Porsche Engineering

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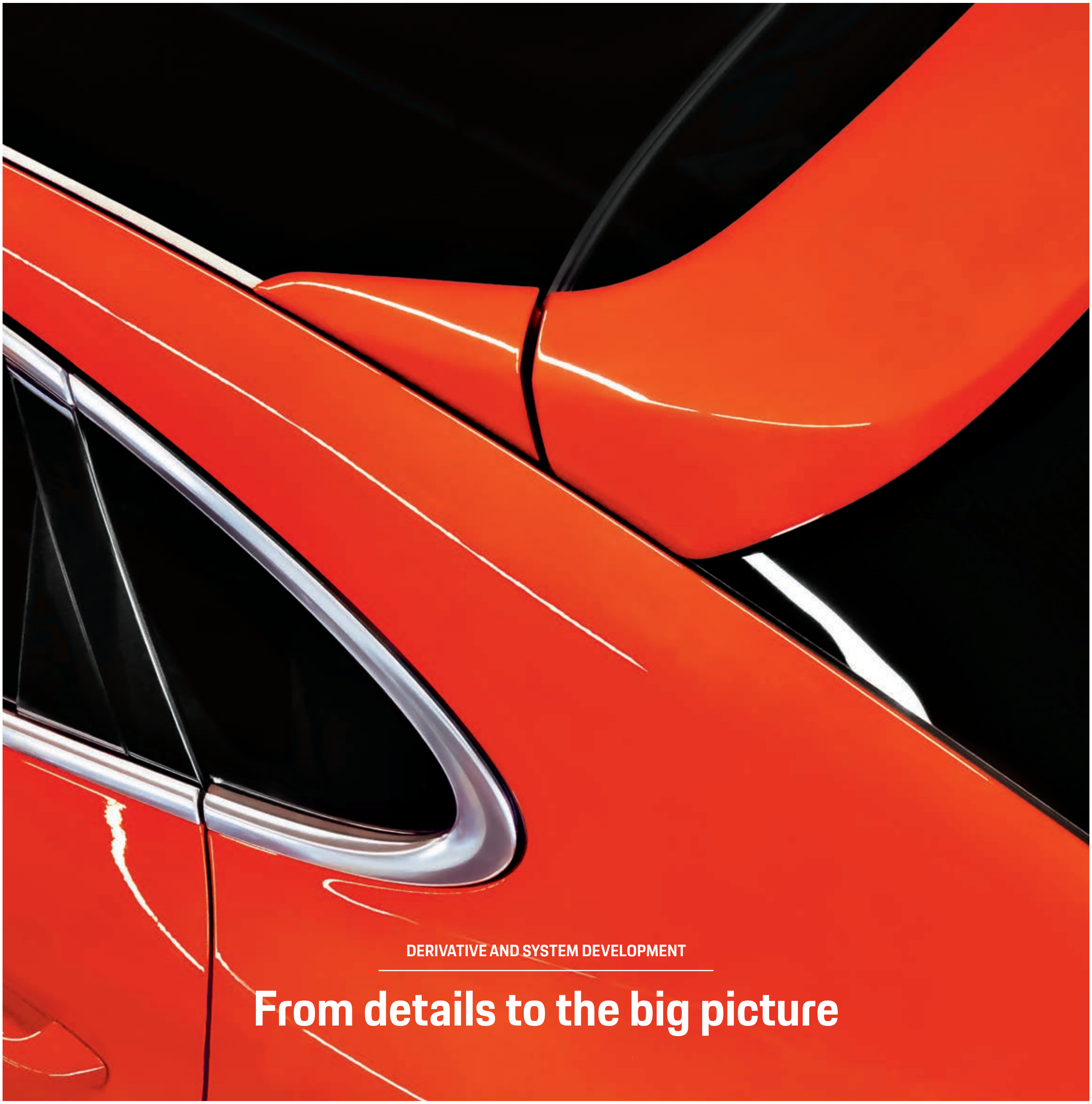
Issue
1/2019

www.porsche-engineering.com



DERIVATIVE AND SYSTEM DEVELOPMENT

From details to the big picture


PORSCHE
S YV 911
If form follows function,
it had better be fast.
The 911.
Extremely dynamic, also in the 8th generation: with a 3.0-litre six-cylinder twin-turbo engine and 331kW (450hp). Sport and comfort combined: the upgraded Porsche Active Suspension Management (PASM). Iconic design: seamless taillight strip and wider track. Discover more at www.porsche.com/911
Fuel consumption (in l/100km) urban 11.1 · extra urban 7.8 · combined 9.0; CO_2 emissions combined 206g/km

PORSCHE

Dr. Peter Schäfer,
Managing Director Porsche Engineering

Dear Reader,

As the new member of the management team, I'm honored to address you and to share with you a look at the monumental transitions the world of automobiles is currently facing. While electromobility, connectivity, and highly automated driving are revolutionizing the automotive industry, conventional technologies nevertheless need to be advanced at ever higher levels of quality.

Consumers are being offered a hitherto unimaginable scope of choice when it comes to models and connectivity features. But at the same time, developers face the challenge of exponentially increasing complexity. Their products are expected to meet diverse requirements in terms of customer desires as well as legal specifications in markets that vary greatly from one another.

That's why this issue is all about that very subject: complexity. Our main theme of derivative and system development illustrates how the growing multitude of derivative variants is being pushed using intelligent methods and tools alongside an in-depth understanding of the vehicle as a whole—always accounting for maximum quality and efficiency. In "Trends and technologies" we shed light on how we're using 5G tech to handle the manifold challenges that come with connectivity and driver assistance systems. To round off the issue, we'll let you know what's going on in the field of charging infrastructure, look at some technology highlights in the new Porsche 911, and learn about autonomous robots exploring the moon.

How do we cope with all of this at once, you ask? We use our most powerful resource: people.

Our engineers view the broad scope of challenges tomorrow brings not as a threat, but as an opportunity. The opportunity to find the ideal option among the many, to perfect it, and to make it usable. Powered by our passion to understand, to think outside the box, to go the next step—and to shape the future hand in hand with our customers.

Peter Schäfer

The new Cayenne Coupé models (from page 1)

CO_2 emissions (combined): 261–212 g/km
Fuel consumption (combined): 11.4–9.3 l/100 km

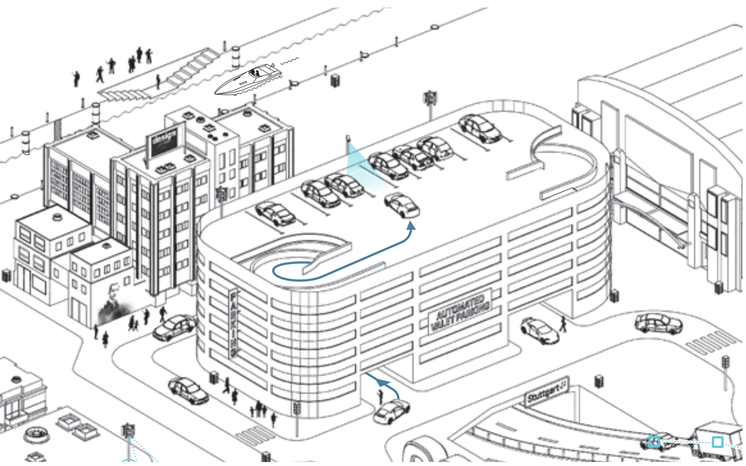
The new 911 Carrera S models

CO_2 emissions (combined): 208–205 g/km
Fuel consumption (combined): 9.1–8.9 l/100 km

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.

DOSSIER

10–29



KTM X-BOW (Sport and Drive)

CO_2 emissions (combined): 288.8–200.9 g/km; Fuel consumption (combined): 9.8–8.6 l/100 km

The new Cayenne Coupé models

CO_2 emissions (combined): 261–212 g/km; Fuel consumption (combined): 11.4–9.3 l/100 km

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Contributors

12 **Johannes Winterhagen** writes mostly about energy, mobility, and production for publications such as the *Frankfurter Allgemeine Zeitung*.

30 **Richard Backhaus** is a journalist who has been working on automobile topics for over twenty years.

30 **Florian Müller:** The Vienna-based illustrator sketches the future of driving for us in this issue.

Nardò Technical Center

New managing director, modern technology, local involvement

Antonio Gratis took over as managing director of the Nardò Technical Center (NTC) in Apulia, Italy, in November 2018. Gratis previously worked for Iveco, Bomag Alfonsine and the Bomag Fayat Group.

The Nardò Technical Center is also shaping up for the future in technical terms: Construction workers have been removing the asphalt on the test track since January 2019 and covering the 12.6 km track with a new surface. They are also installing a new, patented guardrail system. Along the entire circuit, 26 kilometers of electrical and 91 kilometers of fiber-optic cables are being laid. They will enable new tests in the fields of advanced driver assistance systems, connectivity, and electromobility, among others. Beyond the Car Circular Track, the large-scale Car Dynamic Platform is also receiving a new surface. Altogether approximately 100,000 metric tons of asphalt will be put down, as well as 300,000 square meters of geogrids for the prevention of asphalt cracking.

Part of the NTC's mission is also to be involved in the local community. Since 2019, the Nardò Technical Center has been a sponsor of the youth teams of the A.C. Nardò soccer club: Turbo for Talents, a program to support and foster young talents in sports has been established here. The program will kick off with a soccer summer camp for up to 200 youths from the region.

Tongji Porsche Engineering Symposium

Gathering of chassis experts

On November 21, 2018, Porsche Engineering hosted a specialist symposium on the subject of chassis for the first time in collaboration with Tongji University. In 15 technical lectures, experts from the worlds of business and science talked about the latest developments and insights in the field of chassis at the new Porsche Experience Center in Shanghai. Participants also had the opportunity to experience current chassis technology in person as part of a driving experience on the tracks of the Porsche Experience Center. Porsche Engineering has been conducting projects for Chinese clients for over 20 years. Since 2015, the company has operated its own subsidiary in Shanghai.

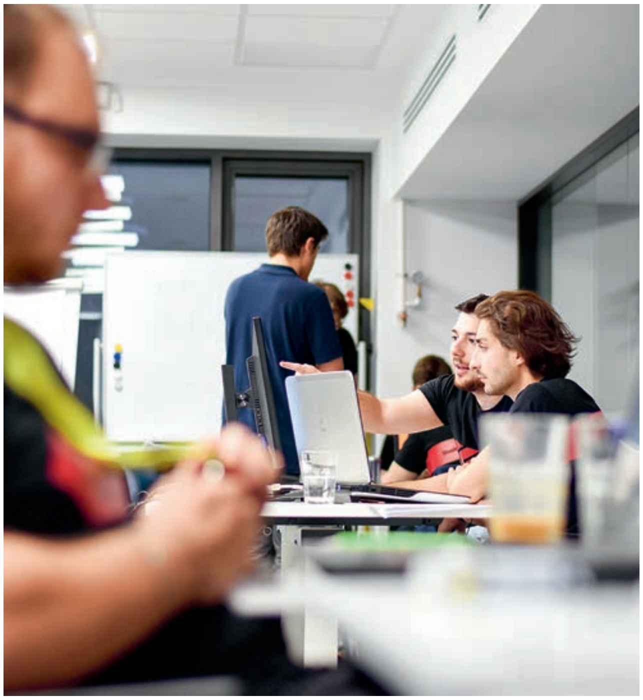
Ostrava location

Digitalization push in the Czech Republic

Porsche Engineering is expanding its digital expertise. In mid-2018, the engineering services provider opened a new location in the Czech city of Ostrava. Currently the roughly 30 software and hardware developers are mainly focused on the areas of future chassis control systems and smart charging solutions for electric vehicles. One example is a completely new type of solution in the field of high-voltage charging infrastructure for electric vehicles of the next generation.

One reason for the choice of the location was the proximity to the universities in Ostrava and Brno in the Czech Republic as well as other universities in Poland and Slovakia. In doing so, Porsche Engineering is continuing a strong tradition: Cooperations with universities have long been a pillar of the company's growth strategy.

The new location in Ostrava complements the capacities that have been in place in Prague since 2001. Porsche Engineering undertook its first steps in the Czech Republic in 1996 in the form of a collaboration with the mechanical engineering department at Czech Technical University. The ties established at that time have consistently grown and intensified since then, with over 200 employees of Porsche Engineering now working at the location in Prague.



Student competition in Romania

Solutions for the mobility of the future

Solutions for the mobility of the future: This was the topic of a competition to which Porsche Engineering invited students in Romania on April 6-7, 2019. Participants could choose from the fields of vehicle-to-grid, reverse engineering, dynamic driver assistance systems and battery charging systems. With the support of professional mentors from Porsche Engineering, the two- and three-person teams had up to two days to develop and present their solutions. The jury evaluated the proposals in terms of their creativity, potential utility, feasibility, and the quality of the pitch. The competition was held in the offices of Porsche Engineering Romania in Cluj-Napoca.

Porsche Taycan

Soul, electrified

With the Porsche Taycan, Porsche's first all-electric sports car will go into series production this year. Two permanent-magnet synchronous motors (PSM) with a system output of over 440 kW (600 hp) propel the Taycan from 0 to 100 km/h in less than 3.5 seconds and reach the 200 km/h barrier in less than twelve. Multiple accelerations in quick succession are possible without a loss of thrust. The all-wheel drive model features 800-volt architecture. It can charge up on the fast charging grid for a range of 100 kilometers in the NEDC in about four minutes. Its maximum range is over 500 kilometers in the NEDC.

Hannover Messe

Electric premiere

Porsche Engineering exhibited at the Hannover Messe for the first time this year. At the 100-square-meter fair stand in the Integrated Energy area, visitors were able to get an impression of the modular and flexible charging park system. In addition to the fast-charging solution, the 919 Hybrid's high-voltage battery developed by Porsche Engineering and the original race car of 2017 were also displayed for the first time.

April 1-5, 2019
https://www.hannovermesse.de

International Vienna Motor Symposium

Expertise across the board

Porsche Engineering was also present at this year's International Vienna Motor Symposium, the renowned conference for combustion engines and drive technology. Exhibits from the fields of combustion engines, hybrid systems, and charging infrastructure were presented.

