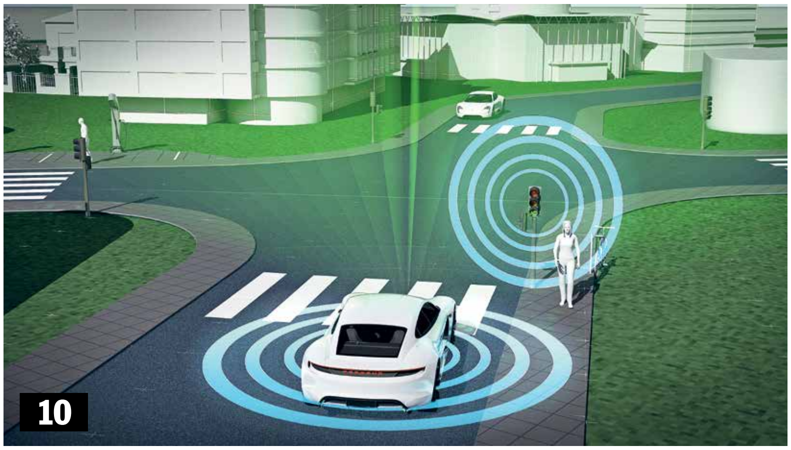
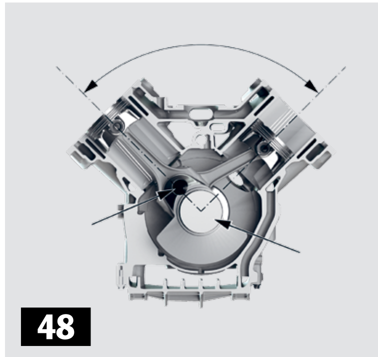
CUSTOMERS & MARKETS
IN THE FAST LANE

Porsche Engineering develops driver cabins for Scania's new truck generation





DIGITALIZATION

CUSTOMERS & MARKETS

TRENDS & TECHNOLOGIES

PORSCHE UP CLOSE

ENGINEERING INSIGHTS

PANAMERA 4 E-HYBRID SPORT TURISMO
Fuel consumption (combined): 2.5 l/100 km
Power consumption (combined): 15.9 kWh/100 km
CO_2 emissions (combined): 56 g/km

COOPERATION FOR THE FUTURE

NEW CONTRACT WITH THE CZECH TECHNICAL UNIVERSITY IN PRAGUE

____ Porsche Engineering is expanding its collaboration with the Czech Technical University in Prague (CTU). To that purpose, Prof. Petr Konvalinka, Rector of CTU, Dirk Lappe, Managing Director of Porsche Engineering Group, and Dr. Miloš Polášek, Managing Director of Porsche Engineering Prague, signed a new collaboration contract at the Czech Institute of Informatics, Robotics and Cybernetics (CIIRC) with the Technical University on May 3rd. The collaboration will now be expanded to new research institutes at the university in order to advance research projects in the automotive industry. Porsche Engineering Prague and the CIIRC Institute work especially closely together in the fields of server-based vehicle functions and the development of charging infrastructure.

The collaboration with CTU began with the establishment of the subsidiary in Prague in 2001. Since then, Porsche Engineering has supported the students with practice-oriented lectures, internships and final projects while benefiting in turn from the latest insights from academic research. ■

News

SOCIAL MEDIA

NEW CORPORATE PROFILES
ON FACEBOOK AND LINKEDIN

____ Technological trends and developments, news from the international Porsche Engineering locations and current job openings: with Porsche Engineering's new corporate profiles on Facebook and LinkedIn, customers, partners, employees and fans can follow the latest developments from the engineering services provider. The profiles can be accessed via the search term "Porsche Engineering" or using the QR codes below. ■

Facebook   LinkedIn

DIGITALIZATION CONTINUES APACE

GROWTH IN CLUJ-NAPOCA

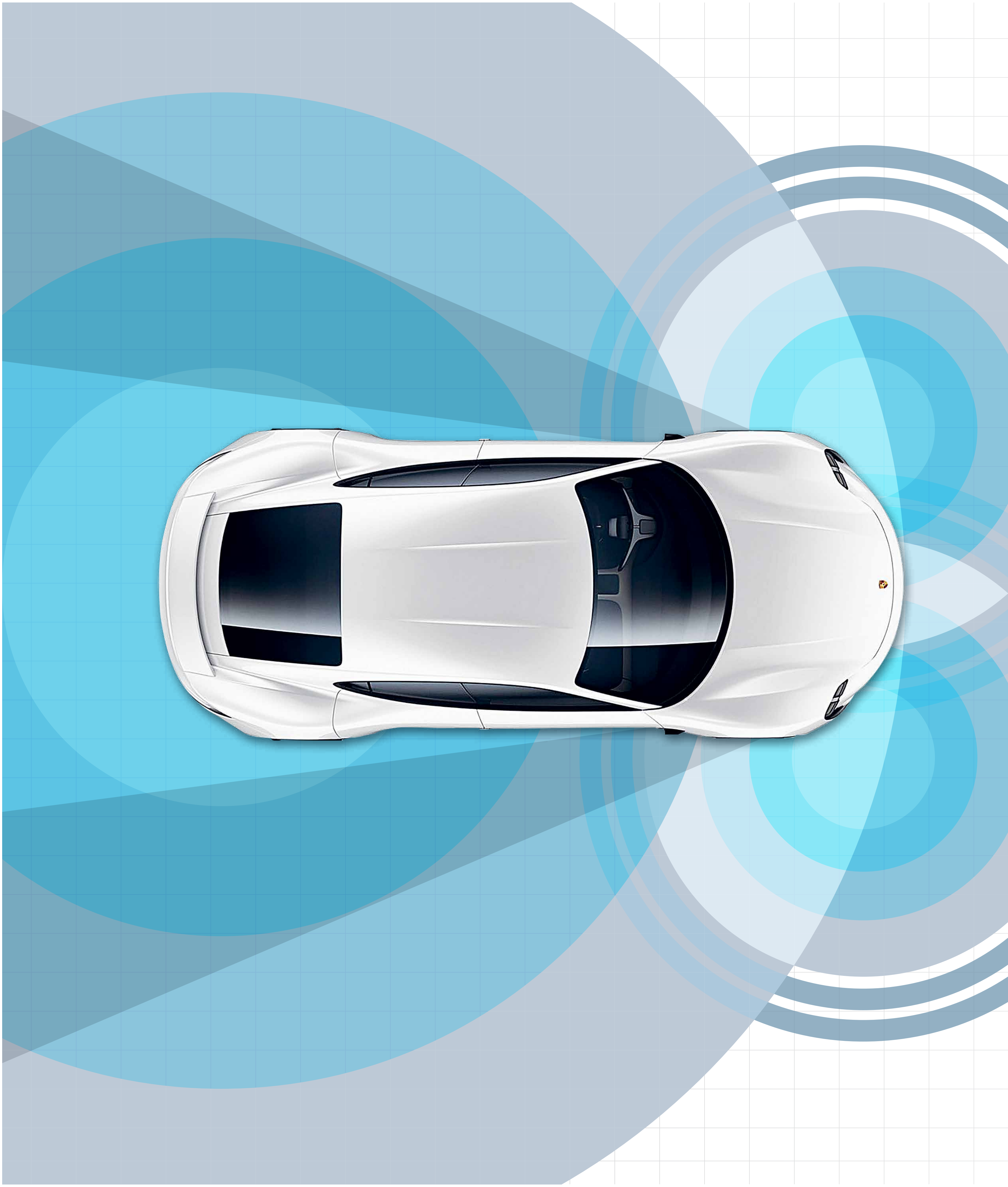
____ Porsche Engineering's software location in Cluj-Napoca has successfully reached its latest growth targets. Development work in Cluj-Napoca focuses on issues concerning the digitalization of vehicles and electromobility. Further growth is planned for the years to come in order to meet the rising demand for function and software development. Recently launched in cooperation with the Technical University in Cluj, the Automotive Engineering program at the university will promote the long-term expansion of the location. ■

FORMULA STUDENT DRIVERLESS

SPONSORED BY PORSCHE ENGINEERING

driverless formula student germany

____ There's a new addition to the Formula Student movement: the new driverless construction competition is dedicated to the development of autonomous race cars. The University of Stuttgart is once again entering a team in the competition and will be supported by Porsche Engineering. Like the GreenTeam for electric driving already sponsored by Porsche Engineering, the formed student group will receive advice from Porsche engineers in the development process and receive access to test benches. The new team will participate in Formula Student races for the first time at the Hockenheimring in August 2017. ■



Precise.

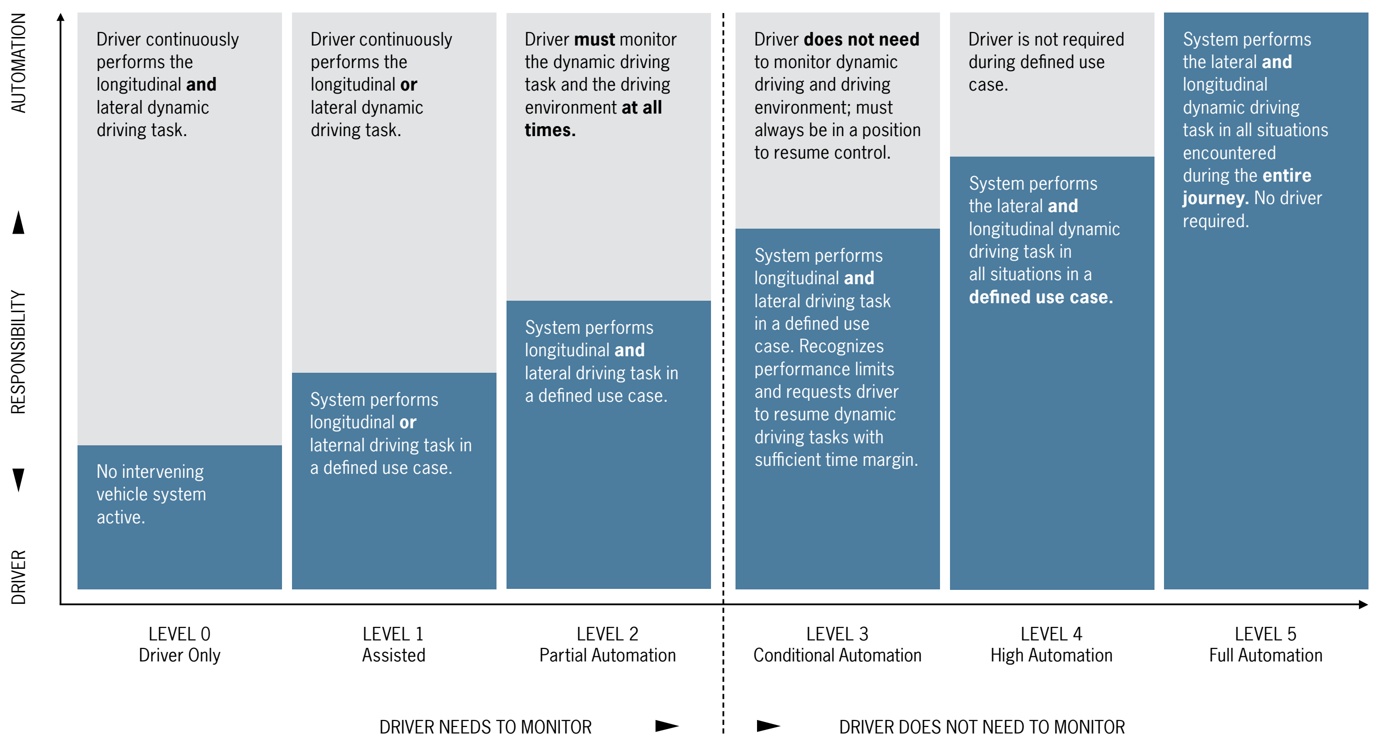
____ That's exactly how we develop digital solutions. Not just technology for its own sake, but always with an eye to the benefits for users and developers. Driver assistance systems need to operate with foresight and work safely at all times. We explain the requirements that thereby emerge for development and how they can be effectively taken into account in the development process. Whether and to what extent digitalization is new, or in fact familiar, in the automotive industry is analyzed by two Porsche experts in our interview. Finally, you can read about how our in-house-developed testing procedure for connectivity applications streamlines the development process—and highlights the possibilities of digitalization for developers and users alike.

Forward-Looking and Safe

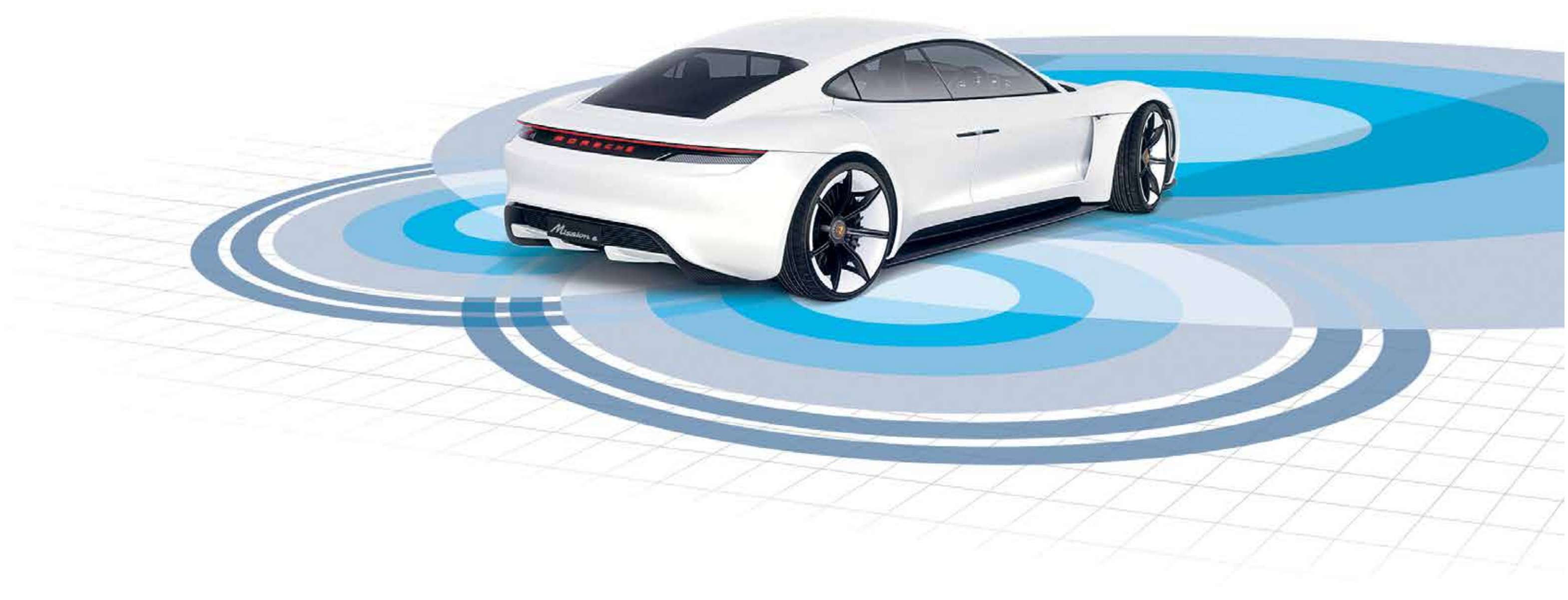
New requirements for the fields of function development, testing grounds and validation

____ In recent years, advanced driver assistance systems (ADAS) have evolved from mere display and warning functions into applications with ever higher degrees of automation. Increasing automation yields new, substantially more demanding requirements in the fields of function development, test grounds and validation.

By Dr. Christian Koelen, Julia Steiner and Johannes Wiebelitz



Scale of automation as per SAE



In keeping with the new demands on driver assistance systems, which increasingly simplify the driving task, the systems are categorized according to classes. In this context, the international Society of Automotive Engineers (SAE) introduced the "SAE Levels of Automation," an automation scale (see figure on page 10).

Initial steps of automation

At the lowest level, 0, the driver conducts the driving task alone, but is aided by display and warning assistance systems with information about the traffic and infrastructure environment. Examples include traffic sign display and a lane departure warning function. Higher-level assistance systems actively intervene in controlling the vehicle, including longitudinal and/or lateral control. From automation level 3 and up, the driver can concentrate on other activities if conditions permit, but must reassume the driving task if the system limits are reached. In other words: the vehicle performs the driving task completely independently, but the driver must be able to control the vehicle manually in a transitional scenario. Precisely this reassumption of control of the driving task by the driver becomes problematic when the driver has mentally withdrawn far from the driving situation. The question of how to handle this situation safely is currently the focus of much discussion.

From highly automated to autonomous driving

Highly automated driving (level 4) differs from autonomous driving (level 5) in that autonomous driving signifies complete performance of the driving task by the vehicle from the start to the destination. In highly automated driving, this applies only to certain application cases; one example of this level is automatic valet parking, in which the vehicle independently parks itself in a free spot in a parking garage without being monitored by the driver.

The development of highly automated and autonomous vehicles represents a major challenge. The correct perception of the environment by the assistance systems remains difficult today, as does situational interpretation. Only the use of self-learning algorithms seems to offer the possibility of mastering the variety of possible driving scenarios with an acceptable degree of effort. Initial approaches look promising; neuronal networks, for example, are currently enabling major advancements in image processing and object classification.