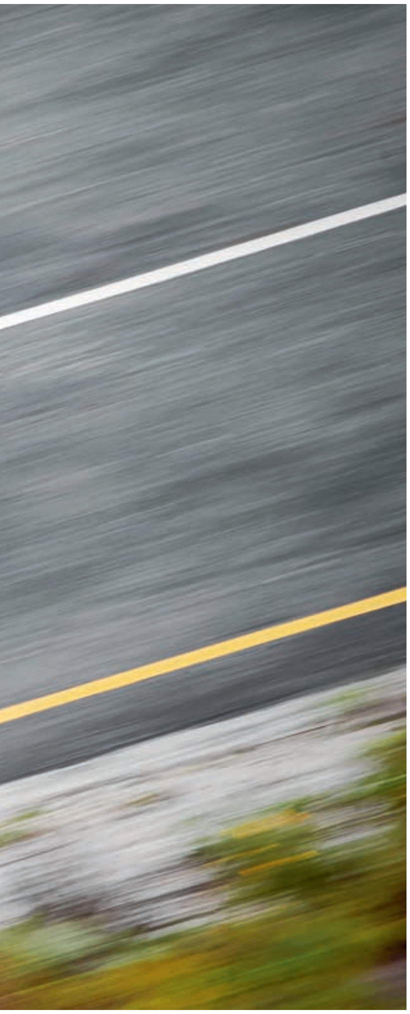
May 15-17, 2019
https://wiener-motorensymposium.at

The art of derivation

The new Cayenne Coupé models

CO_2 emissions (combined): 261-212 g/km
Fuel consumption (combined): 11.4-9.3 l/100 km

Successful derivative development has many facets: the use of state-of-the-art methods and processes. Cooperative relationships. The transfer of innovative technologies to new areas. And most importantly: a focus on details, always keeping an eye on the bigger picture. On unique derivatives. Like, for example, the new Porsche Cayenne Coupé.



New horizons: The spectacular glass roof in the Cayenne Coupé adds an entirely new vantage.

A closer look at the derivative

Text: Johannes Winterhagen Photos: Matthias Just and Tobias Kempe

Porsche is expanding its Cayenne family: With the Cayenne Coupé, an even sportier version of the Cayenne is being added to the third generation of the successful SUV series. Based on a successful base model, the development of the derivative by Porsche Engineering was characterized by the consistent use of digital simulation methods to reduce the number of physical prototypes as well as new production and assembly processes for the unique new glass roof.

Its strikingly dynamic lines and specially tailored design elements make the new Cayenne Coupé markedly different from the Cayenne. It comes as standard with a 2.16-square-meter fixed panoramic glass roof. With a see-through surface area of 0.92 square meters, the roof creates a unique spatial experience for everyone in the vehicle. An optional contoured carbon roof is also available. It also enjoys all the technical highlights of the third model generation, which boasts the impressive combination of powerful drivetrains, innovative suspension systems, digital display and operating concept, and comprehensive connectivity.

The general contractor for the development of the variant was Porsche Engineering. From the concept greenlighting project phase onward, the company headed up complete vehicle development as well as, with a few exceptions, the development of all component assemblies. The scope of work included not only the validation of the technical properties, but indeed managing production launch at the Volkswagen plant in Bratislava.

By the time of handover in February 2016, the principal technical concept for the vehicle had been defined and passed feasibility testing for later series production. This also involved the preliminary styling concept, which was refined and modified at detail level in subsequent development stages. Manufacturability analyses played an important role in the process. While the dimensions of the glass roof were roughly defined in the greenlighted concept, the geometric details were fine-tuned by Porsche Engineering as development progressed further. These details included connection to the body.

Thanks to its experience with numerous customer development projects within and outside of the group, Porsche Engineering was able to adopt the project structure and the existing development processes quickly. They were put in place even before the concept was greenlighted to ensure smooth handover. This included defining simultaneous engineering teams with clearly delineated responsibilities for components. Due to the scale of the project, one focus of the project management was orchestrating the interaction of numerous technical specialists. For the development process, Porsche Engineering used the Porsche IT system environment, in which the employees primarily work on separate servers and make the data available at predefined times.

For the development of the Cayenne Coupé, Porsche Engineering created ten digital prototypes, each of which came with different model properties to analyze different overall vehicle characteristics.

Non-physical validation

Thanks to the consistent use of digital development instruments, Porsche is reducing the number of physical prototype vehicles needed. The use of physical prototypes from prototype tools is largely omitted in the development of variants in order to exploit time savings and financial benefits. The validation of a non-physical development process is largely conducted with digital tools, albeit supported by two manually assembled mule units for the chassis and electrics/electronics. The latter is necessary in order to account for electromagnetic compatibility requirements in the dimensions of the series vehicle—even minor variations in the geometry can change the shielding behavior.

For the development of the Cayenne Coupé, Porsche Engineering created ten digital prototypes, each of which came with different model properties to analyze different overall vehicle characteristics. Validating crash behavior was a key aspect, and was conducted entirely using finite element simulations. Because of glass's particular crash behavior, the model for the glass roof—especially the bonding points—required adjusting in advance through substitute tests. Body-shell stiffness testing was also performed purely

Talking things over: The details of the roll-up sunblind on the glass roof are explained using the hardware and CAD data. From left to right: Jürgen Ossenfort, Hermann Sturm, Helmut Fluhrer, Marco Schmidt, and Holger Rudy.

Double-checking: Acoustics expert Benjamin Bernard prepares a component for testing (below).

Cayenne models

CO_2 emissions (combined): 261-207 g/km
Fuel consumption (combined): 11.4-9.1 l/100 km

The new Cayenne Coupé models

CO_2 emissions (combined): 261-212 g/km
Fuel consumption (combined): 11.4-9.3 l/100 km

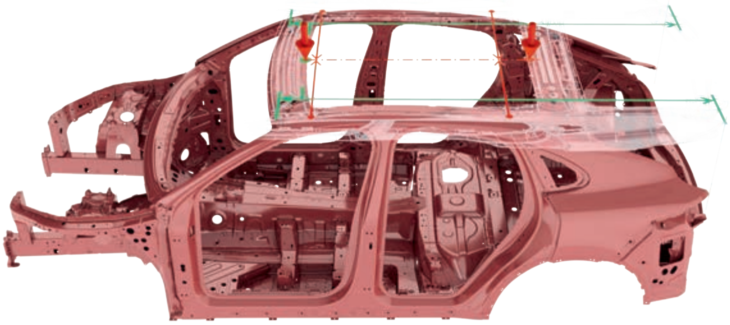
mathematically. The results of these calculations led to individual measures such as additional stiffening and the shifting of connection points.

In order to analyze installation space on the body, for instance for routing wires, the engineers maintained a physical design check model throughout the development process. This was particularly important for the rear area, where adequate headroom for passengers had to be assured in spite of the sloping roofline.

The design of the aeroacoustic vehicle characteristics was done by way of a substitute test as simulation models are not yet capable of providing sufficiently precise results. A clay model was tested in the Porsche wind tunnel in Weissach, making it possible at an early stage to identify potential sources of noise caused by the contour of the exterior shell. The aeroacoustics

Sophisticated tolerance management

To ensure compliance with specified tolerances, a reference point system is used for the Cayenne Coupé. It is applied consistently throughout the entire production process of the roof and body down to the final assembly.



Ready for anything: The development scope handled by Porsche Engineering also included trials and endurance tests.

question also demonstrates the limits of non-physical development, however: A final decision concerning the acoustics in the interior can still only be made by getting in the vehicle and driving it.

The simulation results were validated exclusively with preseries vehicles built of components made with series production tools at the production facility in Bratislava. The production of the first preseries vehicles was brought forward roughly three months compared with a physical prototype-based development process. The development scope handled by Porsche Engineering also included the subsequent cold- and hot-climate tests. As part of the first cold-climate test, the developers also simulated variant-specific misuse cases in order to test the performance of the glass roof. In large glass surfaces, internal stresses from the manufacturing process can cause stress cracks—especially in the edges—if exposed to stark temperature fluctuations. Through intensive checking for internal stresses, a high degree of quality was achieved for the Cayenne Coupé glass panes at an early stage and no stress cracks occurred in test operation. Porsche Engineering's validation process also included endurance testing, which followed the usual test program as defined by Porsche.

Challenge of the glass roof

Due to the dimensions of approximately 1,800 x 1,300 millimeters and the large bending radii due to the sloping roofline, developing the glass roof was a particular technical challenge. The task was to work together with the suppliers to develop appropriate production and assembly processes for the laminated safety glass and the complete roof including the blinds.

The production process begins with independent cutting and edge polishing processes for the two panes, after which they are given their curved shape in a press-bending process. The permanent bonding of the two panes with a polyvinyl butyral (PVB) film between them is done in an autoclave. The glass roof is then given two coats of foam around the edges, with the inner ring used to fasten and seal the blind mount. A process step of this type had never been conducted on a glass roof of this size before, so the required tools also had to be newly designed for the purpose.

In the final vehicle assembly process, the Porsche Engineering developers took particular care in precise tolerance management. A reference point system is used for the Cayenne Coupé consistently throughout the roof and body's entire production process all the way down to final assembly. This made it possible to conduct assembly without the need for post-production work. A suitable manipulator had to be developed to handle the 30.4-kilogram glass roof. It picks the roof up in such a way that it can be positioned using centering pins while suspended over the body-in-white and then presses it into place.

For the glass roof, new production and assembly processes were developed in collaboration with the suppliers.

The crash safety, temperature behavior, and mechanical strength of the glass roof were extensively examined using mathematical simulations and component tests beforehand. It was decided early on that the glass roof would be fastened with a double adhesive seam all the way around to ensure maximum strength. Overall, the testing was very similar to the development process for a windshield, although falling rock tests on a specially prepared test course were added to the proceedings. Moreover, automated endurance trials over 15,000 cycles were carried out on the blind, which due to the roof geometry features a curved shaft and a curved draw bar.

To drivers of the Cayenne Coupé, just how much detailed work is behind the most technologically sophisticated glass roof in Porsche history will barely be apparent—and the same holds true even if it needs repairing. Porsche Engineering even devised a disassembly process should the glass roof ever need to be replaced: The roof is removed in a manner similar to a windshield using a cutting wire that severs the adhesive.

In summary

Complex detail work, intelligent use of digital simulation methods, and a continuous focus on the big picture: With the new variant of the Porsche Cayenne, Porsche Engineering used proven tools while developing new methods and processes. The result: successful execution of a highly complex project. And above all: the new Porsche Cayenne Coupé.

IN BRIEF

Porsche Engineering was the general contractor for the development of the new Cayenne Coupé. From the concept greenlighting onward, the company was responsible for the complete vehicle development as well as the development of nearly all component assemblies, with the glass roof presenting a particular challenge. The applied methods were also innovative: In the development of variants, Porsche largely dispenses with the use of physical prototypes from prototype tools. Validation was therefore largely conducted with digital tools, albeit supported by two manually assembled mule units for the chassis and electrics/electronics. This omission of a physical prototype stage proved successful in the development of the variant.

“Mastering complexity”

Interview: Johannes Winterhagen Photos: Frederik Laux

From the engineer’s point of view, derivative development is an art—the art of redeveloping an existing vehicle while still letting it be the same. The challenges that developers encounter along the way are many and varied. Where simulation methods replace entire physical prototype stages and testing is conducted exclusively on the basis of series production tools, technical expertise, close collaboration, and efficient project management are of the essence. Hans-Jürgen Wöhler and Michael Schätzle, Porsche’s heads of the SUV model line and body engineering respectively, and Peter Schäfer, Managing Director of Porsche Engineering, discuss how the engineers of the Cayenne Coupé mastered these challenges.

For many people, Porsche is principally the 911 ...

— HANS-JÜRGEN WÖHLER: The 911 is unquestionably the heart of the brand. But the Macan and Cayenne SUV model lines have come to play a significant part in Porsche’s success.

Porsche now not only has a lot more model ranges, but also many more variants within the model lines.

— WÖHLER: Essentially it was already a part of the success of the 911 to offer customers as many variants as possible within the model line. So it’s only logical for us to expand the lineup with the SUVs as well and thereby increase our share of this growing market segment. With the Cayenne Coupé we are now bringing a model to the market that combines the day-to-day usability of an SUV with the driving characteristics of a sports car.

2.16

square meters is the area of the Cayenne Coupé’s glass surface.

How exactly do you define the term derivative?

— MICHAEL SCHÄTZLE: We use the term whenever there are changes to the body with regard to the base model. One of the special things at Porsche is that each drivetrain variant is also visually distinct and therefore also associated with changes to the body.

— DR. PETER SCHÄFER: Although the degree of complexity can vary widely between derivatives. The Cayenne Coupé, for example, has a completely new body form that we’ve never had as such at Porsche.

How much extra work does such a derivative involve in terms of development?

— WÖHLER: That depends on the scope of the change compared with the base vehicle. As changes to the body, drivetrain and chassis are interdependent to some extent—needing adequate cooling for a more

Summary: Hans-Jürgen Wöhler, Dr. Peter Schäfer, and Michael Schätzle, (left to right) look back on the collaboration on the Cayenne Coupé.

powerful engine, for example—it's very difficult to generalize in this regard. Ideally, the derivatives are already defined when the specifications for the base vehicle are approved. However, the market doesn't conform to our development cycles, so we also react more quickly if we need to. For us as engineers, still getting a derivative out there in time is an especially exciting job.

That sounds highly complex, not least as the legal requirements for vehicle homologation are becoming more stringent.

— **SCHÄTZLE:** Everything has become more complex. On the other hand, we now have simpler and more comprehensive development processes. It all balances out. And that allows us to achieve our goal: offering our customers greater variety.

Cayenne models

CO_2 emissions (combined): 261-207 g/km
Fuel consumption (combined): 11.4-9.1 l/100 km

The new Cayenne Coupé models

CO_2 emissions (combined): 261-212 g/km
Fuel consumption (combined): 11.4-9.3 l/100 km

— **SCHÄFER:** Without heavy use of simulation methods, the model variety we have today would be unthinkable. With the Cayenne Coupé, we took things a step further and completely dispensed with the first prototype construction stage. Testing was conducted almost entirely with vehicles that were already made with series tools.

— **WÖHLER:** But that only works if you have the corresponding development know-how. For us that was one of the main reasons for handing over major development scopes for the Cayenne Coupé to Porsche Engineering.

What's the secret to a successful project? Sophisticated technical project management?

— **SCHÄFER:** It's not just about project management, but also technical expertise both in terms of breadth

and depth. After all, no development process comes without surprises—and then you need the technical capabilities to resolve issues quickly.

— **WÖHLER:** Nothing works without expertise, but it doesn't work without flexible project management either. The three of us are just here representing our teams, in which there was intense collaboration. I perceived it as integrated work.

Where did you work together especially closely in the development of the Cayenne Coupé?

— **SCHÄTZLE:** The development of the tailgate, the biggest and heaviest one ever built by Porsche, was anything but a routine task. We worked very closely together on the tailgate and the crash safety design. Everything else, from project control to coordination with the production plant in Bratislava, was largely done by Porsche Engineering on its own steam.

— **WÖHLER:** It's all the more noteworthy because the Cayenne shares a platform with other vehicles in the group, which means that a derivative can't be developed entirely independently from the expertise of other brands.

What was the biggest technical challenge that you had to overcome?

— **SCHÄTZLE:** That was definitely the aerodynamics, where there was a significant conflict between the acoustics, the design, and the driving dynamics.

— **SCHÄFER:** In such situations you're in a world full of complex interdependencies. In order to rapidly

"Nothing works without expertise, but it doesn't work without flexible project management either. The three of us are just here representing our teams, in which there was intense collaboration."

Hans-Jürgen Wöhler

"Everything has become more complex. On the other hand, we now have simpler and more comprehensive development processes. It all balances out. And that allows us to achieve our goal: offering our customers greater variety."

Michael Schätzle

process suggestions of how to resolve conflicting objectives, you have to work very closely together in interdisciplinary teams. Not least because the timeframe is very tight, particularly when you're dealing with issues that impact driving resistances and thus type approval of the vehicle. Aerodynamics is definitely one of those issues.

— **WÖHLER:** That's when true engineering acumen comes out. But there were also very positive surprises. For instance the first prototypes from the series tools. They drove immediately, and not bad at that.

Aside from technical development goals that can be framed in objective terms, there is also something like a typical Porsche driving feel. How did you communicate about that?

— **SCHÄTZLE:** It's important to bear in mind that the chassis and the drivetrain were essentially taken over from a very good base vehicle. For the derived variant, the objective is then to ensure that the overall composition works.

— **WÖHLER:** At the same time a developer never runs out of ideas. When the development of the base vehicle has progressed beyond the point where you can bring in something new, a derivative can take a step forward. It will be noticeable that the suspension of the Cayenne Coupé is much sportier.

— **SCHÄFER:** To coordinate concerning the driving impression that will be relevant for the customer, there's nothing better than simply getting in the car and driving. We've always enjoyed doing that together.

Let's conclude by looking to the future: How will derivative development change due to the trend toward electrification?

— **WÖHLER:** Customers will still want different body and drivetrain variants with battery-powered electric vehicles—so the variety will remain unchanged. At the same time, the number of functions will continue to rise. Our task as developers is to master that complexity.

— **SCHÄTZLE:** In a transition period, some of our customers will choose vehicles with combustion engines and some will choose purely electric vehicles. We want to offer the full spectrum of our products to both.

"The most important factors, however, are highly motivated and competent employees who do great work day in and day out in their teams."

Dr. Peter Schäfer

135

millimeters is the distance the rear spoiler extends by at speeds above 90 km/h, increasing downward pressure on the rear axle.

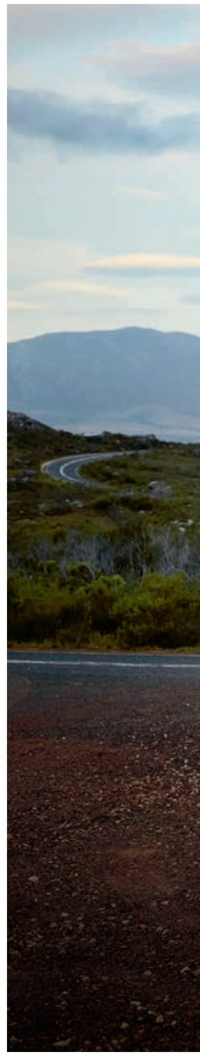
— **SCHÄFER:** Part of the strategy of Porsche Engineering is that in addition to complete vehicle and derivative development, we also want to tap the future fields of autonomous driving, digitalization, and e-mobility. We have been preparing ourselves for that, including through the establishment of specialized foreign facilities, for years—and now things are really taking off in those areas. Our objective is to develop typical Porsche functions independently of a particular vehicle model. This, in turn, is a prerequisite for efficient derivative development. The most important factors, however, are highly motivated and competent employees who do great work day in and day out in their teams.

Michael Schätzle is the Vice President Body Engineering at Porsche. Before that he was responsible for passive safety in all Porsche models and helped shape the 911 as the Complete Vehicle Project Manager through 2013.

Hans-Jürgen Wöhler has been Vice President Product Line SUV since 2013. In that role, he is in charge of technical and business affairs for all model variants of the Cayenne and the Macan.

Dr. Peter Schäfer has been Managing Director of Porsche Engineering since mid-2018. Previously he was Vice President Chassis Development and Complete Vehicle Development at Porsche AG's Weissach Development Center.

The sky's the limit: The standard panoramic glass roof is one of the highlights of the new Cayenne Coupé.



Shaped by performance

The new Cayenne Coupé doesn't just stand out for its striking new appearance—it also has a lot to offer in terms of equipment, such as individual seats in the back and two different roof concepts.

The new Cayenne Coupé models

CO_2 emissions (combined): 261-212 g/km
Fuel consumption (combined): 11.4-9.3 l/100 km

Strong engines: The Cayenne Coupé with its six-cylinder turbo engine and capacity of three liters outputs 250 kW (340 hp) and develops a maximum torque of 450 Nm. The top model is considered to be the Cayenne Turbo Coupé, which offers a four-liter V8 engine with bi-turbocharging, 404 kW (550 hp), and a maximum torque of 770 Nm.

Dynamic design: The much more rapidly plunging roofline lends the Coupé variant of the Cayenne an even more dynamic look and clearly positions it visually as the sportiest model in the segment. The effect is accentuated by a fixed roof spoiler that underscores the coupé-esque silhouette.

Let there be light: The panoramic glass window creates a unique spatial experience. An integrated shade protects against sunlight and cold. Another special feature of the Coupé is the standard individual-seat style setup in the rear bench. Alternatively, the 2+1 comfort rear seat system from the Cayenne is available at no extra charge.

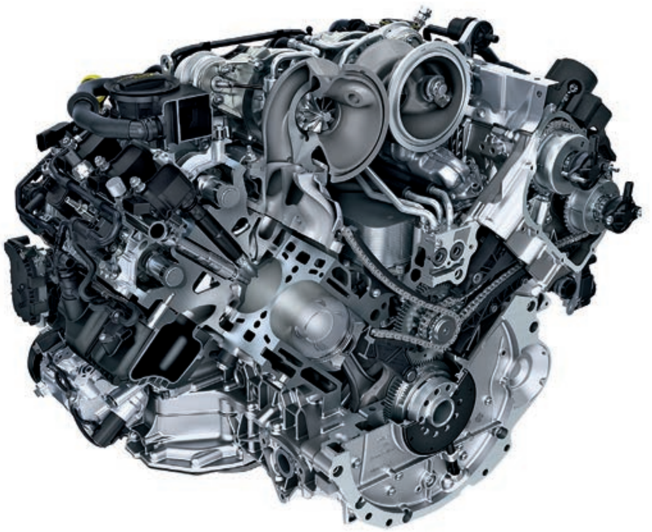
Sporty: The optional contoured carbon roof features a notch down the center and an unmistakably sporty look reminiscent of the Porsche 911 GT3 RS. It is part of one of three lightweight sports packages.

All aboard: The extensive standard equipment package includes front and rear Park Assistant and a reversing camera. The new eight-way adjustable sport front seats with integrated head restraints offer exceptional comfort and optimal lateral support.

Transfer of innovative efficiency technologies

Fuel injection in handheld devices provides greater performance with lower fuel consumption and declining emissions.

A **variable compression ratio** can boost efficiency in motorcycles by four to eight percent.



Water cooling is used in nearly all powersports applications and yields efficiency gains.

Like boats, quads are already benefiting from efficient engines with **water cooling**.

Gasoline engines are not only found in millions of cars — they also power motorcycles, mopeds, boats, small machines, and stationary work equipment. In all of these areas, laws are becoming stricter, and the demands of customers are rising as well. Porsche Engineering can transfer the technologies from the automobile to these non-automotive fields.

Text: Christian Buck

Gasoline engines can look back on an astounding development history: First driven by the desire for greater power and convenience, and later by strict consumption and emissions regulations, today they are technologically sophisticated systems highly optimized for their purpose. Many new technologies have played a role, including direct fuel injection, exhaust aftertreatment, downsizing, and hybridization. And although the long-term trend is in the direction of electric vehicles, gasoline engines will probably still power roughly 70 percent of all passenger vehicles in 2050, albeit mostly as hybrid variants in combination with an electric motor.

Motorcycles, mopeds, and boats will also continue to use gasoline engines for a long time to come. However, legal requirements will become stricter and customers more demanding in this area as well. "For motorcycles, EU emissions thresholds have also been drastically reduced," reports Klaus Fuoss, Director of the Engine Department at Porsche Engineering. "By 2020, carbon monoxide emissions cannot exceed 1,000 and emissions of hydrocarbons will be limited to 100 milligrams per kilometer, which is equivalent to the passenger vehicle limits in place in 2005." As for nitrogen oxides, only 60 milligrams per kilometer will be allowed, which was the limit for passenger vehicles in 2009.

A similar development has taken place for small devices (handheld and non-handheld) such as power

60 milligrams

of nitrogen oxide per kilometer are permitted for motorcycles as of 2020.

saws and lawn mowers. Depending on the displacement of the motor, handheld devices may only emit a maximum of 50 to 72 grams of hydrocarbons and nitrogen oxides respectively (combined per kilowatt-hour of work) under US and EU regulations. For non-handheld devices, between eight and ten grams per kilowatt-hour are allowed.

Beyond legislation, customers are also becoming more demanding, for instance with high-performance motorcycles. "Here the demand is for strong performance at high engine speeds combined with better driving characteristics at low engine speeds," says Fuoss. In emerging economies, by contrast, millions of people are dependent on mopeds that are robust and efficient –and that can comply with ever-stricter emissions limits with inexpensive technology.

With work equipment, users are demanding better protection: The German trade associations, for example, specify a threshold of 35 milligrams of carbon monoxide per cubic meter of breathing air. The odorless gas can collect in mines and other spaces and has a toxic effect. The hydrocarbons in exhaust gas are also problematic: They not only give off an unpleasant odor, but also contain carcinogenic benzene rings.

So the gasoline engine has to become cleaner—and not just in cars. However, many companies in the non-automotive sector lack the big development budgets of the automobile manufacturers. “There is therefore a need for the intelligent transfer of mature technologies from the car to other applications,” says Fuoss. “The motorcycle manufacturers are the furthest along here, with the law lagging six to eight years behind the regulations for passenger vehicles.” Many elements from the car are therefore already in high-priced motorcycles, such as mechanical charging with superchargers.

Familiar with all technologies

Porsche Engineering is well versed in all efficiency and environmental protection technologies in the gasoline engine area and can support companies in the non-automotive sector with the transfer of such technologies to their products—always bearing in mind specific requirements such as low costs or the lowest possible weight. However, not every technology is suitable for every product. “In each case a precise analysis must ascertain whether the defined objectives can be achieved in an economically viable manner,” says Fuoss. To provide better orientation, the experts from Porsche Engineering have examined technologies in terms of their use in motorcycles and handheld and non-handheld devices: alternative fuels, fuel injection, exhaust aftertreatment, variable valve drives, variable compression, down- and rightsizing, electrification, and water cooling.

Analysis

Not every technology from passenger vehicles is amenable to transfer. A precise analysis must determine what makes sense and what doesn't.

The fastest reductions in carbon dioxide and other emissions could be achieved through alternative fuels such as methane as a gasoline substitute: Due to the favorable ratio of hydrogen to carbon atoms, gasoline engines would emit roughly 25% less CO_2. Renewably generated CH_4—for instance produced by way of electrolysis from renewable electricity and subsequent methanization—would actually be entirely climate-neutral. What's more, there are fewer toxic components in the alternative fuel. “From a technical standpoint, it absolutely makes sense to replace gasoline with such alternatives,” says Fuoss. “Moreover, only minor modifications to the engines are required.”

Fuel injection is also one of the promising technologies for non-automotive applications—even in power saws. Through more precise timing and more accurate mixture preparation, the technology offers more performance at lower fuel consumption and emissions levels. Above all, the emissions of hydrocarbons could be reduced. What has already proven successful in motorcycles and jet boats could soon find the way into handheld and non-handheld devices. “The development expense is reasonable, and the additional weight of 100 to 200 grams is acceptable even for handheld devices,” says Fuoss. “When and how quickly fuel injection comes to this area will, however, depend crucially on future emissions limits.”

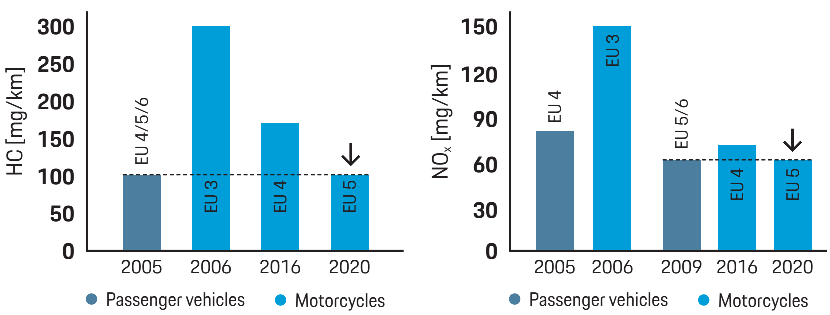
Its use would be particularly useful in combination with exhaust aftertreatment. Three-way catalytic converters are already in use in motorcycles today, reducing their hydrocarbon, carbon monoxide and nitrogen oxide emissions. In principle, handheld devices and stationary work machines could be made more environmentally friendly as well. It would carry a price, however: Due to restriction of the exhaust gas temperature, performance is diminished, and fuel consumption actually rises. “And due to the expensive precious metals in the catalytic converters, costs rise as well,” explains Fuoss. “Technically there are no obstacles to exhaust gas aftertreatment in handheld and non-handheld devices—but it will only be introduced if mandated by law.”