In contrast to the capabilities of the human brain, a self-driving vehicle requires huge amounts of training data in order to correctly classify objects and situations. In order to generate these enormous and highly relevant data sets, it is helpful to gather the data and ultimately the "intelligence" of a large number of vehicles. To this purpose, it is important to utilize a centralized back-end server with which the vehicles exchange all information. The back-end server collects the data from an entire fleet of vehicles and processes it, with the insights gained through the processing then fed back to each individual vehicle.

Validation of highly and fully automated systems

Due to the huge variety of possible driving situations, the validation of highly and fully automated systems › represents a particular challenge in the development process. Traditionally, development and validation processes in vehicle development make use of testing facilities and grounds and simulations.

Validation through simulations

The advantage of simulations lies in the fast and reproducible validation of the implemented functions. In other words, all pre-defined test scenarios can be tested cheaply and quickly. The figure below shows a virtual, simulated environment.

As simulations can only generate a more or less realistic representation of reality, it is indispensable to conduct validation on testing grounds and, ultimately, in real-life traffic situations as well.

Validation at testing facilities and grounds

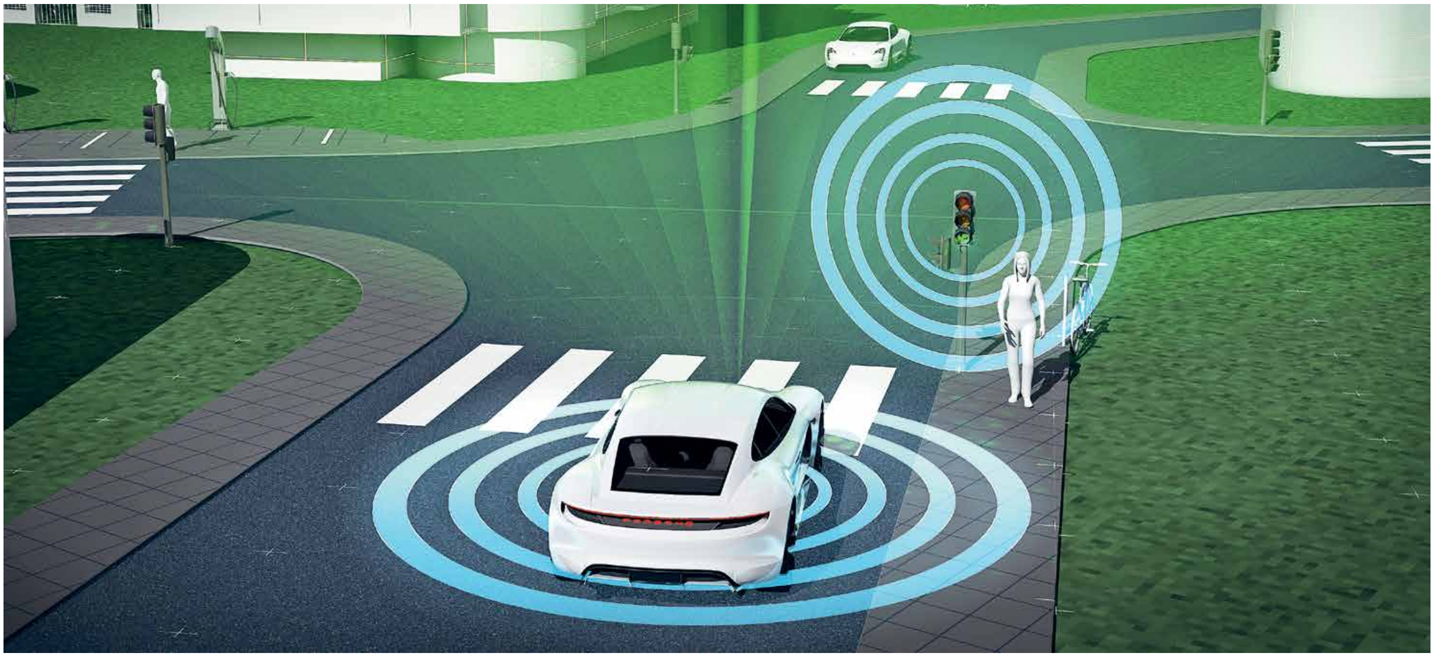
Available testing facilities and grounds currently consist mainly of large asphalt surfaces, high-speed tracks and demanding handling courses. However, in order to test automated driving functions in their different manifestations, these grounds must be designed such that real traffic situations can also be set up and tested on them. A future-ready testing grounds for the comprehensive testing of partially and highly automated driving functions must therefore demonstrate several substantial enhancements over previously available testing facilities.

Digital cartography for the validation of functions using predictive route data

To allow driver assistance functions that use predictive route data (PSD) as their data basis to be tested on non-public test grounds, the grounds need first to be digitally mapped. In doing so, for example, information on route progressions, applicable speed limits, number of lanes or the precise positions of traffic signs must be recorded. In current Porsche vehicles, this information is already available through the navigation database, enabling a preview of static route attributes such as a speed limit that comes into effect in 200 meters.

Precise localization through differential GPS

The testing of highly and fully automated driving on testing grounds requires as-precise-as-possible localization of the test vehicles. This is made possible by local differential GPS (DGPS), for example. In testing operations, the DGPS assists in the precise positioning of vehicles. Beyond the testing of



Virtual vehicle in an environmental simulation

The efficient testing of partially and highly automated functions must be based on mature tool chains.

automated functions and the testing of reproducible test scenarios, it also offers an additional key advantage for the operator of the testing grounds: it increases safety within the grounds, in particular during critical tests in higher speed ranges as rescue operations can be coordinated with much greater precision in that case.

Dynamic environment and interconnection of traffic participants

In addition to localization in terms of the absolute and relative vehicle position, localization within a dynamic environment must also be possible. Dynamic test objects or other test participants could communicate with each other on the testing grounds via a full-coverage Wi-Fi or Internet-capable mobile network. At the same time, this would also create the fundamental prerequisite for testing connected car services as well as a basis for the networking of all static test objects. The precondition for this is that the test environment of the testing grounds already have a controllable and communication-capable infrastructure. Light control systems or other interactive test objects must be capable of functioning in accordance with the requirements of the test scenario. In traffic scenarios, which need to be represented highly realistically, additional controlled pedestrian or cyclist dummies could be used.

Highest enhancement level: simulated city

The combination of all of the testing grounds enhancement described thus far leads to a highly flexible, actually drivable test environment comprising the greatest possible variety in terms of traffic situations and attributes. This level is referred to as the simulated city (SimCity) as city traffic manifests the highest density of traffic situations. Simple implementation options are available through changeable street routing or the use of different predictive route data codes. For comprehensive testing of autonomous driving functions, however, there is also a need to simulate real traffic participants within such a SimCity, to which purpose all coordination scopes and data flows must be agglomerated and controlled in a central management unit.

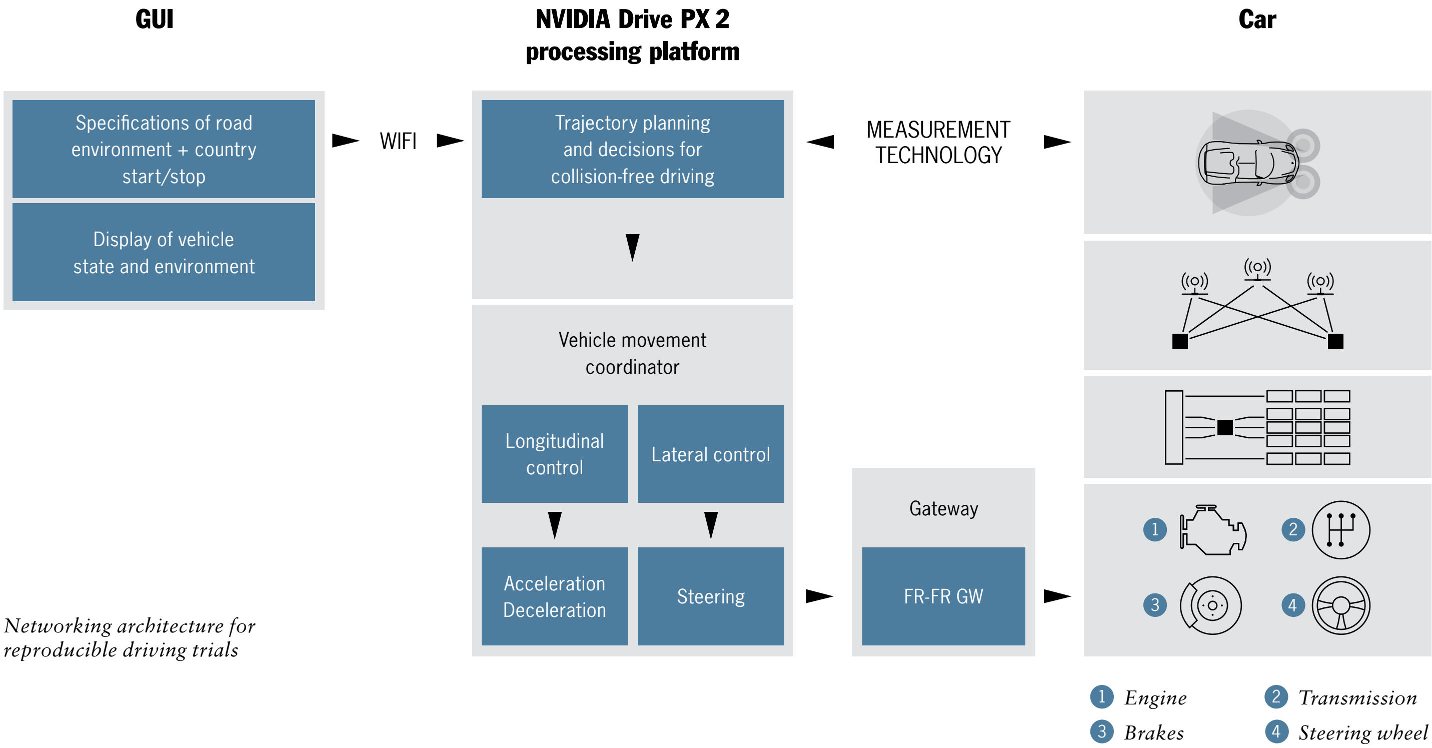
Testing of critical driving situations

To generate a useful basis for the development of safe partially and fully automated driving, a database including all critical driving situations is essential. The data can be used, in the first place, to simulate critical incidents. Purely virtual calculation, however, soon reaches its limits when it comes to evaluating human perception. The simulation of environmental sensing, too, only works to some degree as it only represents partial components. The upshot is that a comprehensive system test of the real vehicle including the drive unit and suspension components can only be simulated to a limited extent.

Reproducible driving tests with robotic vehicles

One solution approach is to test extracts from the simulation in the real testing environment. To achieve this, the robotic vehicles used as environmental traffic participants must be centrally controllable in accordance with the scenarios dictated by the simulation. The appropriate driving maneuvers are selected for each test objective. The basis is a driving maneuver catalog containing a large number of globally relevant scenarios. Many of the driving maneuvers are taken from real test environments. Test vehicles are equipped with extensive environmental sensor technology that records the traffic activity in the immediate vicinity. For the test procedure, these stored driving scenarios are “run” on specially designed testing grounds. The originally recorded vehicle environment, i.e. the traffic participants moving relative to the test vehicle, is represented by the centrally remote-controlled robotic vehicles. In principle, this method can be used to cover scenarios relevant in various customer markets.

The demands placed on the robotic vehicles are high. Each machine must be capable of safe conduct, i.e. designed with redundancy, while at the same time having the capability ›



Networking architecture for reproducible driving trials

to independently transition to a safe state in case of error (see figure on top of page 15).

The efficient testing of partially and highly automated functions must be based on mature tool chains. Only tools that can control and also measure the complex test conditions will be up to the task of handling the ever more multifaceted scenarios that will emerge in the future. In the defined test maneuver catalogs for the validation of new software and functional states, the comparability of test procedures is essential. Because many advanced driver assistance systems, such as adaptive cruise control (ACC), are dependent on the behavior of other traffic participants, robot vehicles are required. The automation of the robot vehicles makes it possible to achieve the highest possible degree of reproducibility of the test maneuvers.

To influence the longitudinal and lateral control of the vehicle, corresponding driver assistance interfaces are brought to bear. ACC is suitable for the longitudinal direction and lane keeping support (LKS) for the lateral direction. This requires an adaptation of the vehicle architecture. For signal manipulation purposes, FlexRay-FlexRay gateways (FR-FR GW) are inserted into the vehicle FlexRay branches. These additional interfaces enable manipulation of individual control unit signals (ECU) through triggering. This enables intervention on the signal level without changing the actual vehicle functions.

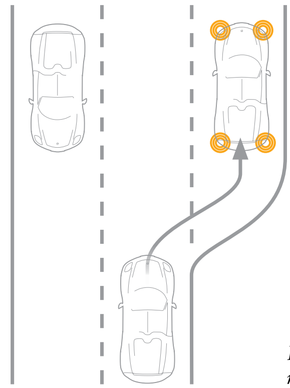
With this approach, recorded measurements can also be automated and reproducibly driven. Development steps become identifiable and improvements measurable. Moreover, an elementary development condition is fulfilled: the reproducibility of tests for the detection of error causes.

Taking into account the vehicle environment sensor technology, additional sensors and user input, trajectory planning and decisions for collision-free driving are made on the NVIDIA Drive PX 2 computing platform.

Reliability for robotic and series vehicles

As the complexity and degree of automation rise, so do the requirements in terms of reliability. This affects automation levels 3 to 5 and applies equally to robotic vehicles used in the validation of assistance functions and to the development of the series function. It is essential to establish redundancy in the sensing capability and the control apparatus so that the vehicle can be transferred to a safe state in critical situations. This "emergency maneuver" state is activated through a trigger based on various different incidents. These include system component failure, or—in a real situation—the unavailability of the driver after a certain retrieval time or through the observation of the driver (such as falling asleep or experiencing a medical emergency). The vehicle then determines the nearest parking position based on map information and infrastructure data and then independently proceeds to the location by means of an upstream trajectory plan based on the ego-position (localization).

This maneuver must be conducted in a collision-free manner and without obstructing other traffic participants or test vehicles. In order to achieve this, monitoring the vehicle environment is indispensable. Both static and dynamic objects need to be detected and avoided in order to prevent accidents. Accomplishing this requires the sensing technology to be extremely precise and designed with diversitary redundancy for plausibility assessment purposes. Here, diversitary means that two or more different systems/technologies (e.g. camera and radar) ensure that an object is detected.



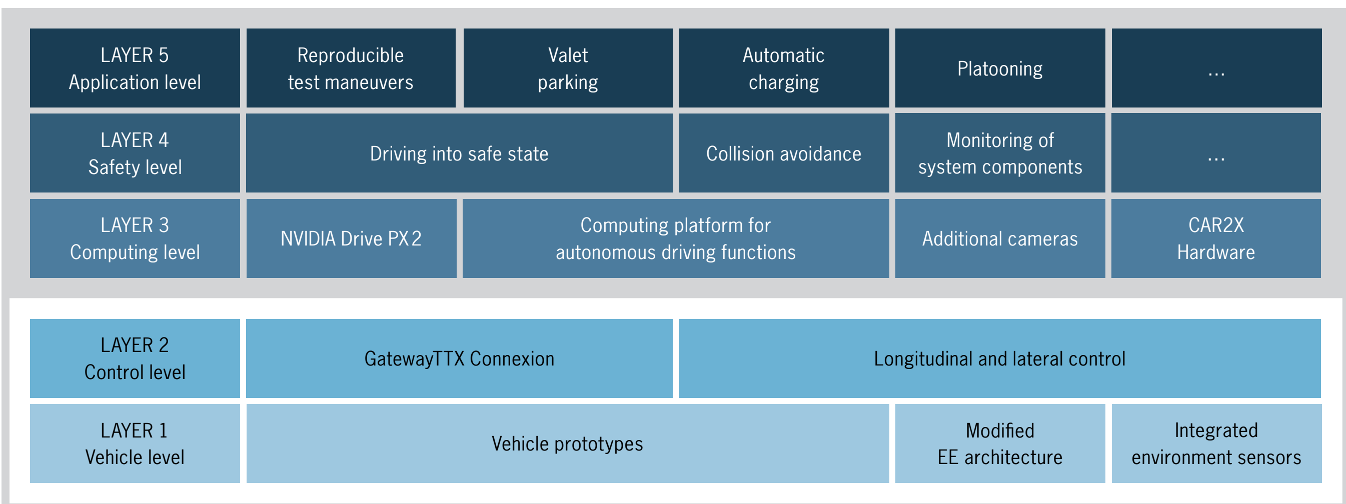
Independent "emergency maneuver" to a safe state

The safe state is regarded as achieved as soon as the vehicle has reached a designated emergency stop bay, decelerated to a stop and secured itself against rolling away or applied the parking brake. Also conceivable would be the transmission of an emergency call. On the Porsche testing grounds in Nardò, the maximum gap between emergency stop bays on the track is three kilometers. So the vehicle must be able to drive at least this minimum distance.

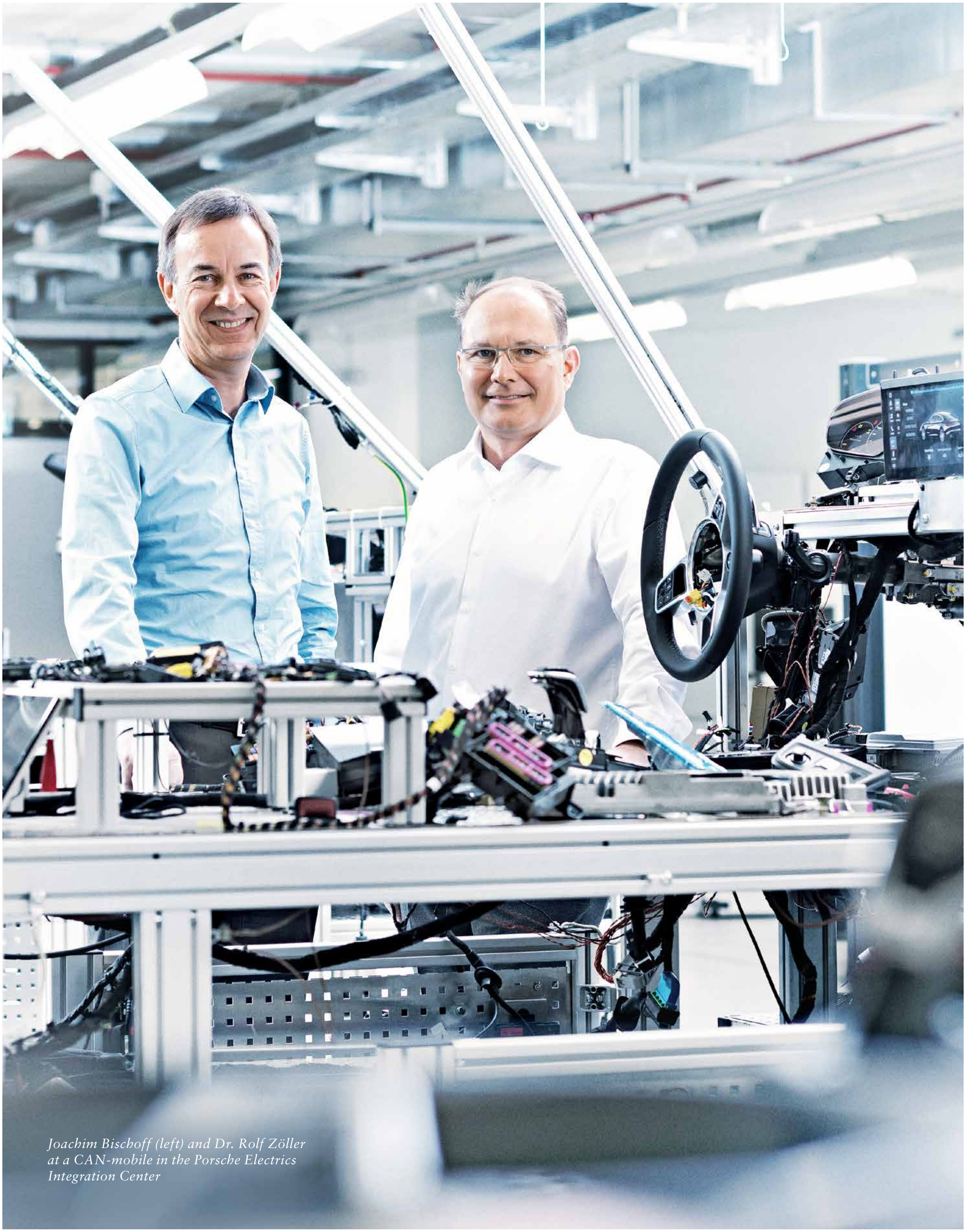
The driving automation layer model required to ensure reliability is depicted in the figure below. The safety level (layer 4) is particularly noteworthy. This is where the system components are monitored and the safe state is requested in critical situations. The upstream computing level fulfills the requirement of the ASIL standard (Automotive Safety Integrity Level—Functional Safety; ISO 26262).

Highly automated driving is in the works

The long-term advancement of driver assistance systems toward higher degrees of automation results in greater demands on the fields of function, testing grounds and validation. In that process, the intelligent further development of self-learning systems, cross-object networking and effective validation processes, as well as the enhancements of variable testing grounds, are essential to making highly automated and autonomous driving a reality. ■



Layer model of driving automation



Joachim Bischoff (left) and Dr. Rolf Zöller at a CAN-mobile in the Porsche Electrics Integration Center

New, Yet Familiar

____ Dr. Rolf Zöller, head of Car Connect at Porsche AG, and Joachim Bischoff, head of digitalization at Porsche Engineering, on the degree of novelty of digital technologies in automotive development, enhanced functions for an optimal customer experience and the digital Porsche product world.

Interview by Peter Weidenhammer; photos by Steffen Jahn

Digitalization is the word on everyone's lips these days—how do you define it?

Dr. Rolf Zöller Digitalization is long since commonplace in vehicles. That's been the case since the 1990s. Today it's almost exclusively digital and networked systems on board. What's new is that the vehicle now communicates with the outside world as well. That's the digitalization that one hears so much about today and the customer experiences. Our goal is to meet the customer in their digital lifestyle, bring them along and provide them with a useful benefit through our product.

Joachim Bischoff At its core, today's digitalization is characterized by massive increases in transmission rates and computing power, ever-rising storage capacity and ever-smaller chips. Those are the factors that enable what we understand as digitalization.

Is the impact of digitalization mainly a question of customer perceptions?

Dr. Zöller Beyond the digitalization perceived by the customer, there are also fundamental impacts on our company and our processes. We have to be mindful of digitalization in our development processes and take more cues from the software industry, adjust our speed and think beyond where we are today—beyond the vehicle as we have known it to date. That is the overall digital experience perceived by the customer.

Bischoff Precisely these two components, the internal and external, are essential for our future success: digital internal processes that enable an unparalleled customer user experience.

How well is the automotive industry prepared for these changes?

Dr. Zöller The industry is actually better prepared for the situation than is generally assumed or in many cases communicated in the media. Vehicle development has been using various digital processes for quite some time. Take numerical simulation, for example. Beneath the sheet metal and in the development process, vehicles have been digital for a long time; it's just not necessarily perceived by the customer as digitalization.

Bischoff The complexity that one has found in the vehicle for the past ten years is astounding. Take the multimedia system, for example. Here the networking of various functions has been in place for some time. Then there is the capability of integrating such complex systems in the vehicle environment, including vehicle functions like the drive unit control system. ›

"We concentrate particularly on functions and services that are characterized by our core competencies and brand-specific characteristics."

Dr. Rolf Zöller

So the question can be posed: is it easier for a software company to build a car, or a carmaker to develop software?

Dr. Zöller What's really new is that we're going beyond the vehicle, competing with other players and having to meet new requirements. Earlier, the competition was other vehicle manufacturers. Today, the competitor might be an IT company, and the customers expect functions in the vehicle that a start-up has only recently brought to the market.

To what extent does digitalization change the traditional business models of OEMs?

Dr. Zöller They will change quite significantly. Enablers, as they are known, foster a new kind of product substance within and outside of the vehicle. One such enabler is over-the-air technology. It makes it possible to transmit software via the air interface, in order to update customer vehicles, for example. This not only allows us to ensure a continuously current status for the vehicle, but also opens up new options in terms of customization. For example, we can offer the customer additional and perhaps time-limited services and functions for a fee as on-demand functions.

What would that look like in practice?

Dr. Zöller Today we're used to selling a vehicle and thereby gaining an immediate profit from the sale. In the future, we will have to assume that the customer is not paying the investment sum in its entirety for the vehicle purchase itself, but over the entire ownership period. What that means is that we will have to continuously add new functions and features over the lifetime of the vehicle. We call it the "car for life" concept and expect it to bring about significant changes for our process worlds and the customer experience.

What does it mean for the customer?

Bischoff The mobility experience is expanding. For the customer, this will open up completely new opportunities in terms of vehicle use, for instance through car-sharing concepts, and make additional services available on-demand.

Dr. Zöller In the future, successful OEMs will be characterized by their ability to strike a balance between new business fields and their traditional activities, because the conventional requirements of vehicles will remain in place as well. And what especially applies to Porsche: a sports car has to be a sports car in the future as well.

What does the digital Porsche product world look like in 2025 from your perspective?

Dr. Zöller Selling vehicles remains the top priority. However, we will increasingly enable and offer more services and service packages as additional products to customize the vehicles.

Customers can expect an overall package specially designed for them and therefore unique. In short: we create a personal ecosystem for customers through which they can continuously stay in contact with their cars, the enhanced functions and the company in every conceivable way.

What themes is Porsche focusing on in particular?

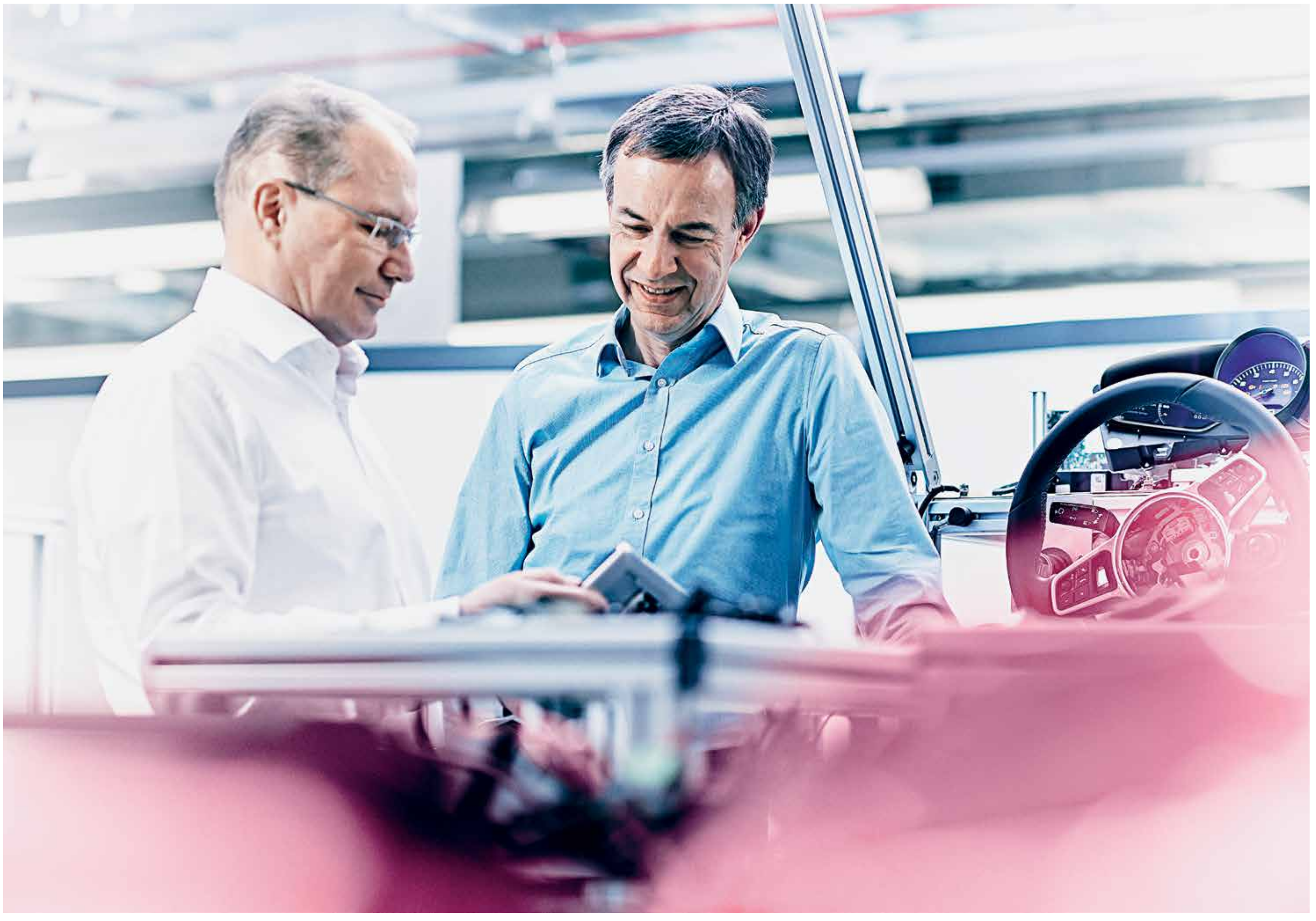
Dr. Zöller We concentrate particularly on functions and services that are characterized by our core competencies and brand-specific characteristics. This would include, for example, functions like the already available Porsche Track Precision app, which allows detailed display, recording and analysis of driving data on a smartphone for closed courses outside the public traffic environment.

Bischoff Chassis functions could also be enhanced through new features: if customers want to drive more dynamically on certain stretches of road, they can specifically condition the vehicle setup for that using special data made available for that purpose.

Dr. Zöller We also regard the topic of premium parking for our customers as very important. In dense traffic in urban areas, it's always a great advantage to have assistance of any kind when it comes to parking. Our objective is always to focus on the Porsche ecosystem and its further development as a whole.

What role do separate organizational units at Porsche such as Porsche Digital GmbH, the Digital Lab and Porsche Engineering play in the context of the digital transformation?

Dr. Zöller They enable us to have an efficient and targeted focus on the various different development phases while simultaneously broadening our horizons. Porsche Digital GmbH steers the early phase. They develop strategies and evaluate product ideas, derive business cases and customer experience on that basis and determine which partners ›



would be most suitable for implementation. The Digital Lab takes care of bringing methods and technologies to maturity and thus advances the tools and processes for the digitalization projects. We see Porsche Engineering as an integral component for series development at the Weissach Development Center. That applies both to the software and its integration into the vehicle and ranges from the design of prototypes to tests and ultimately validation. Across all of these issues, we collaborate closely and do so with great effectiveness and efficiency.

With increasing digitalization, security aspects play an increasingly important role. How do you approach this challenge?

Bischoff Security has always been an essential component of vehicle architecture at Porsche. Traditional vehicle safety with regard to theft and manipulation is now being expanded to include IT security. We regard this as an ongoing theme that is not concluded with the development and delivery of the vehicle but which requires continuous further enhancement. To this end, we've established departments, we engage IT and security experts and we work with established partners from the field.

Dr. Zöller The over-the-air interface has a key role here: On the one hand it has to be secured against outside attacks, but also enables continuous enhancement of the vehicle's security through updates—just like with a smartphone. So we ensure the security of the vehicle long after delivery to the customer.

With rising data diversity and volumes, how do you handle data evaluation and the issue of data protection?

Dr. Zöller We take both issues very seriously. From the very beginning we've firmly anchored data protection in our Connected Car organization. In all products, protecting privacy is part of the fundamental design. It's important that customers know what happens with their data and when what data is used. Privacy modes ensure that no data is transmitted if the customer wishes it not to be. We go much further than all of our competitors in the respect.

What can the data obtained with consent be used for?

Dr. Zöller We have a lot of ideas that concern our core product. How anonymized data from the vehicle fleet, for example, can help us make our vehicles even better. Or the fact that it enables us to generate a highly precise map for real-time traffic notifications. Such data will also play a major role in enabling autonomous driving by providing a lane-specific representation of reality that is up-to-date. This data, by the way, is anonymized in the vehicle before being transmitted.

Bischoff How the data is used and who has access to it will also depend on the individual functions. If a vehicle is blocking a route and is behind a ridge, it would be morally reprehensible to make that data available only to cars of the same brand. Such safety-relevant data would certainly be exchanged between the different brands. Where it gets more restrictive is with data for Porsche-specific functions. They may not be of any interest to other manufacturers, but they are all the more important for high-performance sports cars. And a Porsche will always remain a Porsche. ■

Dr. Rolf Zöller (50)

After concluding his studies in electrical engineering and physics at the Mannheim University of Cooperative Education and the Technical University of Darmstadt with a doctorate specializing in numerical modeling, Dr. Zöller worked in software development for mechatronic systems for over ten years with Carl Schenck AG. From 1998 to 2001, he directed software development for high-end multimedia systems at Siemens VDO. In 2001, Dr. Zöller joined Porsche as the director of the software team in the electronics development department. Since 2016, he has been responsible for the areas of infotainment, Connected Car, HMI and software development.

Joachim Bischoff (56)

After his studies in communications engineering at the Karlsruhe University of Applied Sciences, Joachim Bischoff began his career as a software developer with Nokia in Pforzheim. He subsequently worked for Harman Becker in various roles—first as the director of software development and concluding as Vice President of product development. In 2010, Bischoff joined Porsche Engineering as the director of the system development technical discipline and has headed the digitalization department since August 2016.

Connected and Flexible

Automated testing procedures for connectivity enhancements

____ Every manufacturer develops systems and products to enhance the connectivity between the driver, the vehicle and the world outside. Connectivity is therefore becoming an increasingly major issue in the automotive industry. The pace of this development, and increasingly important functions, present new challenges for testing, testing procedures and test benches. Porsche has developed a solution that utilizes automated procedures to save valuable development time.

By Jochen Spiegel, Stefan Jockisch and Thomas Pretsch

Porsche Connect links drivers and vehicles with the mobile internet. Intelligent apps, functions and services enhance the individual benefits of all Porsche models. At the core of Connect are more than 20 services and apps for navigation and infotainment as well as the querying and control of vehicle functions. Almost all can be easily purchased and set up via the internet.

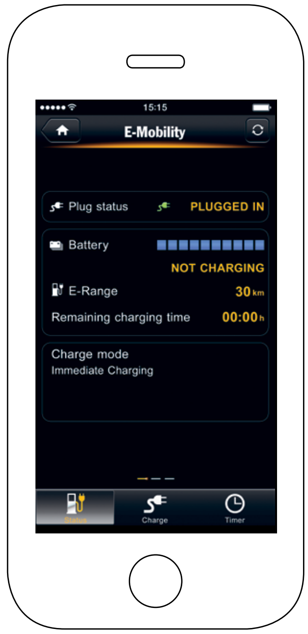
Porsche Connect encompasses numerous different components. The central components are the vehicle itself, with its connected control devices, and the vehicle's own mobile communication interface. The interface sends vehicle data via a group-developed air interface to the group's centralized modular backend system (MBB), which stores the data for later use, for example in the customer's app, and returns any commands to the vehicle. The backend, in turn, is connected to various cloud services that provide information for display in the vehicle. The customer's terminal device, such as a smartphone with the Porsche Connect app, communicates directly with the vehicle's infotainment system.