Variable valve drives are an interesting technology for powerful motorcycles. They enable greater flexibility in the gas cycle, which leads to higher performance, lower emissions, and lower fuel consumption. Due to high costs, however, variable valve drives are not

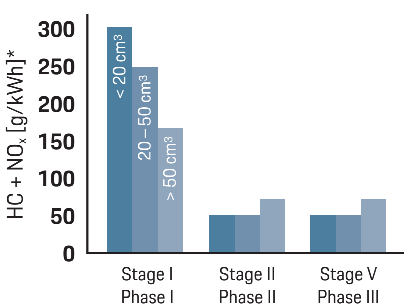
Emissions regulations are getting stricter

As in the automotive sector, motorcycles, handheld, and non-handheld devices are also subject to increasingly stringent limits for carbon monoxide, hydrocarbons, and nitrogen oxides. Compliance with those limits requires the transfer of efficiency technologies from the automotive sector.

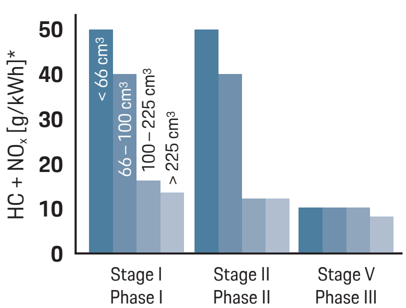
Car vs. motorcycle emissions standards—EU



Handheld



Non-handheld



*NO_x limit for EU stages: 10 g/kWh if not specified; source: Porsche Engineering

Application-specific analysis required

Not every efficiency technology from the automotive sector is suitable for transfer to other applications. Factors such as cost, weight, and dimensions can be decisive.

	Variable valve drive/variable valve control	Fuel injection (EFI)	Exhaust after-treatment	Downsizing	Variable compression ratio	Alternative fuels	Electrification
Performance	●●●●○	●●●●○	●●○○○	●●●○○	●●●●○	●●●○○	●●●○○
Fuel consumption/CO_2	●●●●●	●●●●●	●●○○○	●●●●●	●●●●●	●●●●○	●●●●●
Emissions	●●●●○	●●●●●	●●●●●	●●●○○	●●●○○	●●●●○	●●●●○*
Complexity/weight	●●○○○	●●○○○	●●○○○	●●○○○	●○○○○	●●●○○	●●○○○
Cost effectiveness	●●●●○	●●●●○	●●○○○	●○○○○	●○○○○	●●●●○	●●○○○
Additionally required	ECU	ECU	Closed-loop lambda control	Supercharging, direct fuel injection	Turbocharging	Tank, mixture preparation	Electronics, batteries
Feasibility for motorcycles	Powersports ●●●●○	Mass market ●●●●●	Great potential, if not yet implemented ●●●●○	●●●○○	●●○○○	●●●●○	Urban mobility ●●●●○
Feasibility for handhelds	●●○○○	●●●●○		●●○○○	●○○○○	●●●●○	Purely electric ●●●●○
Feasibility for non-handhelds	●●○○○	●●●●○		●●○○○	●○○○○	●●●●○	Hybrid ●●○○○

●●●●● Very suitable
●○○○○ Not suitable

* Local emissions

an option for handheld and non-handheld devices. A similar picture emerges for motors with a variable compression ratio. “The efficiency gains of four to eight percent could certainly be interesting for motorcycles in the future,” says Fuoss. “There is also the possibility of lowering emissions significantly in conjunction with the Miller method and supercharging. For handheld and non-handheld devices, however, this technology is also too complex and too expensive. As with cars, downsizing and rightsizing can also lead to reduced fuel consumption in motorcycles.

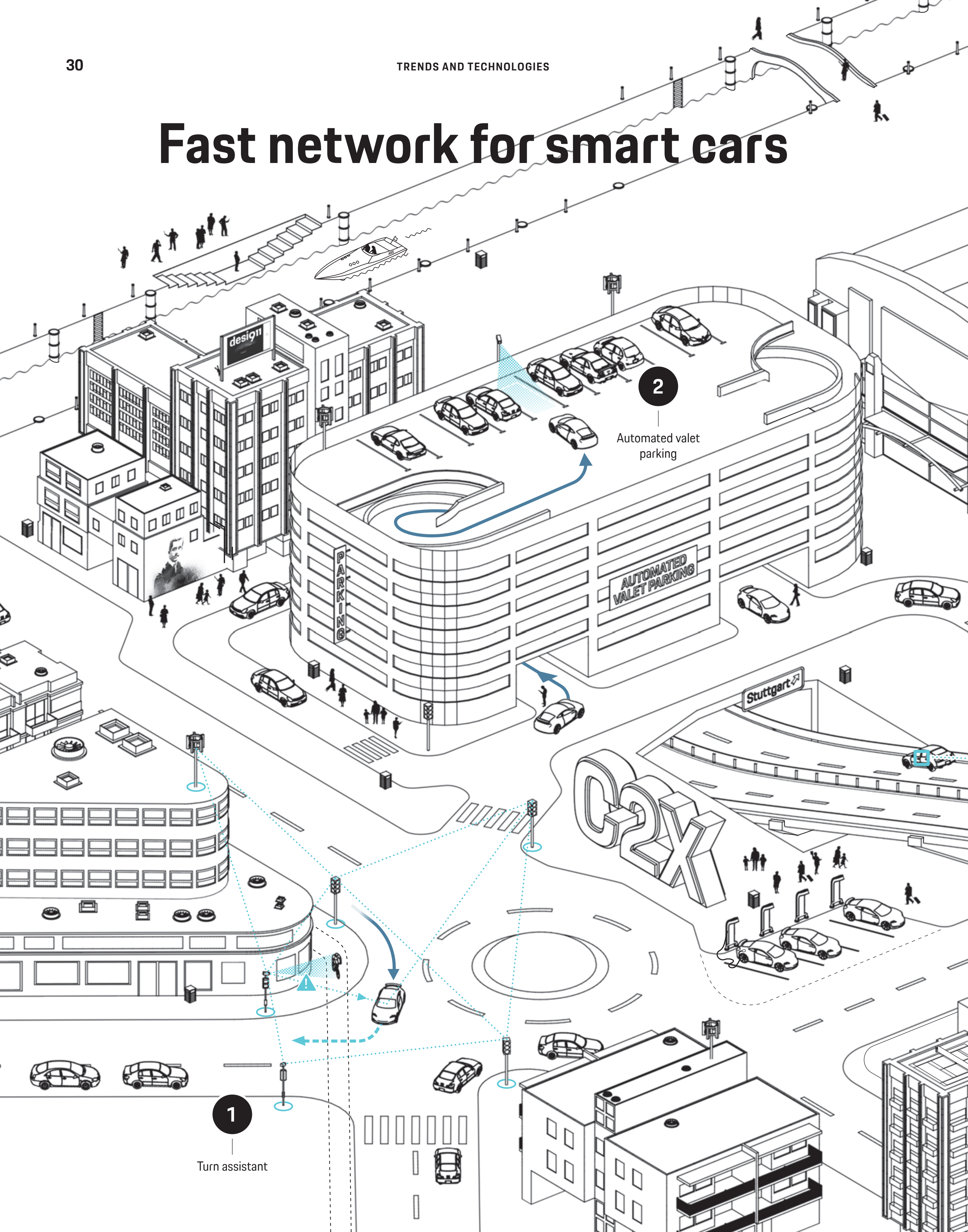
Low range for electric drivetrains

Motorcycles and work equipment can be made locally totally emission-free through electric drive systems. There are still many unanswered questions here, however, such as operating duration. “Electrically powered motorcycles provide outstanding acceleration, but still offer limited range—which is bad for long tours,” explains Fuoss. “So at the moment it is difficult to say whether they will be successful.” And those who wish to power handheld and non-handheld devices electrically may have to secure adequate operating times through the use of multiple batteries—which drives up costs.

Water cooling also yields efficiency gains in combustion engines and is already used in nearly all powersports applications (including motorcycles, boats, and quads). Small devices use simplified water cooling systems in some cases, but they have not gained traction due to cost and weight drawbacks.

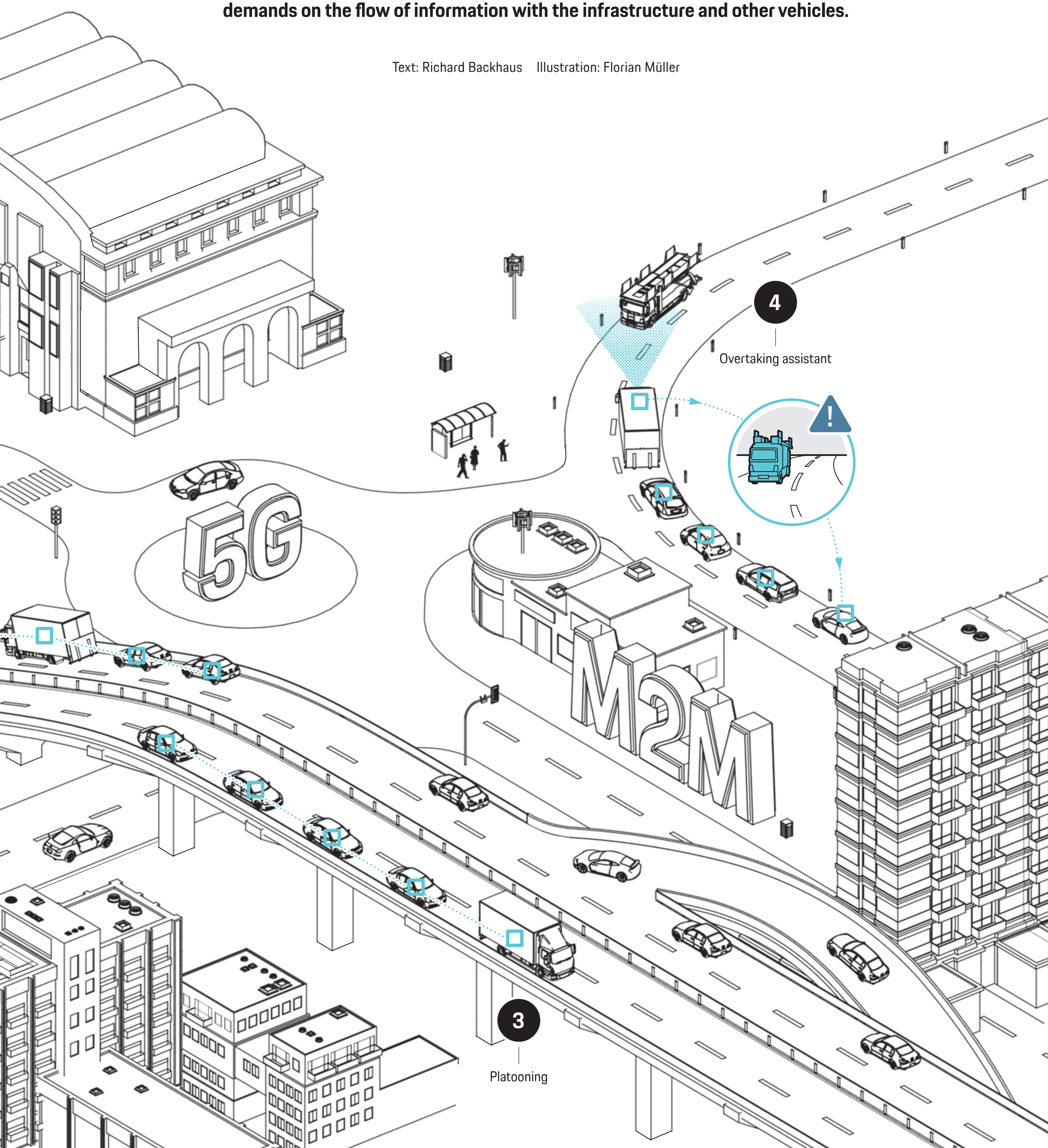
So in the view of the experts from Porsche Engineering, all indications are that gasoline engines will continue to be used for some time to come even beyond automotive applications. It is therefore important to transfer innovative and economically viable efficiency technologies from the automotive sector to new applications.

Fast network for smart cars



The 5G wireless network enables secure and instantaneous data transmission between machines. This also benefits fully automated driving functions, which place high demands on the flow of information with the infrastructure and other vehicles.

Text: Richard Backhaus Illustration: Florian Müller



The data volumes being transmitted via wireless networks are rising inexorably, due primarily to increasing machine-to-machine communication (M2M communication). In the automotive field, it is primarily fully automated driving that is spurring on this development: While the data volumes per hour in current highly networked vehicles are in the gigabyte range today, by 2025 the figure will be multiple terabytes.

5G networks play a decisive role in handling these large data volumes, because in contrast to 3G and 4G/LTE wireless networks, 5G was designed specifically for the characteristics and performance requirements of M2M communications. The network offers a much higher transmission rate of 20, rather than 1, Gbit/s. Moreover, latency—the time between a query and receipt of the response—was reduced from ten milliseconds to one. What that means is that data is transmitted almost in real time. For technical applications such as the remote control of robots or automated driving functions, that is a critical factor as high-performance, real-time connectivity in a networked system enables the implementation of new functions.