Porsche e-hybrid models, for example, already offer access to the engine-independent heating system and the possibility of programming a charging timer via internet or mobile connections. Future generations of hybrid and electric vehicles from Porsche will benefit even more from connectivity. The intelligent home energy management systems and charging stations for users' electric vehicles will be conveniently configured and controlled from one's living room. Using Porsche Connect, in the future it will be possible to prepare drives with an electric vehicle in optimal fashion, reducing travel time to a minimum by utilizing range information, predictive traffic information and information regarding rapid charging stations along the route.

Yet the increasingly complex interweaving of physical and digital functions also leads to a collision of drastically divergent speeds in the development process—which requires a re-thinking of the entire value chain from the concept to the delivery of the finished vehicle.

Different life cycles and development times

With an average duration of four years, the development time for vehicles ranges somewhere between that of smart home systems on the one hand and the extremely fast-paced mobile phone sector on the other. While the most widespread home automation and networking systems have usually been in service for over 16 years, the life cycle for smartphones and tablets is just around one to two years. The only thing more



Porsche Car Connect app with E-Mobility functions

rapidly developed and enhanced is smartphone apps. The requirements for the design and scope of functions of the apps are sometimes redefined by the market multiple times per year.

So while the hardware in the vehicle at the moment when production begins may be at a different stage of development, the vehicle software used in it and the connected IT systems, with their frontends of apps and portals, always need to be absolutely up-to-the-minute. Then there is the demand for updateable functions in the vehicle in consideration of privacy and IT security concerns. The development of a vehicle therefore no longer ends with the start of production. As the components outside of the vehicle—such as the smartphone app communicating with the vehicle—are continuously being further developed, new requirements are likewise continuously being placed on vehicle development function testing as well.

Conventional development processes and methods have to be adapted and expanded to ensure compliance with customer requirements and expectations, as well as industry specifications. For such a complex interplay to succeed, the use of the new software tools is indispensable. Establishing a test › automation apparatus for validating the proper functioning of the vehicle and IT components in the early phase of the project lays the foundation for the regressive test cycles down the line. Moreover, this also makes it possible to largely compensate for the various development and life cycles.

Connectivity demands new approaches in testing

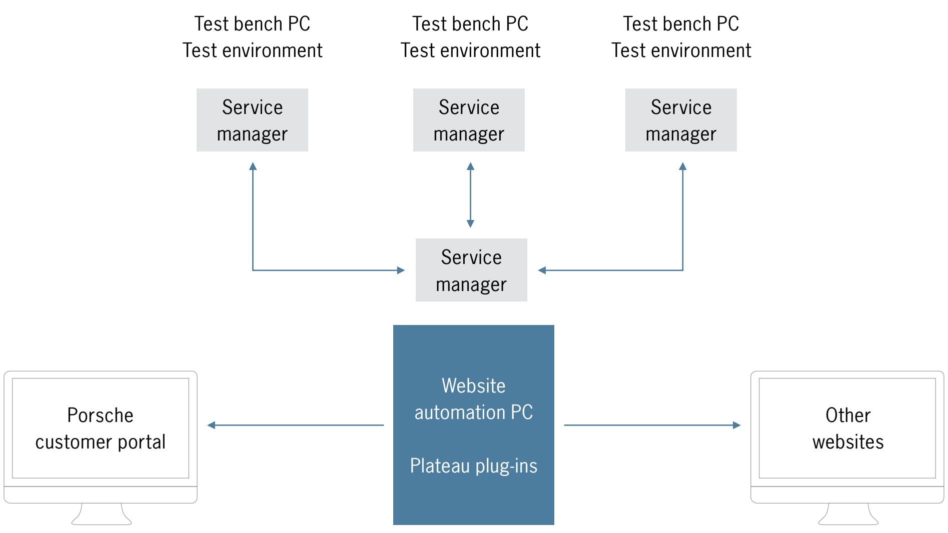
The method of end-to-end regression tests serves as an efficient and useful variant for the functional and non-functional validation of connected services. The focus of this quality assurance procedure is on the entire chain extending from the vehicle via a backend to various user interfaces such as a browser-based customer portal or a smartphone app. The prerequisite for automated tests of services via their connected systems are procedures that enable interactions with all components without manual assistance. The integration of a web-based user interface is achieved by expanding the previous test infrastructure and environment. This makes it possible to define functions in the test environment that operate the interface in an automated process.

The automation of user interfaces involves developments that need to be specifically adapted to the visualizations. The first step in that process is to generate samples that describe user behavior for a defined service function. In complex cases, this sample can be mapped using an activity diagram. Once the user behavior has been recorded, implementation follows. This requires the unique identification of every web element with which interactions via the interface take place. This can be a button that is pressed, or a text field into which a string of characters it supposed to be entered.

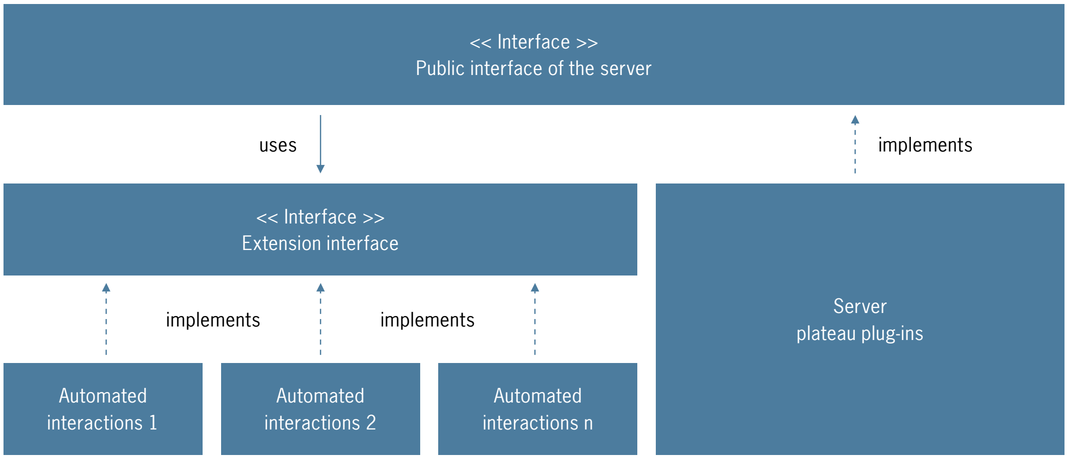
Stable solution for adaptable test concept

Changes to the web-based visualization can therefore also necessitate changes to the automation. Here, things hinge on the development of a stable solution that still uniquely identifies and operates elements even when the user interface is changed. Thus an automated test cycle can be used to check whether the changes lead to adverse impacts on the maturity of the service.

The creation of a plateau plug-in is ideal for the integration of the solution in the test environment. The middleware architecture of this plug-in enables remote activation of the website automation. The option of using plateau plug-ins emerges from the establishment of a centralized solution for test benches in the connected car field. The execution of the website automation runs on an independent device in the Porsche network on the basis of the Selenium framework. Also, a detailed log is generated by the server solution.



The architecture of the concept for website automation enables the centralized and location-independent use of the server by multiple test benches.



New websites and sequences of interactions can be directly connected to the intended extension interface without adaptation on the server.

New websites or new content on existing websites can be integrated via an extension interface. The operations of the additional interface are implemented for every automation and then dynamically accessed by the server. The access concept and the use of centralized databases allow the simple connection of new websites to be automated. The system also offers a means of automating multiple websites in parallel that can be scaled to the number of test benches.

Server enables parallel and time-saving testing

The rapidly expanding scope of functionality in the area of vehicle connectivity and the concomitant rise in the need for testing in turn require ever more test benches. Through the integration of the server, this concept offers the possibility of conducting simultaneous automation of multiple websites and thus productive testing. The use of centralized databases that enable a reaction to changes without recompiling the automations ensures the desired adaptability. The use of proven technologies, meanwhile, secures the long-term stability of the service. This requirement is relevant, particularly in the field of automated testing, as operations frequently need to be maintained without interruption for many hours. The extensive logging also provides a wealth of information about the process of each automation. This information can be used to analyze the results and provide the degree of detail required to trace the actions of the executed processes. Among other things, screenshots that capture the contents of a website in the event of erroneous behavior support error analysis.

In addition to this solution for website automation, Porsche engineers also continue to use a comparable concept for contacting mobile devices. The concept is based on a web server that communicates through a REST API (Representational State Transfer Application Programming Interface) and has implemented the WebDriver interface. The implementation of the WebDriver interface is based on the one from Selenium, which is also used for website automation. The Selenium implementation has been enhanced for use on smartphones. The web server receives commands from a client that contain defined user interactions. Depending on the respective smartphone's platform, the commands are executed by UIAutomator (Google) or UIAutomation (Apple). The results are then sent back to the client as HTTP responses.

These productive procedures create a basis for automated regressive testing of newly developed services—for instance networked charging control—in a manner that is as close to the customer experience as possible, thus saving valuable development time.

Development continues even after production begins

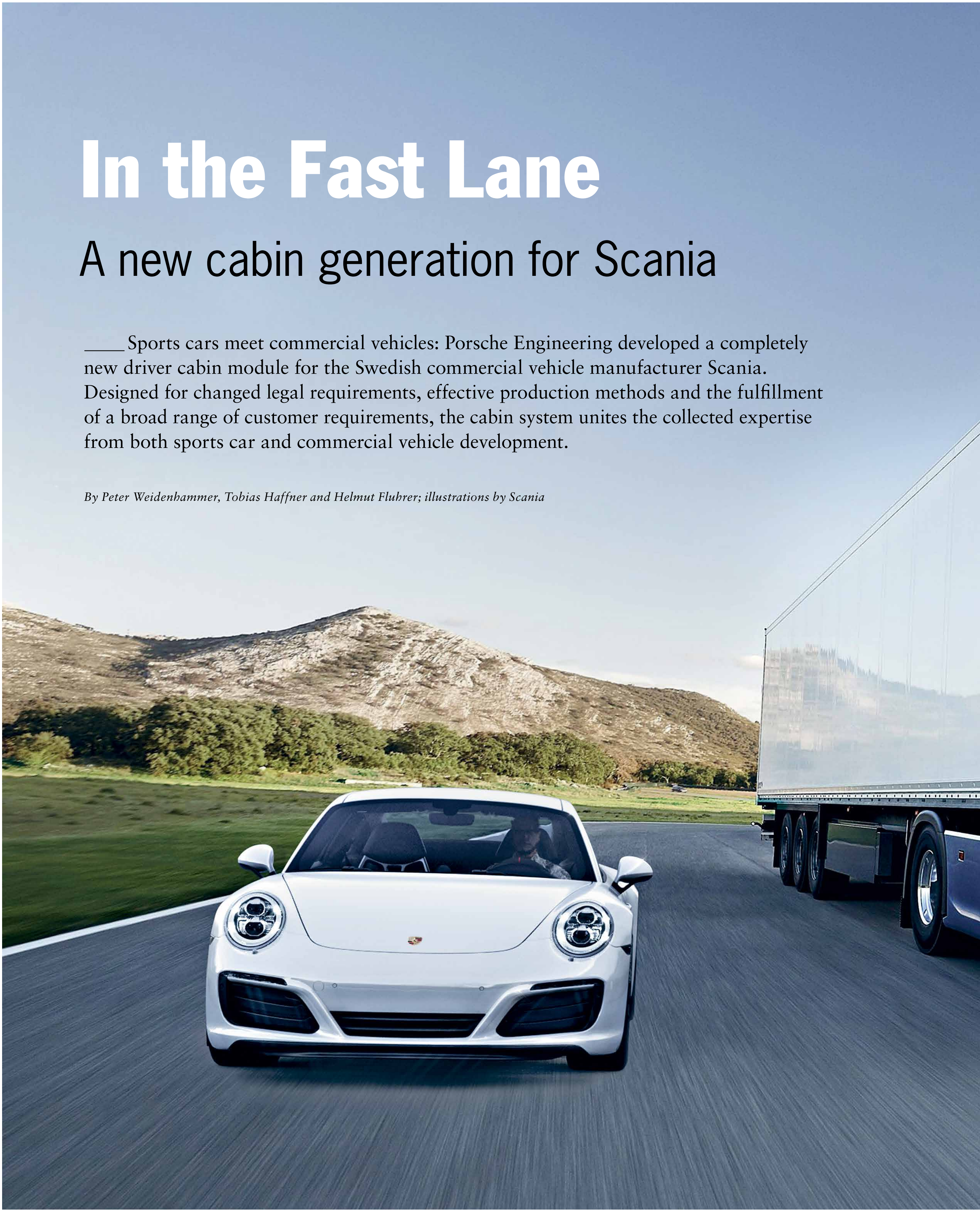
Development processes will also have to adapt to new requirements. Among other things, this means stronger networking of various portfolios such as development, IT and sales, particularly with regard to coordinating the relevant development and validation activities. As has already been said, the development of these networked systems no longer ends when the vehicle goes into production, but is a continuous process. ■

In the Fast Lane

A new cabin generation for Scania

____Sports cars meet commercial vehicles: Porsche Engineering developed a completely new driver cabin module for the Swedish commercial vehicle manufacturer Scania. Designed for changed legal requirements, effective production methods and the fulfillment of a broad range of customer requirements, the cabin system unites the collected expertise from both sports car and commercial vehicle development.

By Peter Weidenhammer, Tobias Haffner and Helmut Fluhrer; illustrations by Scania




SCANIA
R500

The clocks run differently in the commercial vehicle sector. The product cycles are much longer and the mileages are very much higher than in the passenger vehicle sector. Scania, one of the world's leading manufacturers in the premium commercial vehicle sector, offers a vehicle generation for roughly 15 years. That's approximately double the model lifetime compared to the passenger vehicle sector. The use profiles are even more distinct. A commercial vehicle generation covers a diverse range of uses, from construction site transporters for difficult distribution to delivery trucks and long-haul tractors whose total mileage can easily reach several million kilometers. As such, not only the number of chassis variants but also the number of cabin variants in particular are accordingly higher. On the other hand, the number of units produced also differs significantly between the two vehicle worlds. With 70,000 to 80,000 units per year, Scania produces significantly less than volume car manufacturers.

And yet there are also certain similarities between the Swedish commercial vehicle manufacturer and the Swabian sports car developer: both meet premium standards, both utilize high technology and both invest in innovation and efficiency. So it was not too much of a stretch for Scania to turn to Porsche Engineering. "Porsche Engineering has the advantage of being directly connected to the automobile manufacturer Porsche. Their explicit awareness of customer requirements and understanding of the peripheral issues that play a role in completing the job economically are hugely beneficial in our project work," said Dr.-Ing. Harald Ludanek, the former Executive Vice President for Research and Development of Scania in an interview with *Porsche Engineering Magazine* (Issue 1/2013).

Driving forces: stricter legal requirements and growth

The content was not solely the development of a completely new cabin generation, but also of the associated production process. At the top of the agenda was the fulfillment of future legal requirements, and with an appropriately long-term perspective in view of the long product cycles. In order to ensure that the new vehicles would be able to comply with emissions thresholds over the long term, the cooling capacity had to be significantly increased. Yet larger heat exchangers and air intakes were also associated with major interventions in the design and bodyshell. More stringent requirements for the brakes required a shift of the front axle toward the front of the vehicle and thus a different cabin geometry. For a better view, the position of the driver was moved forward and toward the door. The third focal point in the area of legal standards was the fulfillment of foreseeable requirements in terms of crash safety through a stronger bodyshell. Moreover, the new truck generation from Scania is the first in this vehicle segment to feature a side curtain airbag for roll-over crashes.

As a strongly customer-oriented manufacturer, Scania also had some demanding objectives of its own. The priority was on solidifying its leading position in the premium segment. Scania stands for performance. For commercial vehicles, the primary focal points are reliability, economical fuel consumption, long service life, low repair and maintenance costs and powerful engines. Scania wanted to reinforce its premium positioning in order to continue setting new standards in the commercial vehicle sector. The company also wanted to create the conditions for growth, including into new customer segments, through shorter life cycles, faster market launches and additional cabin variants.

Overview of Scania models from 1968 to 2016

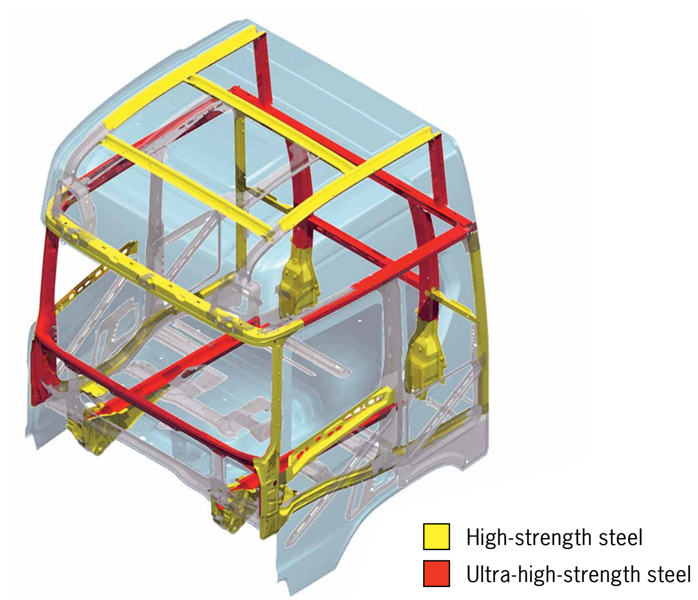
Industry-leading aerodynamics was one of Scania´s goals during the development process.

Development period: six years

The project was devised to encompass four phases over six years. The concept phase began in late summer 2010 and transitioned to the development phase the next year once the design was determined. Prototypes were available from 2012 onwards and at the same time intensive testing scopes as well as the detailed design of the new production facilities started. The final phase, one-and-a-half years later, was implementation with a production start in mid-2016. A steering committee consisting of technical experts from both project partners coordinated the core development areas, such as design and calculation, technology, production, NVH, prototypes, testing and project management. This organizational structure simplified the process of unifying the development processes.

Some features, such as the highly developed simulation procedures of Porsche Engineering, resulted in time savings. The tilting of the cab, for example, while necessary to access the engine of the truck, leads to high stresses to the cab structure during lifting and lowering of the cab. Every change to the tilting axle, then, necessarily influences the weight distribution and thereby the structural design and crash behavior. Through simulations, the design could be adapted to the changes relatively quickly and tested with regard to its behavior under loads.

When it comes to the exterior, Scania has given top priority to aspects relating to aerodynamics and, consequently, ›



Steels of various strengths are used.

Bodyshells of the Scania truck cabins at Weissach Development Center

Photo by Jörg Eberl

Cab matrix of Scania including four cabins of the new truck generation

fuel consumption. Every surface, at the front as well as along the sides of the vehicle and, indeed, even below the vehicle, has been optimized for minimum drag. All clearances and tolerances have been minimized. Good aerodynamics also helps cut noise levels both inside and outside the vehicle, as does the generous use of noise- and vibration-absorbing measures, like carpets and expanding damping materials in various cavities.

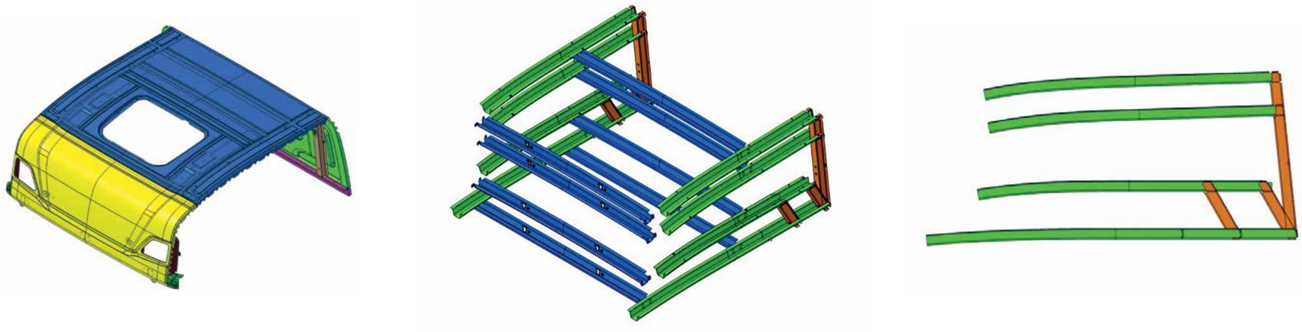
Challenge: simultaneous development of 24 cabin variants

One of the greatest challenges in the project was the simultaneous development of 24 cabin variants in a modular system. The primary differences at Scania are in the floor type, length and roof type. Added to this is the distance to the chassis depending on the use, which has a major impact on the design. Three examples: for a long-haul tractor unit, the view and the preservation of the driver's well-being are key. Moreover, the cabin doubles as a living and sleeping space, meaning that spacious and comfortable quarters with a high driver position are of the essence. For urban vehicles with many stops, by contrast, multiple steps to the driver cabin are time-consuming and tiring. Trucks for waste disposal therefore have low boarding heights. Construction site vehicles range somewhere in between the two extremes depending on the difficulty of the terrain, but require extremely robust designs in any event. The cabin matrix from Scania is therefore divided into different cabin levels over the chassis with variations in roof heights and cabin lengths.

"The challenge is creating a flexible range of cabs that can, without compromise, offer the right solutions and right functionality for all applications and needs," says Göran Hammarberg, Head of Cab Development at Scania. "Despite the fact that needs can differ radically in different driving situations and assignments, our goal is for all drivers to be able to feel confident that no one else can offer a better solution for their particular truck and the conditions they work in."

With their expertise in the development of decidedly stiff and light body structures, the Porsche engineers designed a cabin body utilizing steels of various strength levels. While Scania had previously used mild steels without hot stamping, the new cabin generation also uses modern high- and ultra-high-strength and hot-stamped alloys. The A-pillars are made of hot-stamped boron steel, for example. The extremely high strength enables a leaner and lighter design, offering both enhanced crash safety and a better view for the driver simultaneously.

The use of roll forming profiles enables high flexibility in component ›



Example of modular build of roof with roll-formed profiles

production of the modular assembly system. For example, the production of same-type components of various lengths requires just one tool, which results in greater flexibility and time and cost savings in contrast with using several different tools in the classical deep-drawing process.

New production method: spot-weld bonding and laser brazing

Alongside the modern manufacturing methods in component production, with its new cabin generation Scania also introduced new bonding technologies to its production process. In the floor and front areas, the spot-welding is fortified through the additional application of high performance crash-type structural adhesive. This leads to a huge improvement on fatigue, crash and stiffness performance. The use of the adhesive enhances the already exemplary durability of Scania commercial vehicles even further.

In joining the exterior roof components, the commercial vehicle manufacturer is using laser brazing for the first time. The advantage of the procedure: the quality of the brazed seam obviates the need for the PVC seal that was previously necessary in those areas. Applied in the visible areas of the cabin exterior shell, it also improves the cabin appearance. However, the method does require high dimensional accuracy of the roof exterior components as well as their precise positioning. If the gaps between the elements are too large, the filler wire falls through. In this optimization of the respective production method, the expertise of Porsche played a key role.

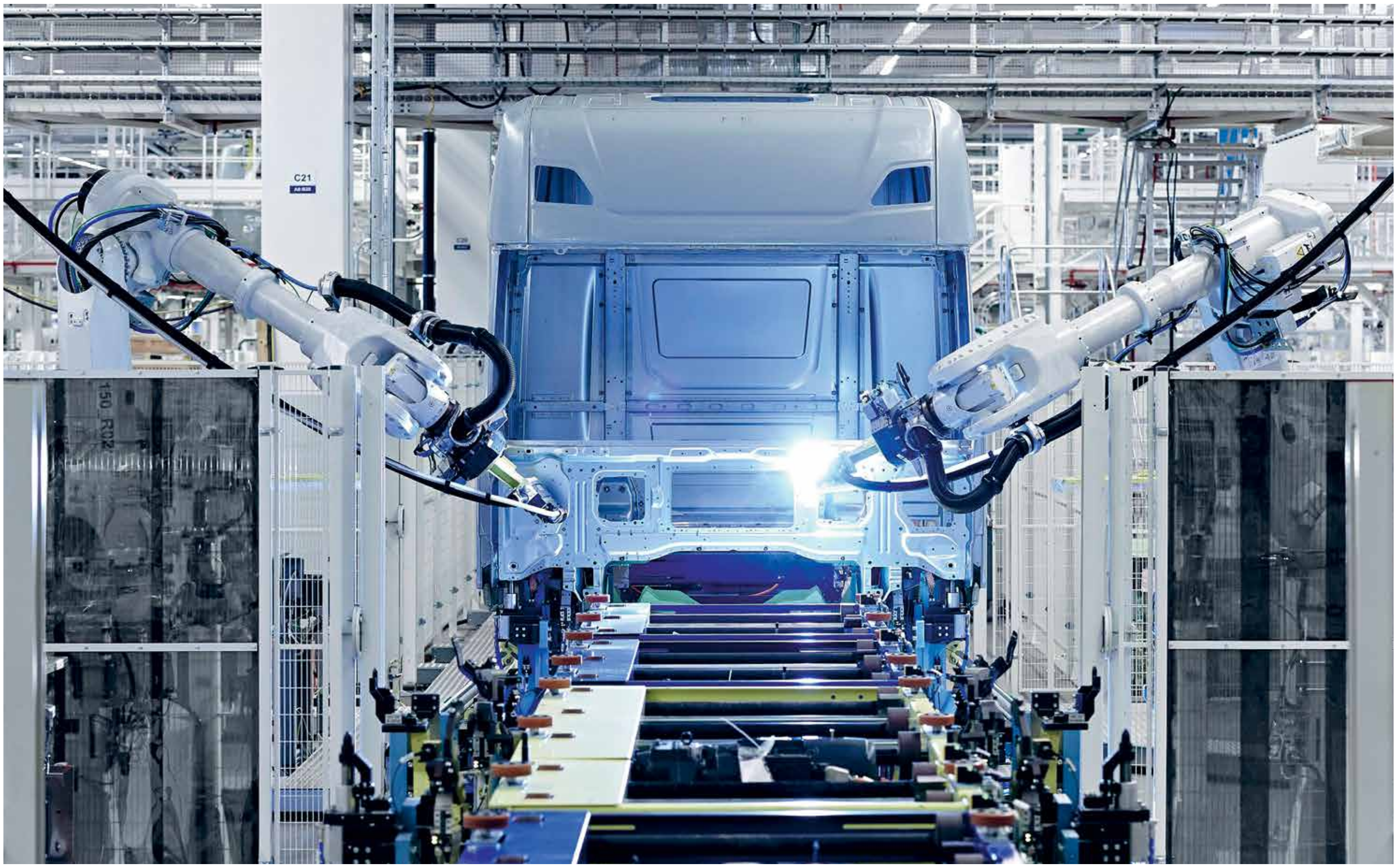
The improved comfort of the new cabin generation also included further enhanced insulation against chassis noise achieved through foaming components within the pillars of the cabin bodyshell. Bulkhead components with expanding foam are used. After painting they expand in the drying furnace and thus attain their sealing function.

The first four main cabin variants of the new Scania cabin generation have been in series production in Oskarshamn, Sweden, since summer 2016. All further variants will be launched successively. The new body shop assembly process involves 283 robots, which can produce up to 350 cabin bodyshells per day. The production facility is designed to accommodate both growing demand and an expansion of the model range. In addition to the body assembly line in Oskarshamn, the new cabin generation will also be produced at Scania's plant in São Paulo, Brazil.

Successful collaboration

Through the efficient collaboration with Porsche Engineering, Scania is prepared to respond to changing circumstances in the commercial vehicle sector that might come up with regard to legal requirements or technical efforts in efficiency, quality and safety. The project also established quality-enhancing and cost-reducing processes in cabin production that will continue to benefit the company well into the future.

Scania approaches the future very well prepared to meet the demanding and exacting requirements of the commercial vehicle market and to position itself as the segment's leader in quality and innovation. ■



Welding in a Scania production plant in Oskarshamn, Sweden

Truck of the Year

Scania's new truck range has been voted International Truck of the Year for 2017. At the 66th IAA Commercial Vehicle Show, a jury of 25 commercial vehicle editors and senior journalists, representing 25 major trucking magazines from throughout Europe, chose the all-new Scania S series for the prestigious award. The jury's motivation emphasized the new truck generation's driver comfort, safety aspects and its positive impact on haulers' overall economy, among other factors. Summing up the jury vote, International Truck of the Year Chairman Gianenrico Griffini commented: "Scania delivered a truck that represents a real 'state-of-the-art'."

Photo by Rafael Krötz

Blueprint for a Success Story

The lithium-ion cell as the modular component for battery systems

____ The electrification of vehicles presents engineers and scientists with new challenges. Even more than the electric motor, the battery system plays a key role. The most widespread technology in use today is the rechargeable lithium-ion cell. Its functional principle allows various different structural designs and properties. Only a precise knowledge of fundamentals and solution approaches enables targeted further development for use in electric vehicles.

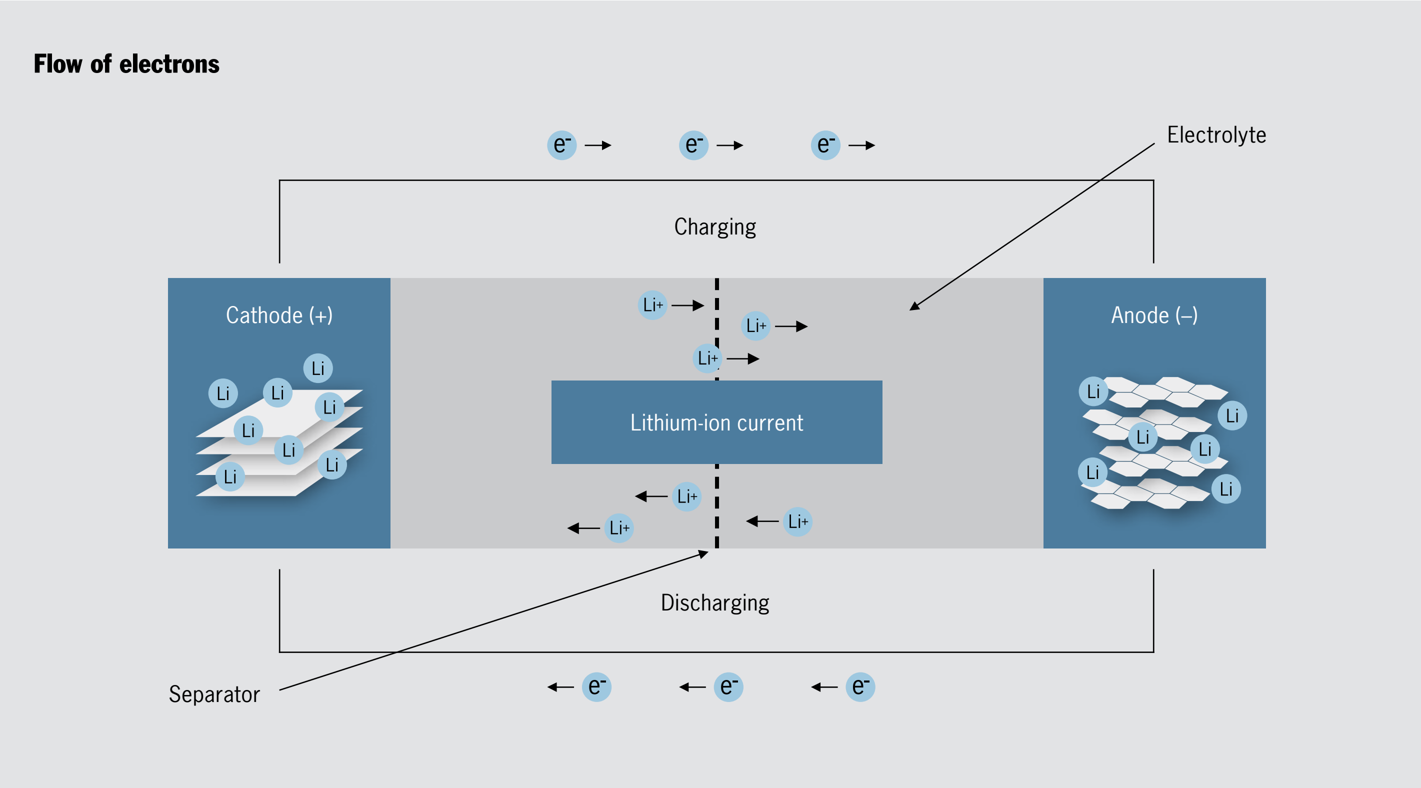
By Dr. Stefanie Ostermeyer and Tim Schmidt

Design and manner of functioning

A battery system is generally comprised of multiple modules, which in turn are made up of individual battery cells. The main components of a battery cell are the anode and the cathode, the separator, the electrolyte and the cell case. The electrodes consist of a thin metal foil (current collector) coated with an electrode film. In the case of lithium-ion cells, the aluminum foil of the cathode is frequently coated with an electrode film based on transition metal oxides such as lithium nickel manganese cobalt oxides. The anode typically consists of a copper foil coated with a graphite-containing electrode film. The porous electrode films consist primarily of the active material and to a lesser extent of conductive carbon additives and polymeric binders.

The two electrodes are electrically isolated from each other by the separator—a semipermeable membrane—in order to prevent a short circuit. Separators are frequently made of microporous plastics like polyethylene. They can also be stabilized by ceramic particles. The pores in the electrodes and the separator are saturated with an electrolyte that serves as a lithium-ion conductor. Solutions of organic carbonates—for instance ethylene carbonate—and a conductive salt such as lithium hexafluorophosphate are commonly used as electrolytes.

Immediately after assembly, a lithium-ion cell is in the uncharged state, i.e. all available lattice sites in the cathode active material are completely occupied by lithium ions. If the cell is charged, lithium ions move from the cathode through the electrolyte to the anode. There, the lithium ions are inserted into the anode structure. This process is also known as intercalation. To balance the charge, electrons flow from the cathode to the anode by means of the connected energy source. When discharging, the exact opposite process takes place, and the electrons and lithium ions move back in ›



How lithium-ion cells work

the direction of the cathode. This back and forth of the lithium ions between the two electrodes is also known as the "rocking chair principle."

The first time a lithium-ion cell is charged, a surface layer forms on the anode. The formation of this so-called SEI (solid electrolyte interface) layer is an inevitable and irreversible process, which results in the loss of lithium ions. However, a stable SEI protects the anode structure against destruction.