However, the theoretical time gains of the 5G network would be decimated in a conventional network topology with a centralized data center due to the excessively long transmission distances to the transmitter towers. To achieve minimal latency, therefore, the 5G network envisions a decentralized solution in which each transmission station has its own computer that receives, processes and independently retransmits data. There are countless individual mini data clouds known as cloudlets. This approach is also referred to as mobile edge computing, as the cloud and computer are at the edge, so to speak, of the mobile network. Furthermore, the machines in the 5G network can communicate directly with each other and without the detour via the transmission station. This can minimize transmission times even further.

Another advantage: Compared with 4G, 5G can also serve a larger number of end devices per network cell. The network prioritizes the applications and adjusts the transmission—if necessary—to the load situation. The data for time-critical applications is conducted through the network faster than other data, such as the video streams of private users.

For safety reasons, automated driving functions must naturally be designed in such a way that all eventualities that may arise during the drive can be recognized and safely handled entirely with the vehicle's own assistance systems. That applies in equal measure on highways, rural roads, and urban roads. In borderline situations such as poor visibility or complicated traffic situations, additional information drawn from the exchange of data with the infrastructure or other vehicles—what is known as C2X communication—can substantially enhance the control accuracy of the onboard systems.

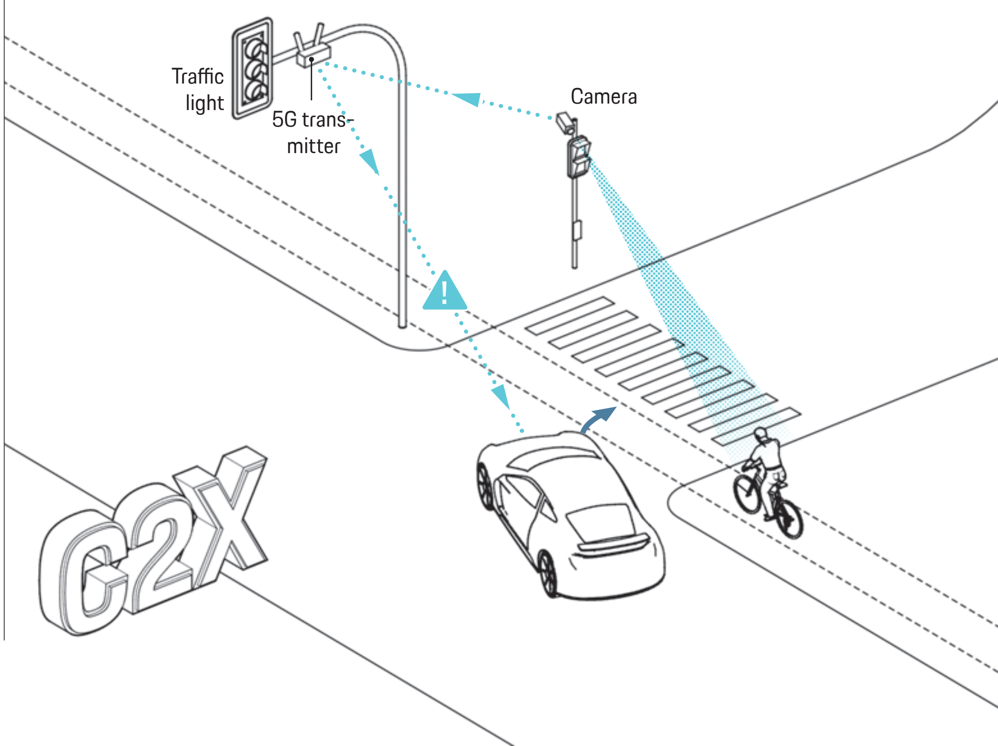
Taking the complete route into account

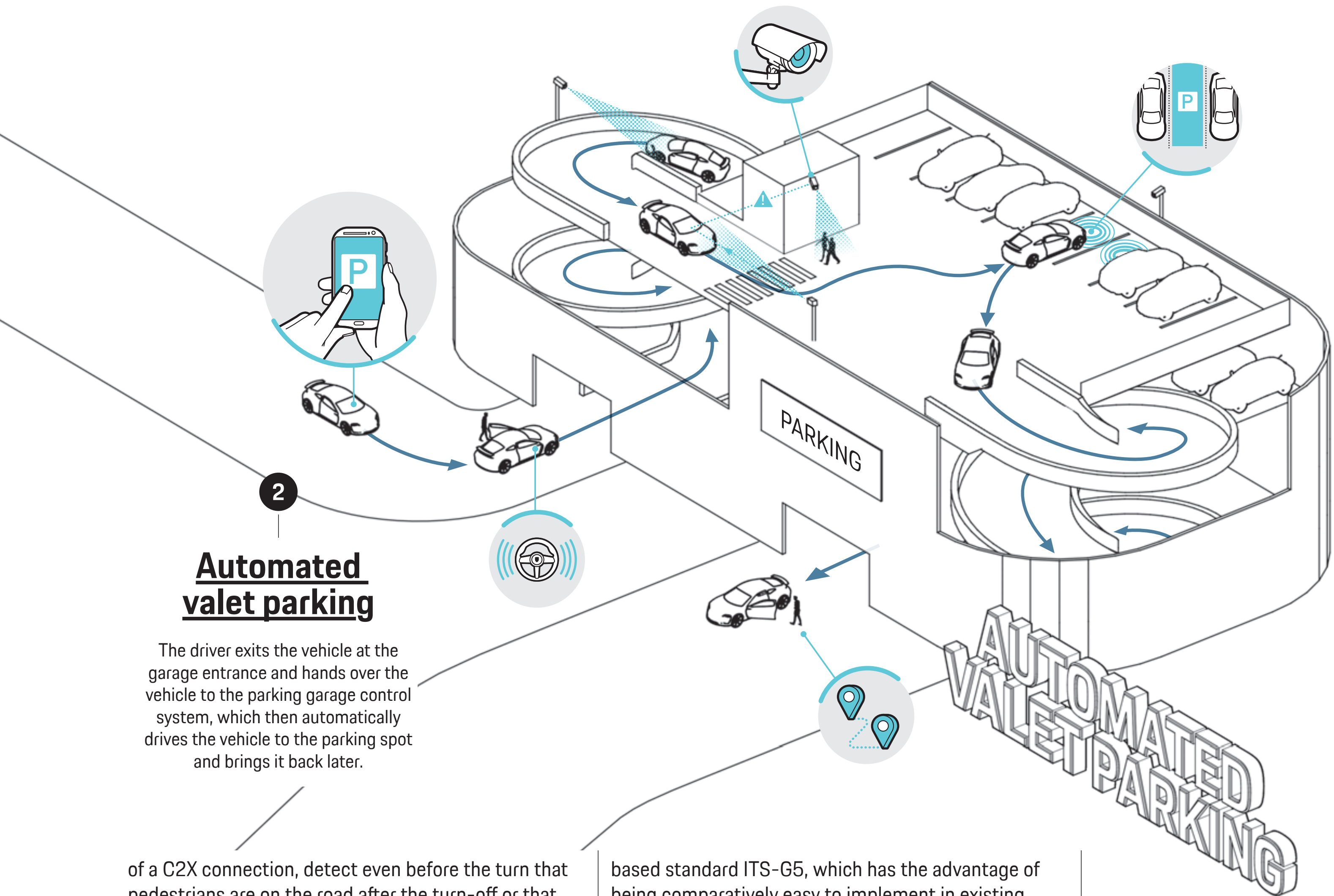
"Currently, the sensor technology on the vehicle only covers a range of a maximum of 300 meters around it. Using the sensor data from other vehicles and the infrastructure, information from all along the entire route can be taken into account," explains Jaime Arveras, responsible for Connected Car functionality at Porsche Engineering. "Driving maneuvers can be much more effectively adapted to requirements and hazard situations detected at an early stage." This, in turn, opens up entirely new possibilities for driver assistance systems. Turn assistance systems, for example, can, with the aid

1

Turn assistant

In the future, the exchange of information between the vehicle and the infrastructure will be a standard procedure—via 5G or WiFi. It will make it possible to avoid accidents when turning, for example.





Automated valet parking

The driver exits the vehicle at the garage entrance and hands over the vehicle to the parking garage control system, which then automatically drives the vehicle to the parking spot and brings it back later.

of a C2X connection, detect even before the turn that pedestrians are on the road after the turn-off or that the route is blocked by an accident.

In enclosed spaces such as parking garages, C2X communication enables automated valet parking. The driver exits the vehicle at the garage entrance and hands over the vehicle to the parking garage control system. It then drives the vehicle, completely automatically, to the parking space and later returns it in like fashion. Another example application based on C2X communication is currently being tested: coordinated driving of multiple vehicles in a line with minimal gaps between
3 them. This "**platooning**" makes better use of the slipstream and could reduce fuel consumption, particularly in highway caravans of commercial vehicles driving in formation. Without fast communication, it is simply impossible: If one vehicle in the platoon brakes, the signal must be transmitted to the following vehicles without delay and braking immediately initiated there in order to avoid rear-end collisions.

The 5G wireless network is especially well-suited to C2X communication because it enables fast, secure exchange of large volumes of data over large distances. As a technical alternative, OEMs also use the WiFi-based standard ITS-G5, which has the advantage of being comparatively easy to implement in existing traffic infrastructure such as traffic lights. Moreover, the interface standard has been defined and is ready for mass introduction. Volkswagen, for example, is planning to equip new vehicle models with WiFi-C2X communication starting in 2019. "Both concepts have their specific advantages and disadvantages. In the medium term, there will probably emerge a hybrid system in which the paths are used redundantly," says Dominik Raudszus, team leader for networking and testing at the Institute for Automotive Engineering (ika) at RWTH Aachen. Over the long term, the coming wireless network will certainly win out over other transmission types such as WiFi.

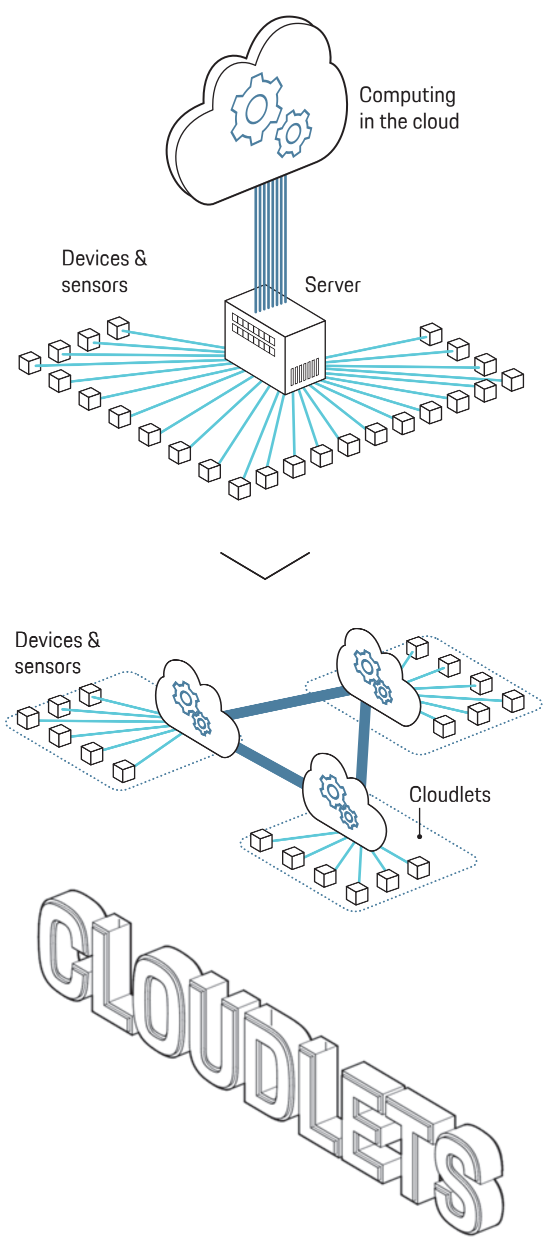
"C2X communication via 5G will in many cases replace the coordination between drivers that we see today, which cannot be represented by sensors," says Kai Schneider, who works on 5G-based C2X concepts as a development engineer with Porsche AG. "This applies, for example, to the smooth and rapid merging procedure on the highway. To achieve fully automated driving with a high comfort level, which can also be integrated into existing traffic, there is therefore definitely a need for communication between the vehicles."

400

billion dollars have been earmarked for the expansion of the 5G network in China.

Distributed computing capacity

To achieve minimal latency, a decentralized solution is planned for the 5G network in which each transmission station has its own computer. The result is countless individual mini data clouds known as cloudlets.



3G

42 Mbit/s

The UMTS (Universal Mobile Telecommunications System) was launched in Germany in 2004. It initially allowed the transmission of voice and data at speeds of up to 384 kbit/s. Mobile surfing became possible. Further development enabled speeds of up to 7.2 Mbit/s, and later 42 Mbit/s.

4G

1,000 Mbit/s

The current standard for smartphones is LTE (Long Term Evolution), which was launched in Germany in 2010. It allows transmission speeds of up to 1,000 Mbit/s. In practice, network capacity limitations generally require users to make do with 50 Mbit/s.

5G

20 Gbit/s

The fifth generation of digital mobile communications is still some way off. The new standard will enable transmission speeds of up to 20 Gbit/s. Latency will be less than a millisecond, which is particularly important for machine-to-machine communication, such as in road traffic and industrial applications.

But even before any fully automated driving functions have been implemented in vehicles, the high speed of 5G communication makes it possible to introduce new assistance functions. For example to provide greater clarity in complex situations, such as when visibility of oncoming traffic is limited. A truck driving in front could transmit its video image of the road to the display of the following vehicle in real time. The driver of that vehicle would then be able to see what's happening in front.

A cross-industry alliance is working together to advance 5G

The use of 5G technology for automated driving is being studied by a cross-industry alliance of telecommunications providers, automobile manufacturers and research institutes in a variety of different projects. "Only through the interaction of various technologies and together with partners in and around the vehicle can the vehicle drive in an anticipatory manner, detect hazards in good time and efficiently carry us from A to B," says Dr. Johannes Springer, director of the automotive 5G program at Deutsche Telekom. One of the biggest national initiatives is the 5G-ConnectedMobility project in which Ericsson, the BMW Group, Deutsche Bahn, Deutsche Telekom, Telefónica Deutschland, Vodafone, 5G Lab Germany (TU Dresden), the German Federal Highway Research Institute (BASt), and the German Federal Network Agency (BNetzA) are all involved. A test network has been installed on the A9, Germany's official "digital testing Autobahn." There are also many smaller projects under way. Vodafone, for example, has equipped the Aldenhoven Testing Center at RWTH Aachen with a 5G research network. For its part, Telekom operates a 5G test network in Hamburg and at the Lausitzring, among other projects. Together with the track operator Dekra, it has established the biggest testing grounds for automated driving functions in Europe over a 545-hectare section of the Lausitzring grounds. In Nardò, Porsche Engineering and various manufacturers are forging ahead with the further development of the testing grounds for the testing of networked driving functions.