Further development of the materials for lithium-ion cells

Fundamentally, five criteria are in the focus of the further development of lithium-ion cells: safety, lifetime, power, cost and energy. Increasing the cell energy is crucial here in order to fulfill the significant demands with respect to the driving range of electric cars at the lowest possible mass volume of the battery. The energy is the product of the average cell voltage U and the cell capacity Q ($E = U \times Q$). In relation to the cell mass or cell volume, one speaks of the specific energy (Wh/kg) or the energy density (Wh/l). To increase these two values, specific core materials are further developed and optimized.

Cathode active materials

The list of cathode active materials is extensive. One important substance class is the transition metal layer oxides (see figure on page 37), with lithium nickel manganese cobalt oxides (NMC) prominent among them. NMC-111, for example, has already proven effective in commercial lithium-ion cells in the automotive sector. However, building electric cars with high driving ranges requires cathode active materials that enable higher specific cell energies, which is fueling a spike in the prevalence of nickel-rich NMC materials with high reversible capacities on the market. NMC-622 has recently become available for automotive lithium-ion cells. Moreover, the optimization of the cathode active material NMC-811 is in progress. Generally, the higher the nickel content, the higher the cell energy, but the cyclic stability of the respective lithium-ion cells declines. Nevertheless, nickel-rich NMC materials have great potential and will presumably be used in cells for automotive battery systems in the near future. Lithium nickel cobalt aluminum oxide (NCA) has been commercially available for quite some time and already powers electric vehicles on the road today. At temperatures over 40 °C, however, cells with NCA demonstrate a shorter cycle life and a lower current rate capability compared to nickel-rich NMC materials.

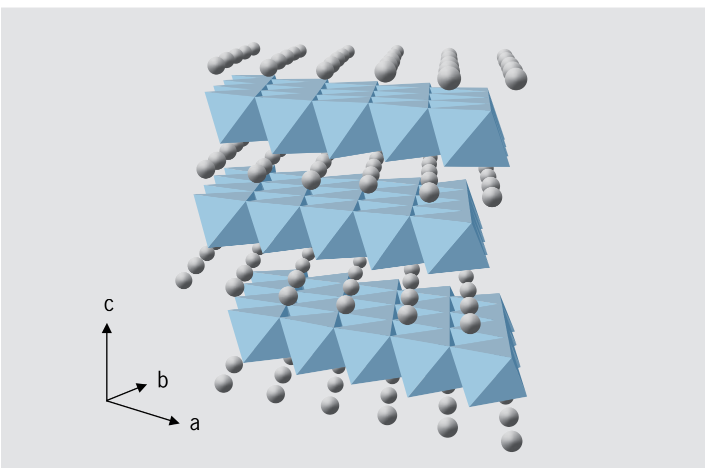
Recently, two new cathode active materials promise a significant increase of the specific cell energy: on the one hand, lithium-rich NMC materials and on the other hand high-voltage spinels. However, both materials are still in the research phase and will require significant optimization. Furthermore, sulfur is being investigated as a cathode active material, due to its low costs and high specific capacity (energy per gram sulfur). Nevertheless, compared to conventional lithium-ion cells, lithium-sulfur cells have a significantly lower energy density (energy per cell volume).

Anode active materials

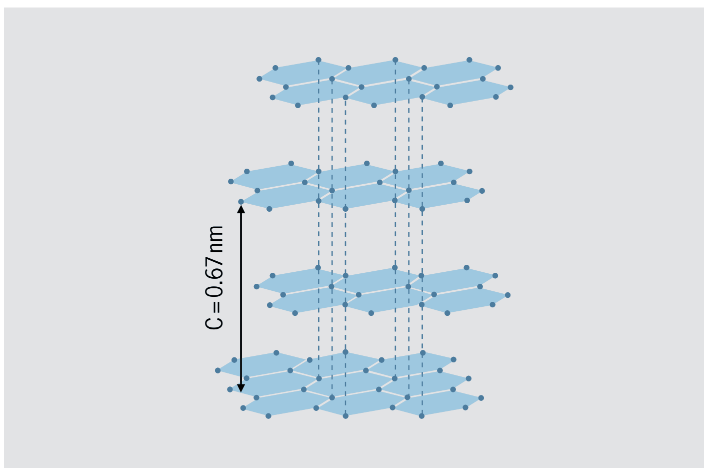
At present, primarily graphites (figure at bottom right) are used as anode active materials. Generally, three graphite types are applied in lithium-ion cells. MCMBs (mesocarbon microbeads), synthetic or natural graphites. All three graphitic carbons have comparable specific capacities and thus enable similar specific cell energies. MCMBs are spherical particles. They provide very good cycling characteristics, but are relatively expensive. Hence, mainly natural and synthetic graphites are used in lithium-ion cells.

In the context of further improving the specific energy of cells, silicon is increasingly moving in the focus of research as an anode active material as it has a specific capacity roughly nine times higher than that of graphite. However, during the insertion and extraction of lithium ions, massive volume changes of the silicon particles take place which adversely impact the cycle life. For this reason, electrodes that exclusively use pure silicon as the active material have not, to date, been applied in commercial cells. One possible way to increase the cell energy while minimizing volume changes is the use of silicon-carbon composites with pure silicon contents of just 5 % to 20 %. They are promising candidates to significantly increase the specific energy of lithium-ion cells, but still have to be sufficiently optimized.

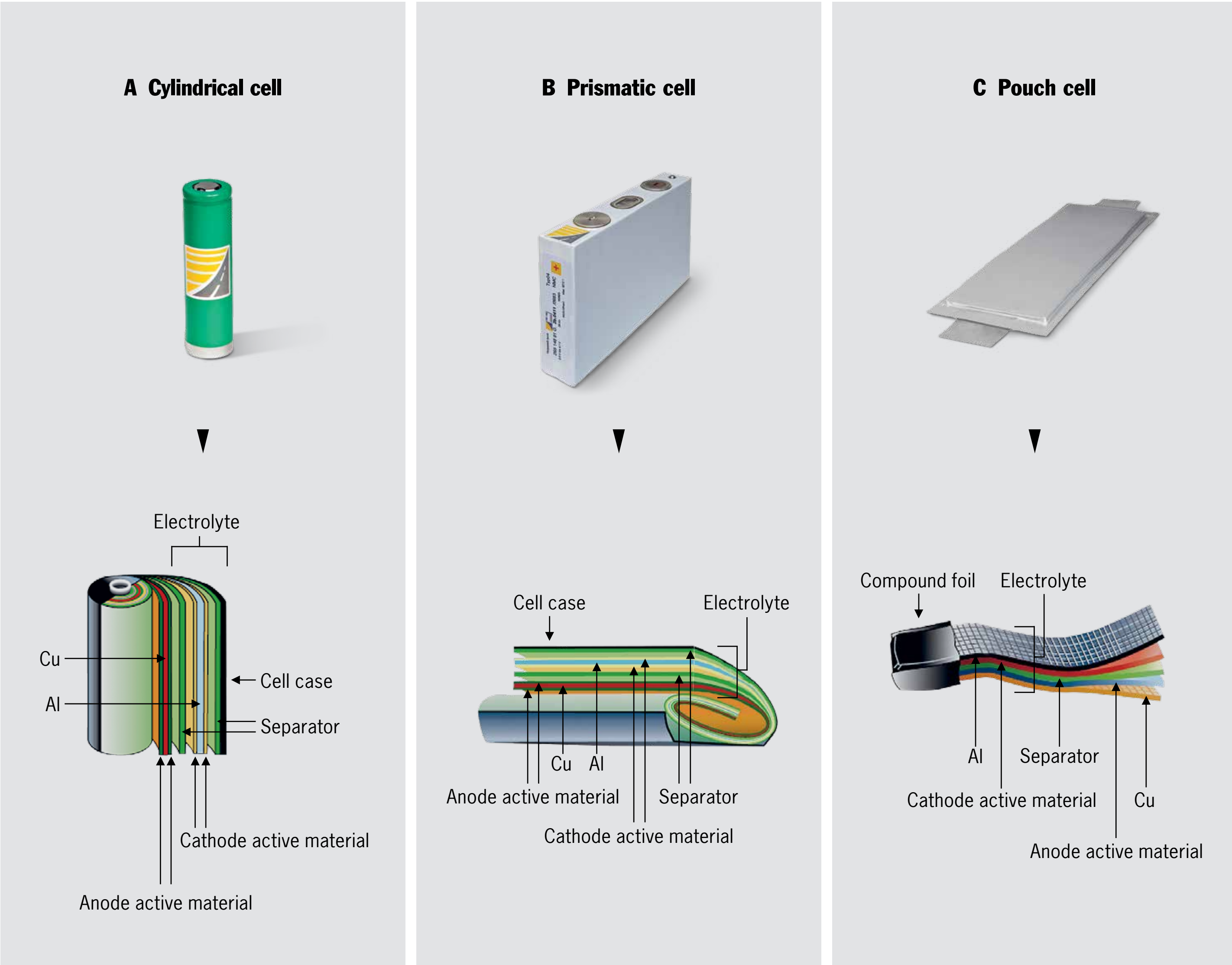
From an energetic point of view, metallic lithium, as the lightest solid element in the periodic table, represents the ideal anode active material since it provides the highest specific capacity. This characteristic is advantageous in non-rechargeable, commercial lithium cells. In the case of rechargeable lithium-ion cells, however, severe problems occur in combination with liquid, organic carbonates. The SEI that forms on the lithium metal surface is not stable. This leads to a constant consumption of electrolyte and lithium. Moreover, when the lithium is redeposited on the metallic anode surface, ›



Structure of transition metal oxides (blue: MO_6 octahedron; gray spheres: lithium ions)



Structure of graphite



Various designs of lithium-ion cells: ***A*** *Cylindrical cell,* ***B*** *Prismatic cell,* ***C*** *Pouch cell. The cells were manufactured by VW-VM Forschungsgesellschaft mbH & Co. KG, a joint venture of Volkswagen AG and VARTA Microbattery GmbH.*

needle-like structures can form. These lithium "dendrites" represent a major safety problem because they can grow through the separator and cause an internal short circuit in the cell. Currently, research is being done to replace liquid electrolytes by solid electrolytes to enable lithium metal to be used as the anode active material in an all-solid-state cell.

Thinner separators for higher energy densities

As already mentioned, currently mainly separators made of polyolefins, which are in some cases stabilized by ceramic particles, are used in commercial lithium-ion cells. The trend here is towards thinner separators (< 20 µm) for the development of high energy cells. In all-solid-state cells, the classic separator should be completely replaced by a very thin layer of solid electrolytes. By this way, higher energy densities could be gained.

Broad spectrum of development in the field of electrolytes

Nowadays, lithium-ion cells for the automotive sector use solvents such as organic carbonates in which a conductive salt is dissolved. These components determine the main properties of the electrolyte, such as the ionic conductivity. Low amounts of additives can further improve the adaptation to the cell chemistry of the lithium-ion cell. Currently, work is under way on new electrolyte formulations for high-energy active materials, although major challenges, including electrochemical stability over 4.2 volts, still have to be overcome. At the same time, massive research efforts are being undertaken in the field of solid electrolytes for an all-solid-state cell with high cell energy. The big problem with pure solid electrolytes is their low conductivity compared to liquid electrolytes. For this reason, initial efforts are focusing on partially liquid concepts with ionic liquids, for example. While they do not yet meet automotive requirements, solid-state cells have a great deal of promise in principle.

Three common forms of the electrode-separator arrangement

For the electrode-separator arrangement in lithium-ion cells, there are three different variants: cylindrical jelly rolls, prismatic jelly rolls or stacks (see figures on opposite page). These are generally inserted into round or prismatic hard cases and laminated compound foil housings.

In the case of cylindrical jelly rolls, a homogeneous contact between the electrodes and the separator is ensured. Their big disadvantage lies in the fact that the roundings cause a high mechanical stress on the electrodes. Moreover, the round electrode-separator arrangement manifests an unfavorable heat distribution from the inside to the outside. Yet, the good cell-interior density of this design enables high energy densities. Cylindrical cells are frequently manufactured in the 18650 format.

In contrast to round jelly rolls, prismatic jelly rolls exert less total mechanical stress on the electrodes. In addition, they have a better temperature distribution. The cell-interior density, however, is lower compared to cylindrical cells due to the housing edges. A frequently used variant in the automotive sector is the PHEV2 hard-case cell.

The stacked electrode-separator arrangement exerts the lowest mechanical stress on the electrodes. The heat distribution is also uniform and the contact between the electrodes and the separator is homogeneous. Due to the separator overhang, the interior density of this cell type is a little lower than with cylindrical jelly rolls. Moreover, the production speed is slower compared to the winding technique. The right-hand figure on the opposite page shows a pouch cell with a stacked electrode-separator arrangement for the use in electric vehicles.

Safe and light cell housings are still contradictory

Regarding the cell housings for the above-mentioned electrode-separator arrangements, hard cases have the advantage over compound foils that the side walls are highly resistant to deformation. Moreover, a CID (current interruption device) can be integrated as a passive safety element. The CID is activated when high pressure forms within the cell and cuts the connection between the electrode and the external pole of the cell. Consequently, the lithium-ion cell is deactivated before a critical state emerges. However, the production of hard cases is complex and expensive from a technical standpoint due to the number of components. In addition, these stable cell cases also have a high intrinsic weight, which has a negative impact on the specific energy of such cells.

Compound foil-cell housings, by contrast, have a very low intrinsic weight and consist of substantially fewer components. This makes it possible to achieve high specific energies. Due to the flexible shape of pouch cells, however, the side walls are easily deformable and penetrable. Mechanical stability is only achieved through additional side walls in a module. Moreover, laminated compound foil-cell housings cannot accommodate passive safety elements.

Porsche expertise for the selection of the best-suited lithium-ion cell

Lithium-ion cells are complex and very multifaceted systems. The wide range of materials available for the various cell components and the cell design are correlated with individual characteristics leading to different advantages and disadvantages in terms of safety, service life, output, costs and energy. A precise understanding of the lithium-ion cell including all chemical and physical processes is, however, the prerequisite for the selection of the most suitable cell for the respective vehicle—whether it is a sports car or another vehicle in which Porsche Engineering is involved in the development process. ■

PANAMERA 4 E-HYBRID SPORT TURISMO
Fuel consumption (combined): 2.5 l/100 km
Power consumption (combined): 15.9 kWh/100 km
CO_2 emissions (combined): 56 g/km

PANAMERA 4 SPORT TURISMO
Fuel consumption (combined): 7.9–7.8 l/100 km
CO_2 emissions (combined): 180–178 g/km

PANAMERA TURBO SPORT TURISMO
Fuel consumption (combined): 9.5–9.4 l/100 km
CO_2 emissions (combined): 217–215 g/km

PANAMERA 4S DIESEL SPORT TURISMO
Fuel consumption (combined): 6.8–6.7 l/100 km
CO_2 emissions (combined): 178–176 g/km

PANAMERA 4S SPORT TURISMO
Fuel consumption (combined): 8.3–8.2 l/100 km
CO_2 emissions (combined): 189–187 g/km

Sporty Addition

New body version in the Panamera family

____ There has been a strong addition to Porsche's Panamera family: in March of this year, the Panamera Sport Turismo celebrated its world première at the Geneva Motor Show.

This consistent development of the Panamera model series—Panamera Sport Turismo—is available in five different versions: Panamera 4, Panamera 4S, Panamera 4S Diesel, Panamera 4 E-Hybrid and Panamera Turbo. Based on the successful Panamera sports saloon, the new version once again makes a profound statement in the luxury segment with its unmistakable design. At the same time, the Sport Turismo, with up to 404 kW (550 hp), is more versatile than any other model in its class. With a large tailgate, low loading edge, increased luggage compartment volume and a 4+1 seating concept, the new Panamera model offers the perfect combination of everyday usability and maximum flexibility. "For Porsche, the Panamera Sport Turismo is a step forwards into a new segment, but retains all of those values and attributes that are characteristic of Porsche", says Michael Mauer, Director of Style Porsche. ›

Proven technologies form the basis

From a technological and design perspective, the Sport Turismo utilizes all the innovations introduced with the brand new Panamera model line launched only last year. These include the digital Porsche Advanced Cockpit, pioneering assistance systems such as Porsche InnoDrive with adaptive cruise control, chassis systems such as rear axle steering, the Porsche Dynamic Chassis Control Sport (PDCC Sport) electronic roll stabilization system, and powerful powertrains. In addition, all Panamera Sport Turismo vehicles are equipped with Porsche Traction Management (PTM)—an active all-wheel drive system with electronically controlled multi-plate clutch—as standard. As of the S models, adaptive air suspension with three-chamber technology is also supplied as standard.

The design and concept of an all-round sports car

Just like the coupé-style Panamera sports saloon, the Sport Turismo is characterized by its very dynamic proportions—a perfect reflection of the Porsche design DNA. The vehicle is 5.049 meters long, 1.428 meters high and 1.937 meters wide, while the large wheelbase spans 2.950 meters. The silhouette is further characterized by short body overhangs and large wheels measuring up to 21 inches. Beginning from the B-pillars, that is, from the start of the rear doors, the Sport Turismo features a completely unique rear design. Above the pronounced shoulder, an elongated window line and equally long roof contour lend the vehicle its striking appearance. At the rear, the roof drops away much less dramatically than the window line, resulting in a prominent and distinctive D-pillar that transitions into the shoulder section in a coupé-like fashion.

First adaptively extendible roof spoiler in the segment

At the top of the vehicle, the roof extends into an adaptive spoiler. The angle of the roof spoiler is set in three stages depending on the driving situation and selected vehicle settings, and generates an additional downforce of up to 50 kg on the rear axle. Up to a speed of 170 km/h, the aerodynamic guide element—a central system component of the Porsche Active Aerodynamics (PAA)—stays in its retracted position with an angle of minus seven degrees, which reduces drag and thus optimizes fuel consumption.

Above 170 km/h, the roof spoiler automatically moves to the performance position with an angle of plus one degree, thereby increasing driving stability and lateral dynamics. When in the Sport and Sport Plus driving modes, the roof spoiler automatically moves to the performance position at speeds of 90 km/h upwards. The PAA system also provides active assistance by adapting the roof spoiler's angle of inclination to plus 26 degrees when the panoramic sliding roof is open at a speed of 90 km/h or above. In this case, the spoiler helps to minimize wind noise.

Porsche E-Performance: Panamera 4 E-Hybrid Sport Turismo

Adaptive roof spoiler in the new Sport Turismo model range

Attractive interior design

The interior design also remains faithful to classic Porsche principles. The center console ascends towards the front, the analog rev counter is positioned in the middle of the instrument cluster, and the dashboard is flat and conspicuously wide. In between the compact gear selector is the center console, which features touch-sensitive buttons for direct access to the most important functions. The dashboard incorporates a high-resolution 12-inch touchscreen display.

Two high-resolution screens, one to the right and one to left of the rev counter, display virtual instruments, maps, and a range of other information. In conjunction with optional four-zone automatic climate control and individual power seats in the rear, the rear passengers also have a touchscreen display of their own.

Three seats in the redesigned rear

The new Sport Turismo is the first Panamera to feature three rear seats. The two outside seats take the form of individual seats—in keeping with the model line's claim to sporty performance with maximum passenger comfort—thereby producing a 2+1 configuration at the rear. As an option, the Panamera Sport Turismo is also available in a four-seat configuration with two electrically adjustable individual seats at the rear.

The raised roof line of the Sport Turismo allows for easier entry and exit at the rear of the vehicle and ensures greater head clearance. The usability of the luggage compartment benefits from the wide opening tailgate, which is electrically operated as standard, and a loading edge height of just 628 millimeters. Measured to the upper edge of the rear seats, the up to 520-liter storage capacity of the Sport Turismo (Panamera 4 E-Hybrid Sport Turismo: 425 liters) betters that of the sports saloon by 20 liters. When the vehicle is loaded up to roof level and with the rear seats folded down, the gains amount to around 50 liters. The backrests of the three rear seats can be folded down together or individually (in a 40:20:40 split) and are unlocked electrically from the luggage compartment. When all of the backrests are folded down, the loading floor is virtually level. In this case, the storage volume is expanded to up to 1,390 liters (Panamera 4 E-Hybrid Sport Turismo: 1,295 liters).

A luggage compartment management system is available on request for the Panamera Sport Turismo. Among other things, this variable system for secure transport includes two rails integrated in the loading floor, four lashing points, and a luggage compartment partition net. An optional 230 V electrical socket can also be provided in the luggage compartment. ■

Under One Roof

Vehicle concept development in the context of changing mobility

____ Porsche Engineering works with all types of mobility concepts. For roughly the past ten years, that has increasingly meant vehicle concepts in the field of electromobility as well. The scope of activities ranges from the expansion of existing platforms to completely new designs. Experience shows that in vehicle concepts with electric drive systems, much, but not all, is different.

By Stefan Bender and Horst Plate

Automobiles of today are, fundamentally, the product of some 130 years of continuous development, starting with the horse-drawn carriage. Since then, the center cell of passenger vehicles has become established as the basis for positioning the people, and the front and rear areas for the drive unit, technology, energy store and a more or less large compartment for carrying things.

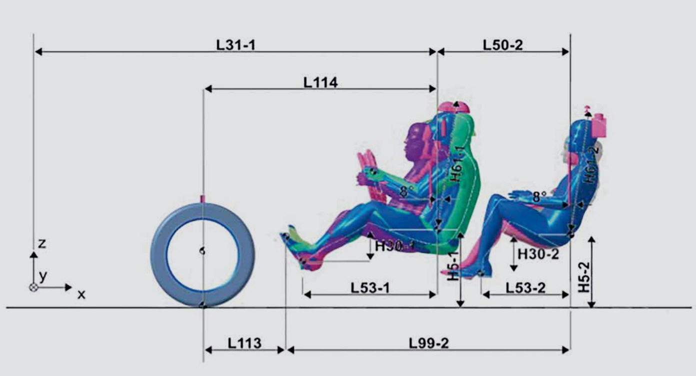
What changes can be expected with the transition to electromobility? In order to answer this question, it is important to know what a vehicle concept is and with which important sub-concepts it can be described. First and foremost, the objective of every vehicle concept is the optimal accommodation of people as the users of the vehicle. This aspect is defined in the ergonomic concept. Based on this concept, the vehicles are described formally in terms of holistic geometric relationships and thus assume what is known as the dimensional concept. As the shell, the dimensional concept defines the space for the accommodation of the people and components as well as the vehicle design. In the package concept, finally, the complete structural space for all systems and functions is specified and harmonized. An examination of these three concepts with regard to electromobility makes it possible to draw some conclusions as to the scope of the expected changes.

User-oriented: the ergonomic concept

Concept development for vehicles is fundamentally based on the user of the product. The insights of anthropometry—the study of the human body and skeletal properties and their precise function—play a crucial role in ergonomic principles. The keys here are the selected user spectrum and the defined threshold and target values for the vehicle. The body measurements and movement spaces are defined as geometric dimensions of the user spectrum (5th- to 95th-percentile person) and are thus a direct component and basis of the dimensional concept. Additionally, the concept developer fleshes out the ergonomic concept of the new vehicle with further definitions: operation, view toward the outside or of operating elements, different motion patterns such as getting in or out, subjective influences and habits of the user.

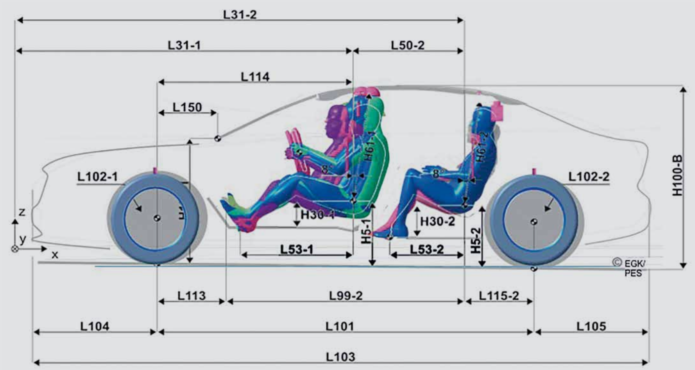
A more minor role here is played by the differences between the drive concepts. With a strong focus on particular variants of the drive concepts—for example favoring particular driving characteristics or usable spaces—compromises ›

01 ERGONOMIC CONCEPT



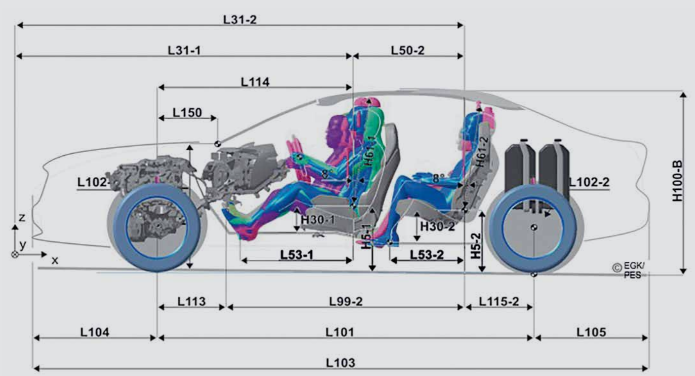
Ergonomic concept of an anthropometric selection collective with main dimensions

02 DIMENSIONAL CONCEPT



Ergonomic plus dimensional concept with styling specifications and package boundaries

03 PACKAGE CONCEPT



Ergonomic plus dimensional concept with styling specifications and initial package concept for a specific ergonomic design must be found. This could relate, for example, to the primary operation of the vehicle—elements like steering and braking.

The technical framework and the fundamental vehicle topology, comprising a few very specific dimensions, form the architecture of the vehicle. It is shaped by the interaction of the ergonomic concept and the drive concept as well as the desired stylistic proportions of the product. Highly distinct drive concepts, for example, have an impact on the dimensional concept through the architecture. One important task for the concept developers, ultimately, is to bring the specifications from the targets and legislation into the dimensional concept and then to present that as the framework for the styling.

Space and technology: the dimensional concept

Based on the dimensions from the ergonomic concept, the core of the dimensional concept of a vehicle emerges from the inside outwards. The dimensional concept describes the geometric values and parameters. It takes legal requirements into account as well as the physical dimensions for design spaces and the traditional construction spaces for the required systems. Moreover, spaces and dimensions have to be set aside in the dimensional concept for changes due to operation of the vehicle, such as temperature differences. Many dimensions are part of complex dimension chains that will be harmonized between the various development departments in the subsequent iterative development process. The concept development team has various brand- and country-specific framework conditions as well as safety requirements to take into consideration. The technical influences on the dimensional concept are primarily defined by the development department of the OEM. More importantly, the interests of the company as a whole determine the character of the product, with legal requirements, customers, the market and the environment presenting additional key factors.

Electric drives scarcely impact dimensional concept

In view of the emerging shift toward electromobility, the question arises as to whether the changes have an impact on the aforementioned pillars of the overall concept and thus the dimensional concept. From the customer's point of view, one can assume that the desire for the conveniences of modern mobility will remain unchanged or indeed grow. Safe and comfortable travel will continue to be in the foreground. Moreover, the accustomed diversity and different vehicle variations such as sports cars, sedans and minivans are expected. The customers of tomorrow will continue to have different needs in terms of vehicles, be they use-related (for example vans or city cars) or based on personal preferences (sports cars or sedans).

And legal requirements today already have an impact on the formal design of modern vehicles. Noteworthy in this regard are the rising safety requirements, which are reflected in significantly larger and heavier vehicles. Through electromobility, there will be additional requirements primarily in the field of high-voltage safety, although fundamental changes in the dimensional concept are not to be expected.

The market and environment exercise their influence principally through the fact that the fulfillment of more stringent environmental standards and the tapping of new sales segments will presumably only be possible with zero-emission vehicles. But here again, this does not require changes to the dimensional concept. In terms of the vehicle concept, electromobility will therefore not bring forth any magnitudinous changes.

Everything in the right place: the package concept

The idea of the package concept is to bring the goals of the departments into line with their sometimes contradictory requirements. A majority of the component positions is already defined by the previously described dimensional and ergonomic concept. Legal and brand-specific requirements also impact the package concept substantially. The positioning of the vehicle lighting, for example, is very tightly circumscribed, and is a typical brand-specific element. The Porsche's left-side ignition lock position is another example of this. The concept developer has the task of allowing these brand-specific elements, and harmonizing them technically—in close cooperation with the departments.

Modern vehicles, particularly in the premium segment, are equipped with numerous additional systems, which means that the mere task of including all of the functions and features listed in the specifications requires a great deal of discipline and readiness to compromise. Including components stands in constant conflict with comfort issues such as the luggage compartment volume and approach angle, ergonomic issues such as the sight angle and headroom and, last but not least, country-specific safety requirements such as pedestrian protections and head impact in the interior.

Electric drive systems critically alter the package concept

In terms of the package, in the future, electric drive systems will resolve some conflicting objectives while creating others. In the current dilemma of the range situation of electric vehicles between sufficient battery capacity and fast charging options, the high-voltage (HV) battery has a decisive role to play. The HV battery has until now been the largest and heaviest individual component in an electric vehicle, and subject to special safety requirements. This gives rise to the necessity of giving the HV battery particular attention in the package concept.

There is only a limited amount of space for the position of the new components. There are three fundamental positioning options for an HV battery: in the front end, under the passenger cell or in the rear. The position also has an impact on the vehicle design—low seating position and flat vehicles with an HV battery under the passenger cell, for example, are currently mutually exclusive properties.

At the same time, the electric drive architecture provides greater design freedom with respect to accommodating the components in the existing design space. Anything from multiple-motor concepts in the front and rear and even single-wheel drive systems is possible. However, the theoretical advantage of a smaller package size with electric motors evaporates with multiple installations. And the requirements in terms of functional safety rise as well, resulting in costs and complexity related to regulations. It must also be taken into account that the high-voltage supply of the drives brings additional challenges as well.

Battery determines package concept for electric vehicles

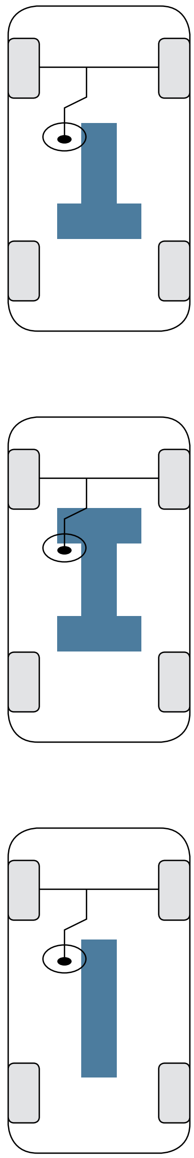
In the end result, the package concept for an electric vehicle is subject to the need for conceptual changes in order to accommodate the new components and the simultaneous omission of conventional changes. The focus here is on the integration of battery systems. Due to the greater volume and the technical complexity, this integration process represents a core requirement in the package area. In the development process, this requirement is frequently fulfilled on the basis of established vehicles powered by combustion engines.

The Porsche Boxster, for example, was converted into a fully electric Boxster E as part of a research project. The area that would normally accommodate the mid-engine proved an elegant position for an HV battery. In addition to the volume, the considerable weight of the battery also made it possible to retain outstanding weight distribution and additional typical sports car characteristics such as the body shape and a low seating position.

It also emerged, however, that the "mid-battery" designed for two-seaters is of limited applicability for compact cars and sedans. A range of other variable concepts for the accommodation of HV batteries have accordingly been developed for other vehicle types. In general, there are no fixed boundaries for the development, so we can expect further innovative approaches in the future.

The challenge: a standalone concept for electric vehicles

The overriding task in the near future will be to develop comprehensive concepts with which electric vehicles can adequately replace conventionally powered vehicles. In this effort, modified package concepts will play an especially important role with regard to the changed overall concept in electric vehicles. The vehicle concept of the future will ultimately be determined by other components in the package—with unchanged requirements for the dimensional concept. Changes due to the increasing Digitalization of the vehicle will also be necessary. So it is clear that the introduction of electric vehicles will change some elements in the vehicle concept—but not everything. ■



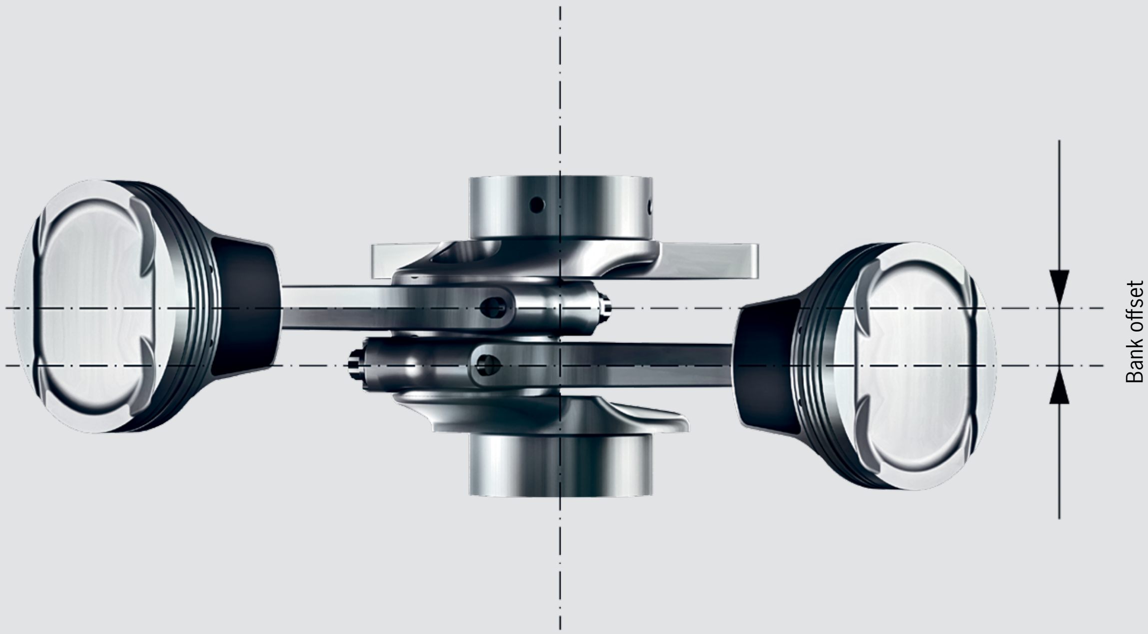
Alternative concepts for the position of the HV battery

Eight

The V8 success story and its basics

____ Powerful eight-cylinder engines have been as much a part of the Porsche story as the traditional flat-six engine for decades. Porsche Engineering also develops V8 engines—for customer orders. The reasons for the popularity of this engine type are revealed by the fundamental properties of the engine architecture of the V8 machine.