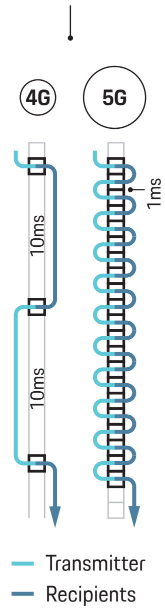
Compared with the 3G and 4G networks, the 5G standard currently slated for use in Germany works with higher frequencies of 2 and 3.6 GHz. They can handle larger data rates, though they have the physical limitation of a smaller range. Building the network will therefore require the installation of many more cell towers than for 3G and 4G. It is—unless prescribed by legislation for the required network coverage—controlled by the network operators on the basis of local requirements: Where large data exchange volumes are required and it is economically viable, they install the base stations. For automated driving, an ultrafast high-performance data network will take shape along the traffic arteries (on highways, on federal and state roads, and in urban areas).

In Germany, licenses for the use of 5G radio frequencies will be auctioned off, with the first event slated for early 2019. The revenue from the auction will benefit an investment fund for the expansion of the digital infrastructure. According to current plans, the first 5G cells are set to go online as part of the regular network in Germany in 2020/2021. Further expansion will proceed according to requirements. In the US, some providers aim to launch 5G services for end customers in 2019. But the first frequency auction in the US will probably only be held in 2020. China has assumed the pioneering position internationally in terms of 5G network expansion: According to a study by Analysys Mason, the People's Republic currently already has more than 350,000 cell towers that support 5G communication—ten times more than the US. According to the current five-year plan, the government plans to invest 400 billion US dollars in the expansion of the 5G network by 2020.

To ensure the international compatibility of 5G components, binding standards must be introduced worldwide. Here, too, an important milestone has already been reached: In June 2018, the first 5G standards were passed by the competent authority, the 3rd Generation Partnership Project (3GPP).

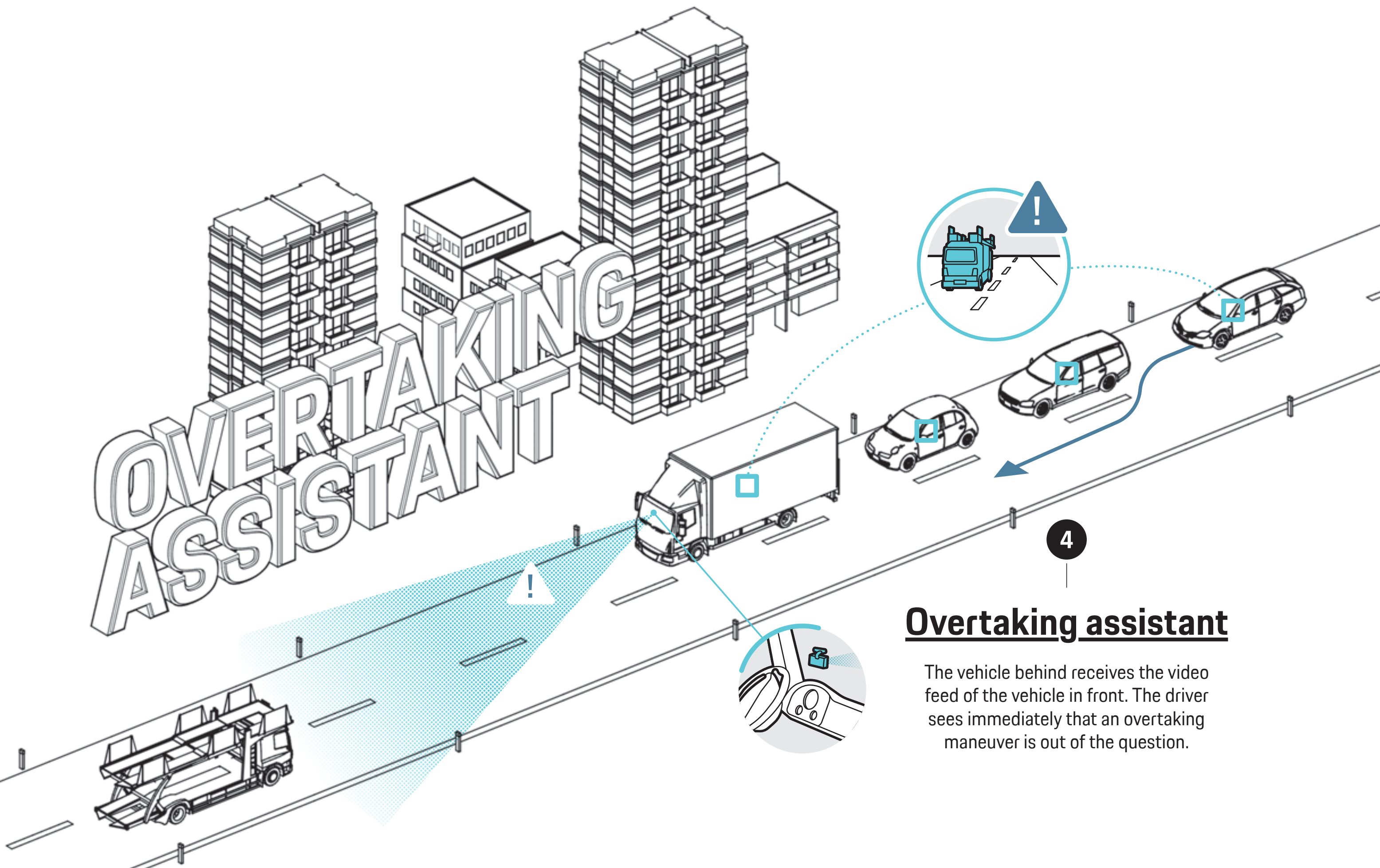
Fast response

With 5G, the time between a query and a response will be less than a millisecond. Today it generally takes ten times as long.



IN BRIEF

Automated driving functions in particular will result in ever greater data volumes being transmitted. The new 5G wireless network will play a key role: It is designed specifically for machine-to-machine communication and offers latency of just about a millisecond. 5G will also enable new driver assistance systems, such as overtaking assistants, that make use of the video images from vehicles in front.



Overtaking assistant

The vehicle behind receives the video feed of the vehicle in front. The driver sees immediately that an overtaking maneuver is out of the question.

Creativity on the brink of chaos

GUEST WRITER

University Prof. em. Dr. Klaus Mainzer is Emeritus of Excellence at the Technical University of Munich and Senior Professor at the University of Tübingen. His publications include the books *"Komplexität"* (UTB 2008) and *"Künstliche Intelligenz. Wann übernehmen Maschinen?"* (Springer, 2nd ed. 2019).

Photo: Udo Keller Stiftung/Hamburg

Complexity is one of the burning issues in current scientific research. Can the emergence of order and self-organization in ecological environments teach us how to control the complex processes of our technical and social systems?

Complex systems comprise myriad elements whose interactions produce collective order and patterns. Complexity theory examines the laws governing these dynamic processes—from complex atomic, molecular, and cellular systems in natural environments up to complex social and economic systems. It applies interdisciplinary approaches to investigate the interaction of multiple elements within a complex system, for example molecules in a material, cells in organic structures, or people in markets and organizations, and to find out how these interactions produce order and regular structure—or chaos and turbulence. A system is considered chaotic when minute changes to its initial conditions induce substantial change. You may have heard this referred to as the "butterfly effect:" The beat of a butterfly's wing could trigger changes in weather on a global scale.

Markets and business enterprises are examples of economic systems in which humans enact multiple, interacting functions. The automotive industry, in particular, makes for a good field of research. Its products and business practices have undergone considerable change in recent years. Besides handling classic vehicle development, automotive companies invest their resources in researching the rapidly growing fields of digitalization and artificial intelligence. The increasing diversity of product variants and technologies is resulting in ever-greater complexity.

Classic liberalism, as well as classic 18th- and 19th-century physics, have traditionally failed to take this complexity into account when addressing economic systems. Instead, a linear propensity toward equilibrium was usually assumed that would result in economic forces naturally organizing to produce the "wealth of nations" (Adam Smith). However, as it is an open system that is constantly exchanging materials, energy, and information with other markets and the natural environment, a market economy can never approach final equilibrium. In the same way as a biological ecosystem, it is in constant flux and responds sensitively to the smallest of changes in its boundary conditions. Also, an economic system's agents are humans, and thus possess the capacity to learn: Short-term fluctuation in consumer preferences, lack of reactivity in production behavior, even speculation in resource and real-estate markets all show how susceptible economic systems are to change. We call these highly interdependent systems "non-linear." Take two competing products, for example, with positive feedback from rising revenue. If we want to find out what effects random fluctuations in the early stages will produce, we need a non-linear model. The slightest market advantage early on (perhaps a greater market share in a specific region, perhaps political contacts, or a better lobby) can entail knock-on effects that provide a breakthrough for one of the products. In turn, a certain technology may take hold more easily, increasingly gaining in significance in a way that could not have been predicted at the outset.

Companies need to identify how closely their typical fluctuations can approach instability to trigger surges in innovation.

Even a technical standard, for example a computer operating system, that was not the ideal solution from a technical viewpoint, might come out on top in the end. Non-linear dynamics prove that a variant does not need to be the best in order to become established—in evolution, in economics, in politics. We need to remember this when heading into a competitive field so that we don't underestimate the impact even the minutest change in circumstances can have and so that we remain prepared to take appropriate action.

The human mind cannot hope to keep track of the overall developments of every detail—in system design, for example, the many variables entail too rapid an increase in complexity. Production and sales address this by making more and more use of machine learning to train system components like robots in the tasks they need to perform in collaboration with humans (Industry 4.0).

But tomorrow's markets will remain decisively dependent on humans as the driving force of businesses' innovation potential. Complexity management succeeds where we exploit the non-linear dynamism of complex systems. We find the greatest promise in the behavior on the "brink of chaos:" Companies need to identify how closely their typical fluctuations can be allowed to approach instability to trigger surges in innovation. It is when we stand on the brink of chaos that we discover our greatest creativity.

One example would be a stable business venture that surrounds itself with a ring of start-ups, investing in innovative fluctuation with uncertain outcomes: The business would be operating intentionally on the brink of chaos—Silicon Valley's proven modus operandi. Companies that favor excessive prudence by remaining on the straight-and-narrow and resting on their previous successes are ultimately overtaken and fail. There's even an historical example at a global scale to show how to survive and prosper on the brink of chaos: The communist regime in China allowed controlled, incremental establishment of capitalist free-trade zones, ultimately producing an incredible economic boom. The former Soviet Union, on the other hand, pursued its command economy to an utter standstill that resulted in its total collapse.

Through the snow as if on rails

Text: Constantin Gillies Photos: Tobias Habermann

Thanks to variably distributable drive power, electric vehicles with separately powered wheels can remain stable even in critical situations—as long as the torque control reliably detects deviations from the target state and reacts immediately. Porsche Engineering has developed and tested a solution for e-SUVs that does precisely that. Without additional sensors—entirely through software.

It's a situation that every driver dreads: a snow-covered road, a surprisingly tight corner, and barely any time to brake. With a normal vehicle, a dangerous loss of control is an all-too-real possibility. The rear could swing out, causing the car to spin and land in the ditch. Yet in this test, everything goes differently: The driver turns and the SUV steers confidently into the corner—without even slowing down. A glance at the speedometer (80 km/h is the reading) removes all doubt that this is no ordinary vehicle. The SUV being tested in this wintry environment is an electrically powered all-wheel-drive vehicle with four motors—one for each wheel.

Until now, this drive technology was seen only in Mars rovers, but now it has reached the everyday world: Porsche Engineering recently developed a torque control system for electrically powered series SUVs. It was truly pioneering work. "We had to develop a lot of it from the ground up," says Dr. Martin Rezac, Team Leader for Function Development at Porsche Engineering. There was also an additional challenge: The driving characteristics had to be optimized exclusively through software. The Porsche engineers could not install any additional sensors and had to use the existing control devices. The task, in short, was essentially driving stability by app.

Purely electronic control of torque

An electric all-wheel-drive vehicle with multiple motors has a fundamental advantage over gasoline or diesel engines: The front and rear axles, indeed all four wheels, have their own electric motors, enabling extremely variable distribution of the drive power. "It's almost as if you had a separate gas pedal for each axle or wheel," explains Ulf Hintze of Porsche Engineering. In a conventional all-wheel-drive vehicle, there is just one engine at work, whose power is distributed to the axles through a central differential. As a rule, the torque ratio is fixed: one-third up front and two-thirds in the back, for instance. The ratio can, in theory, be changed, but additional mechanical gadgetry is required for that (multi-plate friction clutch), and it works rather sluggishly. In an electric vehicle, by contrast, the torque is purely electronically controlled, which works considerably faster than mechanical clutches. Every millisecond, intelligent software distributes the forces in such a way that the vehicle always behaves neutrally.

"The vehicle feels noticeably more stable."

Dr. Martin Rezac,
Porsche Engineering

All-wheel drive vehicles

with electric drive systems feature a separate motor for each wheel. This enables extremely variable distribution of the respective drive power.

It takes around 50 ms

for the software to redose the forces to the wheels. That is much faster than for many mechanical solutions for conventional drive technologies.