By Matthias Penzel, Vincenzo Bevilacqua and Thomas Raab



The cylinder bank offset in a conventional V engine is the width of a connecting rod big end, but the bank offset can also be avoided through the use of interlocking fork-and-blade rods (e.g. in Harley-Davidsons).

Luxury sedans and sports cars, SUVs and pickup trucks—in each of these vehicle categories, the eight-cylinder combustion engine in the V configuration enjoys an outstanding reputation. Depending on the use, it embodies either luxury and comfort or sportiness and emotion. The reason for the popularity of the V8 compared to other engine configurations is its fundamental advantages.

The V8 is only slightly longer than an inline four-cylinder engine with the same cylinder spacing. The slight increase in required structural length is due to the offset of the two cylinder banks (see figure to the left). So the V8 is also a promising option for hybrid drivetrains with an additional electric motor on the crankshaft flange, as the Porsche 918 Spyder demonstrates.

The distribution of the total displacement among many cylinders results in uniform torque output and thus smooth running. So in a four-stroke V8, there are four power strokes per crankshaft revolution. Larger numbers of cylinders offer smoother running and therefore greater comfort, but their greater structural length and higher weight are drawbacks in terms of the vehicle's architecture and the axle-load distribution. In sports cars, for example, this can be compensated for through a mid-engine configuration or, in the case of front engines, by resolutely shifting the ten- or twelve-cylinder engine towards the center of the vehicle. For drivers and passengers, however, this results in space constraints—which is not a viable route for luxury sedans. Here, the structural length of the engine is completely incorporated into the longitudinal geometry of the vehicle, which with a V12, for example, results in a longer wheelbase or overhang and thus disadvantages in terms of vehicle agility. Special designs such as the W12 compensate for this disadvantage of the classic V12, albeit with a higher degree of technical complexity. So the classic V8 represents a good compromise, offering small structural space requirements with a simple engine architecture, high power-to-weight ratio and extremely smooth running characteristics.

The basics of V engines

Conventional V engines have a special characteristic: The two piston rods of the respective opposing cylinder pair connect to a shared crank pin of the crankshaft (see figure at the top of page 50). The bank angle of the V is immaterial, because even with some engines with horizontal, opposing cylinders, two connecting rods connect to a shared crank pin. Engines such as that of the Porsche 917 are therefore grouped not with the flat engines but with the V engines—albeit with a 180° bank angle. With the flat engine characteristic of the Porsche 911, by contrast, the connecting rods of the opposing cylinder pairs run to separate crank pins offset from each other by 180°. For this reason, the flat engine in modern architecture has more main crankshaft bearings than a comparable V engine. The usual number of main bearings today is

- for V engines = (number of cylinders : 2) + 1
- for flat engines = number of cylinders + 1

This in turn results in a further difference in the offset of the two cylinder banks: in a V engine, the bank offset is determined by the width of the connecting rod, while in a flat engine it amounts to half the distance between cylinders.

Bank angle

The bank angle of a V engine influences the engine height and width as well as the position of the center of gravity in the vertical axis. Ideally, in a V engine it is selected so as to produce an even ignition interval. For a four-stroke V8 engine, that means: 720-degree cycle angle, i.e. two crankshaft revolutions for a complete working cycle, divided by the number of cylinders (8) yield a 90° bank angle or a whole-number multiple thereof.

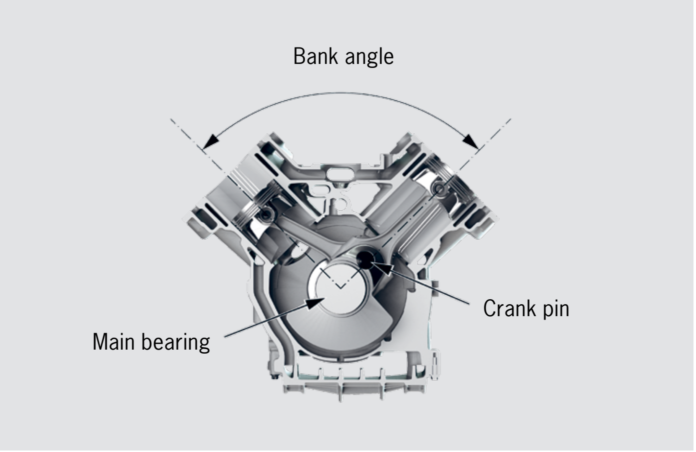
Derivative with a trick up its sleeve: V6 engine

The usable construction space, or when vehicle platforms are offered with V engines with different numbers of cylinders, can necessitate deviations from this rule. One example of this is the V6 engine: to achieve a regular firing order, this four-stroke, six-cylinder engine requires a bank angle of 120°, which is associated with an unfavorably large structural width. Moreover, in most cases the mounting space for a V8 variant with a 90° bank angle is predetermined. The V6 is then also implemented with a 90° bank angle. To compensate for the resulting irregular firing order, engineers fall back on a trick of sorts: the "incorrect" bank angle is compensated for through an additional crankpin offset on the crankshaft. This requires split-pin crankshafts or even flying arms (see figures to the right of page 50) with an angle offset making up the difference. For a V6 with a bank angle of 90°, the requisite angle offset is then 30°.

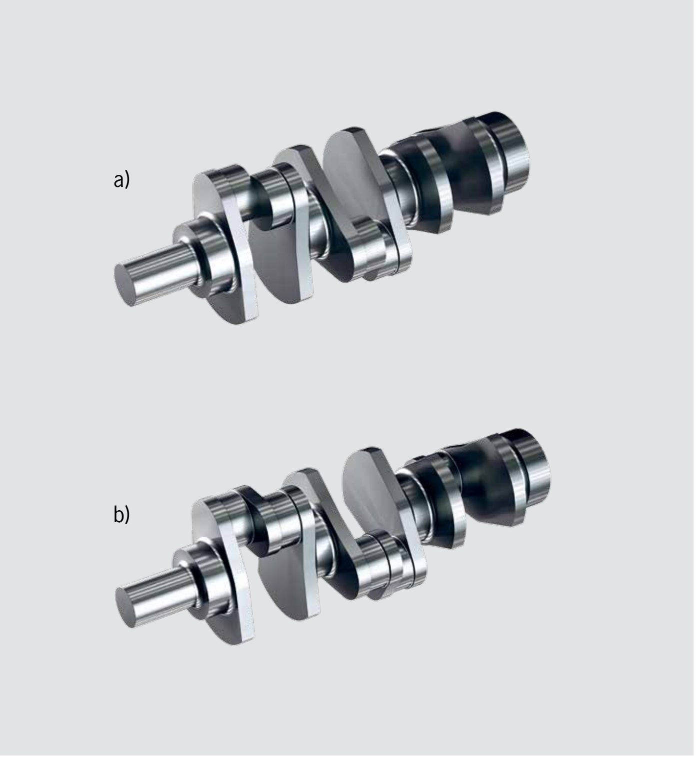
Design of the crankshaft

In the basic design of a V8 engine, designers have another important bit of room for maneuver: the configuration of the › crank throws on the crankshaft. This has a crucial influence on the principal characteristics of the engine—whether sporty/aggressive or with comfort-focused smoothness and low vibrations.

The decision regarding the arrangement of the crank throws is shaped by the dichotomy between maximum power potential and optimal balancing of the free inertia forces and torques. Due to the kinematic coupling in the crankshaft drive, the inertial forces are produced by the oscillating motion of the piston and connecting rod masses. Depending on whether these inertial forces are produced one or two times per crankshaft revolution—for example through the upward or downward motion of the piston—we speak of primary and secondary forces in relation to the engine speed. If for the free inertial forces there is also a moment arm with respect to the engine center, this produces free inertia torques. As the engine speed rises, free inertial forces and/or torques are felt in the form of increased vibration, which, particularly as primary and secondary forces, are perceived as unpleasant and can only be partially mitigated through the engine mounts. For the most part, conventional V8 engines feature one of two crank variants: the "flat-plane" crankshaft in which all crank pins are on a single plane, and the "cross-plane" crankshaft, in which the crank pins of the four cylinder pairs are arranged at 90° angles to each other (see figures on page 51).



V engine with 90° bank angle



V6 split-pin-crankshaft (a) and V6 crankshaft with flying arms (b)

Emotional sound: cross-plane V8

One typical feature of the cross-plane V8 engine is the characteristic sound, defined by the emotional sound often referred to as "burbling." What sounds pleasant for enthusiasts, however, impacts the gas exchange in the engine. However, an efficient gas cycle is a fundamental prerequisite for the optimal utilization of the displacement in terms of cylinder charge and volumetric efficiency and therefore the potential output. The gas cycle can be impeded by two effects:

> flow resistance in the inlet and exhaust path
> incomplete gas exchange and thus residual gas in the cylinder

In gasoline-powered engines, residual gas also promotes a tendency toward hard, explosive combustion after ignition—i.e. knocking. Persistent knocking leads inexorably to piston damage. In order to prevent this under any circumstances, a knock control system has to intervene—but then the ignition cannot take place at the thermodynamically optimal time, which in turn leads to compromised thermal efficiency.

A V8 engine with a cross-plane crankshaft experiences this problem in a particularly pronounced form. In spite of the generally even firing order in the engine as a whole, with a 90° bank angle there is still an uneven firing order in each cylinder bank. Two cylinders per bank always fire in direct succession (90° ignition interval). What that means in concrete terms is that the exhaust pressure pulse of the subsequent cylinder already occurs while the exhaust valves of the previously ignited cylinder are still open. As a result, exhaust is pushed back into these cylinders, which in turn adversely affects the quality of the gas cycle.

In practice, heretofore this disadvantage could only be countervailed through greater complexity: for example, through accordingly great lengths of the individual exhaust manifold pipes—although here the limits are generally defined by the vehicle package—or through cross-bank exhaust manifolds for V engines in which the exhaust side is in the V angle. As part of a current V8 engine project, Porsche Engineering has now broken new ground in this context. With specific control times for each individual cylinder, the residual gas problem can be eliminated with minimal effort. This was demonstrated in impressive fashion both in the simulation and on the engine test bench.

The cross-plane V8 engine typically earns high marks in two other important categories: smoothness and low vibrations. In terms of free inertial forces and torques, the cross-plane configuration is ideal. While there is a remaining primary free inertial torque, this can be relatively easily counteracted through balancing masses on the outer counterweights of the crankshaft. The result is perfect balance.

The double four-cylinder: flat-plane V8

The crankshaft for the flat-plane V8 engine looks like that of an inline four-cylinder engine—aside from the wide crank pins, which in a V have two connecting rods. The similarity to a four-cylinder is no coincidence. The flat-plane V8 embodies the original idea that led to the development of V8 engines, i.e. combining two inline four-cylinder engines in an angled configuration. And this is what gives rise to the fundamental advantages and drawbacks of this configuration. The secondary free inertial forces of the four-cylinder are retained and combine vectorially in the V configuration. The gas cycle, on the other hand, is considerably more harmonious. The firing in a flat-plane V8 jumps from one cylinder bank to the other, which eliminates the residual gas problem of the cross-plane V8. The even, alternating expulsion of the exhaust also produces a completely unique engine sound that sounds noticeably like that of two inline four-cylinder engines—penetrating and aggressive. Putting all of these characteristics together, the flat-plane V8 suggests itself primarily for use in high-performance sports cars such as the 918 Spyder.

Differing firing orders depending on the manufacturer

While the firing order determines the crankshaft rotation angle traveled between the ignition of two cylinders, the firing order defines the unique sequence of the cylinders in succession. As fixed geometric variables, the bank and crank angles only allow certain orders. The respective configuration defines which pistons reach their top dead center. The firing orders of flat- and cross-plane engines therefore differ in principle. Nearly all modern flat-plane V8 engines fire in identical sequences; in cross-plane V8 engines, by contrast, one generally finds manufacturer-specific firing orders. This takes into account a circumstance that can lead to slight confusion: worldwide there are different definitions as to which cylinder is counted first and how the other combustion chambers are numbered. This would seem to result in different firing orders. Removing the effects from the different cylinder counting methods, the variance in firing orders drops markedly.

If one begins the cylinder count in each case with cylinder 1 according to DIN 73021, there are a total of eight theoretically possible firing orders for each rotational direction in a flat-plane V8. With a cross-plane engine, the total is 16, as here the angle position of the center crank pin is interchangeable. ›

Cross-plane V8 crankshaft

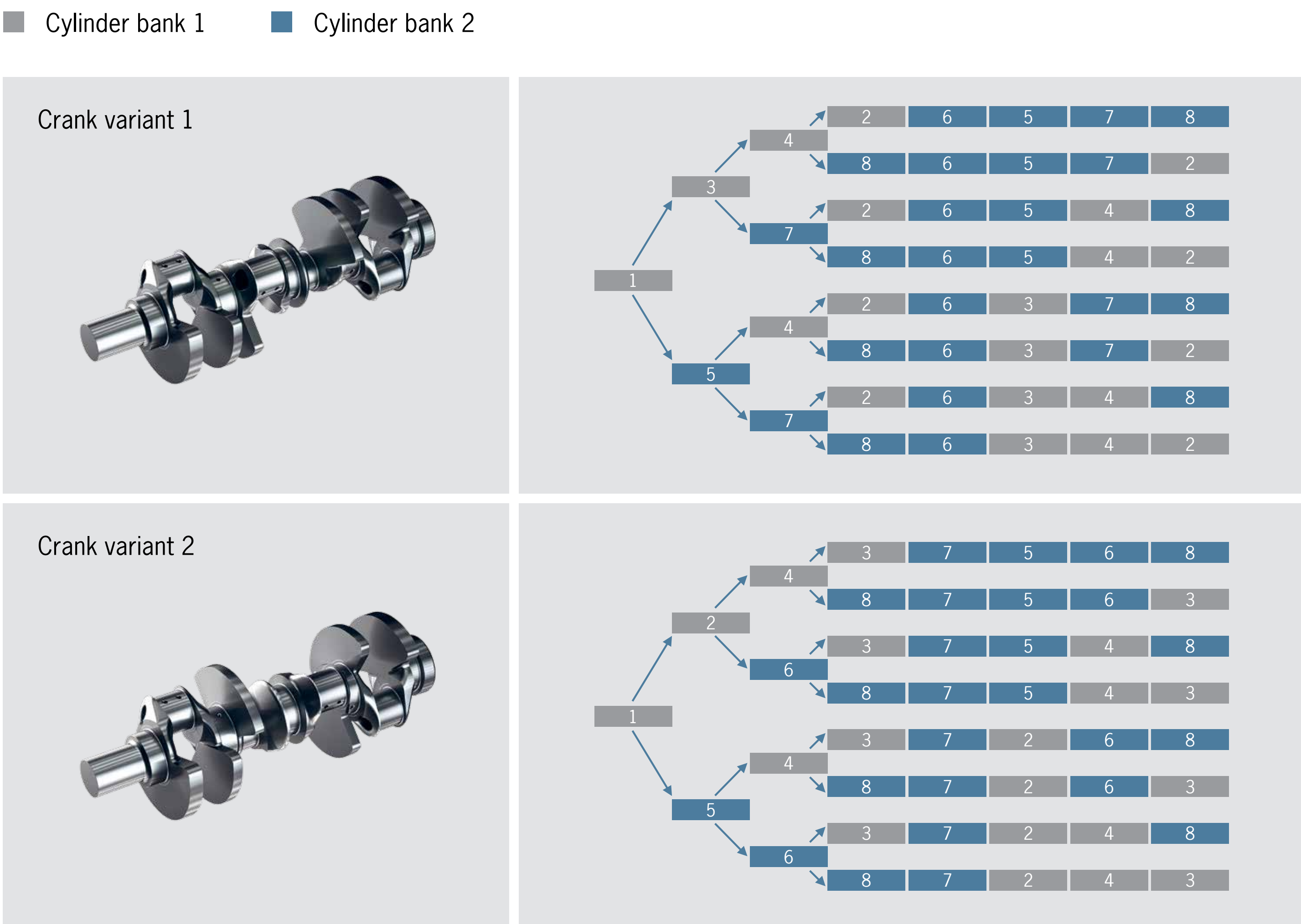
Flat-plane V8 crankshaft

However, not every theoretically possible firing order is implemented in reality. The objective is always the best-possible compromise between the following criteria:

> Gas cycle
> Stress on the main crankshaft bearings
> Vibration stimulation of the crankshaft drive through deformation of the crankshaft under loads
> Rotational irregularities

Porsche Engineering carefully examined the question of the optimal firing order for both flat-plane and cross-plane V8 engines. Nearly all flat-plane engines fire identically, with alternation between banks always a possibility even with a deviating firing order. The result for cross-plane variants was likewise no surprise: particularly with a focus on maximum robustness of the crankshaft bearings, the firing order 1-3-7-2-6-5-4-8 is the best choice in view of all characteristics—which is the firing order for all Porsche cross-plane V8 engines since the 928. Even so, the other implemented firing orders also have their justifications; here the objectives of the manufacturers in terms of their conceptual decision do vary. The results of the analysis also revealed another interesting point: There are certain firing orders that have never been implemented in reality but which also demonstrate exceptional balance in the fulfillment of the specified objective criteria.

One thing is clear in any case: for all the competition between different drive technologies for future mobility concepts, the V8 will continue to have its place under the hoods of premium vehicles—not only as an icon of past glory, but due to the sum total of its technical characteristics. ■



Theoretically possible firing orders for a given rotational direction in a cross-plane V8

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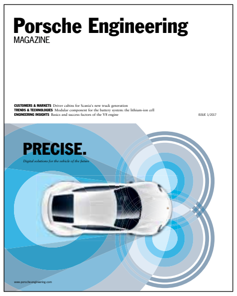

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