Choice

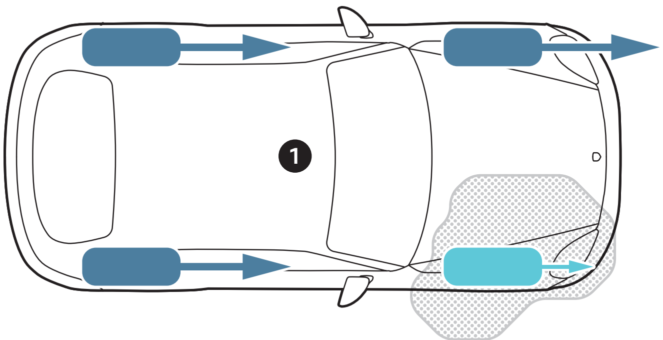
Thanks to the electronic optimization of the forces, it would be possible to offer the driver different modes, for instance for sporty or smooth driving.

And Porsche Engineering developed just such a torque control system for all-wheel drive SUVs. The software can be used for different constellations and motor configurations—for other electric vehicle types as well, of course. In general, development begins with the base distribution, i.e. software that controls how much power is transmitted to the front and rear axle, respectively. For straight-line driving and balanced weight scenario, for example, a 50/50 distribution would make sense. If the driver accelerates, the software switches to full rear-wheel drive—or all front-wheel drive around a sharp bend. "This makes the vehicle noticeably more stable, even for the passenger," says function developer Rezac. As the optimization is achieved entirely electronically, theoretically it would even be possible to offer the driver various different configurations: one mode for sports car sprightliness, another for smooth cruising.

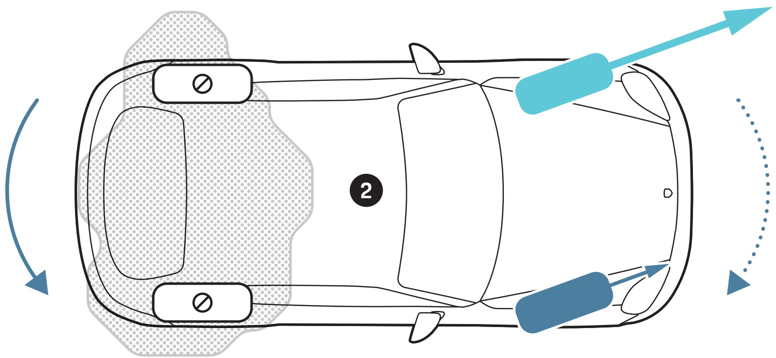
The second task of the control software is to adjust the torque to the wheel speed. The algorithms follow a simple objective: All wheels are supposed to spin at the same speed. That's easy to accomplish on a dry freeway, but it is considerably trickier when driving on a snowy mountain pass. If the front wheels encounter an icy patch, for example, they could—without electronic intervention—start spinning. But the torque control system detects the suboptimal situation immediately and directs the torque to the wheels that are turning more slowly and still have grip within fractions of a second. There is something similar in the world of combustion engines—the speed-sensing limited-slip differential, also known by the brand name Visco Lok. In this component, gear wheels and hydraulics

Precisely dosed power

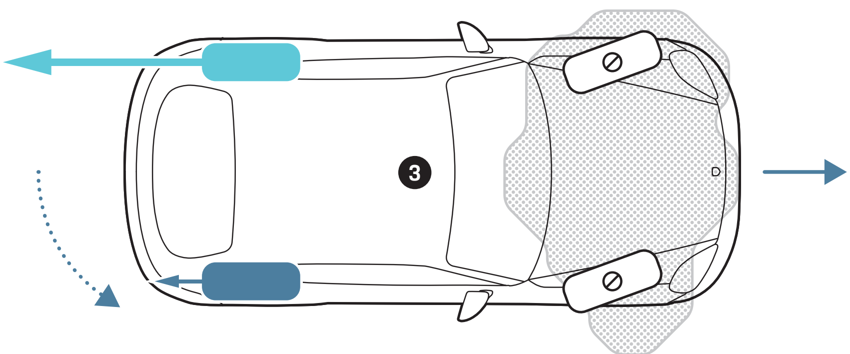
In any situation, a tire can only transmit a certain amount of force, regardless of the direction. What that means is that the greater the drive or brake force transferred to it, the lower the lateral forces it can transmit, for example. The electronic torque control uses exactly that to good effect: It takes the propulsion forces off of one tire, for example, so it can push the car in the desired direction.



Situation 1: The driver wants to accelerate as quickly as possible. The front wheel has little friction (for example due to a puddle or ice) and starts to spin. The torque is therefore transferred to the other side and to the rear (dark arrows).



Situation 2: The car is driving into a left-hand bend. The rear wheels hit a slick spot, causing the rear axle to spin out (solid arrow). The software takes all drive torque from the rear wheels to lighten their workload. At the same time it transfers a lot of torque to the front left in order to generate an angular momentum that acts against the spin-out (dotted arrow).



Situation 3: The driver wants to drive into a left-hand bend but the front wheels lose traction. The car travels straight ahead (forward arrow). The software takes the torque off the front wheels and brakes the rear left wheel significantly more than the rear right wheel to create angular momentum into the corner (dotted arrow).

"It's as if you had a separate gas pedal for each axle."

Ulf Hintze, Porsche Engineering

Three functions

provide driving stability and safety:

Static distribution
The force is distributed among the four wheels depending on the axle load

Torque adjustment
On difficult surfaces, the control system immediately directs the power to the wheels with the most grip.

Lateral dynamics control
This neutralizes critical driving situations like oversteer and understeer.

ensure that no wheel turns faster than the others. But mechanical solutions are slow. In an electric SUV, by contrast, software assumes the role of the differential—with much swifter reactions and naturally entirely without wear.

The third and most important function of the torque control system lies in its control of lateral dynamics, i.e. the ability to neutralize critical driving situations like the one mentioned at the outset: a slippery surface, a tight corner, and high speed. An uncontrolled vehicle would quickly understeer in this situation. In other words, the driver initiates the turn, but the vehicle slides in a straight line without slowing down. The control software in the e-SUV immediately puts an end to understeering. In a left-hand turn, it would brake the rear left wheel and accelerate the right one until a neutral driving situation was restored. The system takes similar measures when oversteer occurs (rear end swinging out). The driver, meanwhile, ideally notices nothing of these interventions, because the torque control system acts very subtly and quickly. "It feels like driving on rails—an SUV behaves with the agility of a sports car," says Hintze, summarizing the effect.

The observer module keeps watch

The driving state observer (shortened to simply the "observer" by the engineers) is involved in all intervention decisions. This software module continuously monitors a variety of factors: how forcefully the steering wheel was turned, how much the driver is accelerating, and how much the vehicle is turning around its vertical axis. The data is provided by a yaw sensor. This actual status is compared with a dynamic model of the vehicle that represents the target state under normal conditions. If the observer detects deviations, for instance due to oversteer or understeer, the software intervenes. If the vehicle is not turning into a corner as quickly as would be expected from the current steering wheel position and speed, individual wheels are selectively braked until the direction is back on line.

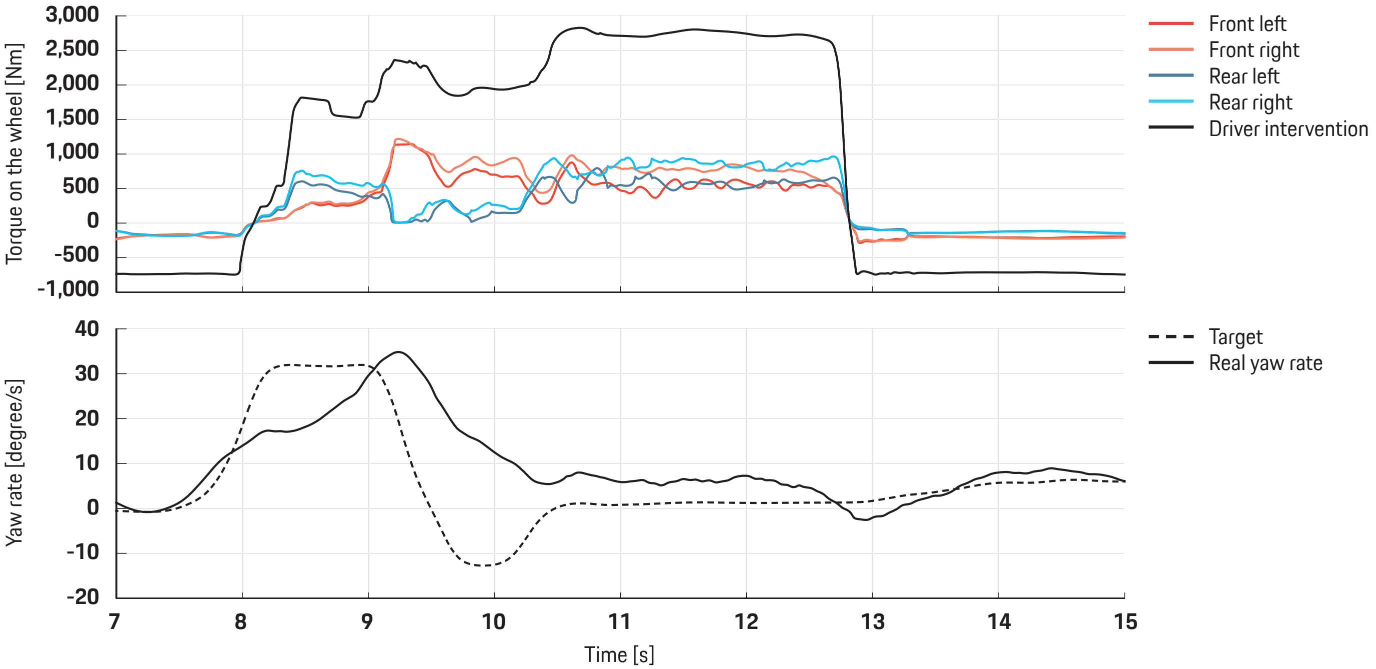
The same effect may be achieved by a conventional electronic stability control (ESP) system as well—but in an electrically powered all-wheel-drive vehicle, the safety system can do more: While a conventional ESP system only brakes, in an electric vehicle the individual wheels can be accelerated as well. This "pulls" the vehicle back onto the right track without losing speed. The intervention is also less jerky than in a hydraulic ESP system; the typical juddering familiar from anti-lock brake systems is omitted.

"The development of the vehicle observer was the biggest challenge," says Rezac. The fact that so much development work was required here goes back to a fundamental problem: A car knows relatively little about its own state. It doesn't know its own speed; it can only derive it from the speed of the wheels, which is difficult on ice and snow particularly. The observer therefore has to use additional information about the longitudinal and lateral acceleration in order to estimate the speed. The information regarding weight distribution is equally vague. While the suspension does capture the load on the individual wheels, even this information provides mere clues rather than certainty. If the shock absorbers report increased weight on the rear axle, for example, it could be due to the vehicle being parked on a slope—or simply being heavily loaded.

The data situation is decidedly meager. And because the client insisted that no additional sensors could be added, the SUV project called on the creativity of the software developers. "The observer has to estimate the vehicle's important parameters," explains Rezac. Some unusual data sources are brought to bear: The torque control system communicates with a sensor that detects the inclination of the car, for example, which is usually used for the automatic adjustment of the headlights.

The tale of a left-hand turn

The yaw rate indicates how quickly a vehicle is turning around its own axis in a corner. The two bottom lines show the yaw rate desired by the driver (dotted line) and the measured yaw rate (solid). The four lines above (red, orange, dark blue, light blue) show the drive torques, and the black line on top the gas pedal position. We see that the car first understeers. At about nine seconds the rear axle spins out and the car begins to oversteer. From about 10.5 seconds, the driving behavior stabilizes to a moderate understeer. The drive torques are mainly on the two right wheels.



The entire software package not only had to be developed, but calibrated in real test drives. And all that in a very short period of time: There were just two winters available in which the fine-tuning could be tested on a frozen river. It emerged, among other things, that the great advantage of electric motors—their rapid reaction times—sometimes resulted in undesired side effects. "The electric motors respond so quickly that vibrations can occur," reports Hintze, who conducted the test drives with his team. In a few situations the software transfered the torque between the axles at increasingly fast intervals, which resulted in an audible revving of the motors. Thanks to close collaboration between the calibration team and the development team around Martin Rezac, however, they quickly managed to put a stop to this build-up through a modification of the software.

This detailed work is exactly where the challenge lies in such projects. As the software is to be used in a series vehicle, it has to be tested for every imaginable situation, no matter how improbable it might seem. If the sensor reports faulty data, for example, the torque control has to decide if it is still allowed to function even without the data source or should be switched off.

ESP vs. electric vehicles

A conventional ESP system only brakes. In an electric vehicle, individual wheels can also accelerate. This "pulls" the vehicle back onto the right track without losing speed.

Another hurdle was posed by the limits of the electric drive technology. It may be the case, for example, that individual e-motors cannot transmit the available battery power. The function developers had to take such limitations into account. "The control range collapses in this case," says Hintze. Instead of 100 percent torque on one axle, perhaps only 60 percent might be available. And the torque control has to take that into account as well. But all involved are convinced: The pioneering work was well worth the effort, as electric vehicles with up to four motors will soon shed their exotic reputation. And many drivers will be grateful that they can drive through the snow as if on rails.

IN BRIEF

Porsche Engineering developed a torque control system for an all-wheel-drive e-SUV that provides maximum stability and safety in every situation—without additional sensors on board. All four wheels are actuated with the optimal force within milliseconds and stabilize the vehicle. The software was not only developed by Porsche Engineering, but also calibrated in real test drives over a period of just two winters. The software is suitable for different constellations and motor configurations.

Successful marriage

Text: Jost Burger Photos: KTM

Since 2018, the X-BOW from KTM has also been available with an automatic transmission. Porsche Engineering was responsible for the calibration. Among the challenges: Specified components had to be persuaded to work together. In the end, the X-BOW and the double-clutch transmission proved a perfect couple.

Unmistakable: The X-BOW is a car one doesn't soon forget.

Anyone who has seen it won't soon forget it: The X-BOW from the Austrian manufacturer KTM is an unusual vehicle. The company from Mattighofen im Innviertel is actually better known for its motorcycles—yet since 2008 KTM has also been active in four-wheel motorsports with the limited X-BOW series. With its unconventional design, the roadster quickly built a devoted fan base, and is also available in a street-legal version. But it doesn't yield its racing character even then: The vehicle dispenses with electronic driving assistance functions such as ESP, and ABS is optional. And of course, the X-BOW is shifted by hand, with a clutch and shift lever at knee level.

At least until recently: Since 2018 the X-BOW has been available with a six-speed automatic transmission as well, which can also be retrofitted. The impetus for this variant came from the sales department. "At presentations in countries such as China or the US, many interested customers had difficulties even driving the car," reports Jürgen Gumpinger, Vice President for Sportcars at KTM. They had never learned to drive a manual. This, in turn, meant that an automatic transmission would be needed to market the cars successfully in those regions.

The company opted for a double-clutch transmission from the VW Group, which under the designation DSG (for direct shift gearbox) became the first large-series-production double-clutch transmission in 2003. In the world of motorsports, the technology had already been developed and successfully used by Porsche in the 1980s. In 2008, the Porsche PDK double-clutch transmission went into series production with the 911 Carrera. Owing to its multitude of experience within and outside of the VW Group, KTM commissioned Porsche Engineering to take on the X-BOW transmission calibration.

The challenge was a daunting one, and not only due to the short timetable. The team was charged with getting the predefined and unchangeable components such as engine, transmission and corresponding control units to cooperate in a new race car. If just a single component didn't play along, the entire car wouldn't work. "The trick in such projects is actually to get the new transmission to communicate with the existing control units," says Dr. Jan-Peter Müller-Kose, Senior Manager Drivetrain Testing at Porsche Engineering. "This electrical integration presented us with significant challenges." At one point in the project, for example, the horn sounded when the turn signal lever

231 km/h

The KTM X-Bow reaches a top speed of 231 km/h.

1,984 cm³

The inline four-cylinder gasoline engine with direct fuel injection and exhaust gas turbocharger has a displacement of 1,984 cm³.

< 3.9 sec.

The X-BOW goes from 0 to 100 km/h in <3.9 seconds.

KTM X-BOW (Sport and Drive)

CO_2 emissions (combined): 288.8–200.9 g/km; Fuel consumption (combined): 9.8–8.6 l/100 km

was used. "The goal is for the given components not to even notice that they're in a different car and for the car ultimately to have the character of a race car through a custom transmission calibration," says Dr. Müller-Kose, summing up the unusual commission.

Electronic gear ratio assistance

With the small scale of production insufficient to justify a complete redesign, the job called for engineering acumen with the software of the DSG's controller. The hardware was therefore adopted from series production, but was tapped to do service in a different environment—that is, to react with race-typical gear changes in race-typical driving situations. Moreover, the software was accustomed to data that a vehicle like the X-BOW simply cannot provide. ABS, for example, which normally provides information of the wheels' rotational speed, is only available as an option. So the search was on for a different way of getting the desired information—naturally in a format that the standard transmission software could understand.

The problem was resolved by means of a gateway, which enabled the information between the components of the transmission control unit, shift lever, and instrument panel of the X-BOW to be exchanged in

"Everyone who drives the car says: That was really fun!"

Jürgen Gumpinger,
Vice President Sportcar KTM

the correct format. "If you combine different components, the data addressing doesn't match up," explains Dr. Müller-Kose. "Furthermore, the measurement values from sensors are in value ranges that the other participants of the system can't use."

Practical test in Italy

As a rule, in such projects the experts from Porsche Engineering make substantial use of complex development and simulation tools before the practical tests begin. In the case of the X-BOW, however, a "hands-on" approach was taken in view of time constraints, and the prototype came to the track at a very early stage. It quickly became clear that excellent work had been done: The components worked well together and performed their tasks brilliantly. But the prototype passed the real test of its mettle at the Nardò Technical Center in Apulia. "At the Porsche Engineering testing grounds in Nardò, we have a circuit based on the classic race tracks," explains Dr. Müller-Kose. Only there was it possible to fine-tune the shifting strategy of the transmission optimally for the engine and vehicle handling under race conditions. This, then, was where the final tuning and acceptance were conducted.

The transmission calibration specialists went through their paces, collected measurement data on the track and sent it all to their electrics colleagues in Germany for analysis. For their part, the electrics team was responsible for the electrical integration of the transmission control unit and the shift lever, as well as their networking with the rest of the vehicle. They analyzed, for example, whether the signal exchange functioned properly and the control unit functions worked. They then reported their results back to Nardò. Where necessary, changes were implemented and the results again tested on the track. In this manner the team inched its way forward in iterative loops over a period of several weeks, and ultimately toward the goal of optimized driveability.

Thanks to the switch from manual shifting to the double-clutch transmission, cornering maneuvers now necessitate neither the torque interruption on the rear axle nor a reach for the gearshift lever. The result is higher cornering speeds with better vehicle control. Drivers can keep their hands on the wheel in corners, which allows even less experienced drivers to drive the car with a sportier style at higher speeds without compromising on safety. In the end, all involved were satisfied. Conclusion: The marriage of the X-BOW and the double-clutch transmission was a success. Or as KTM Race Director Grumpinger puts it: "Everyone who drives the car says: That was really fun!"

Pure driving pleasure: With its striking design, the roadster (shown here in the manual version) quickly gained a following.

Precise: The DC Energy Meter (below) is a meter for direct-current charging stations with an output of up to 350 kilowatts. The LC display shows the amount of electricity drawn.

Precision measuring technology for high-power charging

Text: Monika Weiner Photos: Verena Müller

Direct-current charging stations can charge an electric car in mere minutes. As, however, no meters existed until recently that conformed to calibration laws, Porsche Engineering filled this gap.

If you like sporty driving, you dislike long refueling stops. That's why charging the Porsche Taycan for 100 kilometers of NEDC range should take no more than about four minutes. Naturally, when you buy an electric vehicle, you expect infrastructure for high-power charging to exist.

The charging stations for electric vehicles publicly available in Germany today mostly supply alternating current (AC) with only a relatively low charging output. They take several hours to fully charge a vehicle battery. Direct-current (DC) charging stations, with output rates of up to 350 kilowatts, are much faster, earning them the moniker of "high-power chargers." Charging a sports car like the Taycan for the next 100 kilometers at one of these will really take only a few minutes.

Add to the above that, up until now, no measuring technology existed that conformed to calibration laws. There was no legally approved way to meter the electricity consumed during charging. Compliant metering requires conformity assessment and approval by the PTB, Germany's national metrology institute. The PTB inspects technology systems to judge whether they comply with the various German measurement and calibration laws. Because certified DC high-power chargers did not exist, and their availability at the launch of the Taycan was uncertain, the specialists at Porsche Engineering went and developed them themselves: Their Porsche DC Energy Meter is a certified meter for DC charging systems with a capacity of up to 350 kilowatts. It establishes the grounds for building a high-power charging infrastructure in time for the Taycan's launch.

"We faced quite a challenge—we needed to design a system without actually knowing the precise requirements it needs to meet," explains lead engineer Alexander Schneider-Schaper, who is in charge of the project. As late as last fall, there was still only one thing that was definite: Every customer was entitled by law to know precisely how much energy they had acquired and when. This meant that the engineers were forced to start work on the DC Energy Meter while several questions remained as yet unanswered. When work began, the DKE, the German committee on electrical engineering and information technology—a body called into being by the German national standards institute DIN and the electrical engineering association VDE—was still drafting

A few minutes

is all it takes a DC high-power charging station to recharge an e-vehicle for the next 100 kilometers.

The DC Energy Meter at a glance

Voltage measuring range

0 to 1,000 V

Current measuring range

0 to 500 A

Temperature ranges

–40 to +85 °C
Storage temperature

–40 to +70 °C
Operating temperature

Dimensions

DC Energy Meter casing

W **162 mm**
H **82 mm**
D **55 mm**

Sensor body

W **130 mm**
H **104 mm**
D **59 mm**

Quantities measured

Voltage
Current
Power
Energy

Display

Energy consumption
Duration
Time
Date
User ID

Accuracy

0.5 %

of **voltage** measured value

0.4 %

of **current** measured value

Weight

530 g

The DC Energy Meter meets the meter standards **EN 50470-1** and **EN 50470-3** and complies with the latest measuring requirements, for example in terms of electromagnetic compatibility, temperature, and vibrations. The casing is protected against liquid ingress in accordance with protection class **IP 30**.

proposals. The proposed directives then still needed to be submitted to another investigative committee (the REA) for assessment and finally forwarded to the national calibration office.

It can be very complicated to measure the energy transmitted to an electric vehicle at a charging station. Unlike a household, where you always have the same user and simply reading the meter once a year suffices, public charging stations run through a whole cycle of users day in, day out. Each and every one of them is entitled to a precise, transparent bill. Porsche Engineering translated this set of conditions to a requirements catalog for developing the Porsche DC Energy Meter: It needed to identify the user, log the time of charging, and measure current, voltage, and time during the charging procedure. The measurements can then be used to calculate electrical work in kilowatt-hours. All of these data subsequently need to be transmitted via a backend to the provider who then issues a detailed invoice to the customer.

The next major challenge was then that charging stations themselves offer fairly little space inside. Most of their interior is taken up with connection sockets, the charging cable and its integrated cooling, and the charge control units. To accommodate the additional technology, the engineers decided to design a two-part system comprising the DC Energy Meter itself and a sensor unit measuring current and voltage. The latter is wired into the electrical circuit between consumer and charging station. Its measuring capacities range up to 500 amperes and 1,000 volts.

Connection to backend server

The sensor transmits the values it measures to the actual DC meter, which was constrained in size to the volume of a half-liter beverage can. The meter records the data and computes the transferred energy, linking it to the customer data, and packaging the whole lot in a tuple with a unique signature—a data bundle that can no longer be edited. This tuple is what the backend operator receives and uses to write the invoice. The backend operator is also the contact with whom customers can check—using transparency software like an app, for example—when, where, and how much electricity they have drawn. Naturally, this information is also shown in real time on a Porsche Engineering LC display during charging.

Project team: Alexander Schneider-Schaper, Sunny Rohilla, and Jiri Naprstek (left to right).

"Protecting the system against tampering was a key consideration when designing it," says Schneider-Schaper. To make sure that no-one opens the sensor or DC Energy Meter, the casing design is securely closed and sealed. Approval by the PTB—at present the only body authorized to assess conformity in the field of electromobility—will be granted before the end of 2019, now that the assessment criteria for approval have been decided. Assessed factors will include design and operation, environmental compatibility, and whether the charging station and software comply with measuring and calibration laws when in operation.

All hurdles to rolling out the technology have thus been cleared. "At the moment, everyone is concentrating on the expansion of the existing infrastructure, even if not all specifications or standards are final," Schneider-Schaper tells us. "This gives Germany the opportunity to act as pioneer and to establish the technology that is already certified and approved here."

PTB tested

The *Physikalisch-Technische Bundesanstalt PTB*, Germany's national metrology institute, checks whether a meter meets the requirements of Germany's calibration and metering laws (MessEG and MessEV).

Alexander Schneider-Schaper is Porsche Engineering's lead engineer for the Home Charge Manager. He is Porsche AG's voice on various calibration and metering law committees when it comes to electromobility.

Sunny Rohilla is a design engineer for energy technology at Porsche Engineering. An expert in microelectronics, he was in charge of developing the high-precision, compact meter for DC charging stations.

Jiri Naprstek is head of electronics development at Porsche Engineering Prague. He oversees technology development across a number of projects in the field of charging infrastructure, including the DC meter as a turnkey solution.

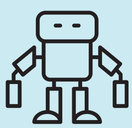
Encounter in an artificial crater: Prof. Frank Kirchner and walking robot Charlie

Man on the moon

Text: Christian Buck Photos: Cosima Hanebeck; DFKI

In Bremen, the team led by Prof. Frank Kirchner is working on robots for missions in space and underwater. Far from earth, they have to find their way and make decisions independently—similarly to autonomous vehicles in road traffic.

The moon has a branch office in Bremen. The slope of the artificial crater is nine meters wide; five-and-a-half meters of elevation must be scaled from the foot of the depression to its top. Those wishing to climb it must overcome inclines of 25 to 40 degrees. People are generally spectators here, though, for this moonscape was designed as a training ground for astronauts of steel: In the space exploration hall at the German Research Center for Artificial Intelligence (DFKI), robots practice independent exploratory missions on the satellite of Earth. The choice of terrain is no accident: Craters and their surroundings are among the most interesting places on moons and planets because their slopes contain sediment layers from different eras, as well as traces of material from the solar system. Their walls also provide information about the origins of moons and planets.



1920

Czech writer Josef Čapek coins the term *"robot."* It is derived from the word "robota," which means "work" or "forced labor."

The creator of the climbing robot is Professor Frank Kirchner, who heads the Robotics Innovation Center at DFKI on the outskirts of Bremen and works on mechanical astronauts with his team. His creatures are often biologically inspired, such as the four-legged walking robot Charlie, which looks like a monkey, or Mantis, a contraption with six extremities that looks like its namesake from the animal kingdom. At present, Coyote III, a gray-and-orange rover with star-shaped wheels and a flattish silhouette is navigating the artificial moonscape.

Intelligent and autonomous robots are indispensable for space exploration because they require no food and no oxygen. And once the mission is done, they don't need a return journey to Earth. They do, however, have to be able to hold their own, to some extent, on strange moons and planets. The artificial crater in Bremen provides an opportunity to see how well they do at it. The crater was built by a company that ordinarily builds indoor climbing walls. “The template was photographs taken by Apollo astronauts of a crater at the Moon’s south pole,” explains Kirchner, one of the world’s foremost experts for autonomous space and underwater robots.

Autonomous submarine for the moon of Jupiter

Outer space and the underwater world have more in common than one might assume at first glance. One of the most interesting places in the solar system, after all, is Jupiter’s moon Europa, under whose ice sheet a vast ocean of liquid water has been postulated—a place, in other words, in which life could have developed. So the Bremen-based robotics experts have also built an eight-meter-deep water tank in which they can test the Europa Explorer, among other things: The pipe-shaped drill named Teredo is designed to penetrate the 3 to 15-kilometer-thick ice sheet on the moon’s surface and then launch the underwater vehicle Leng to explore the ocean beneath. Because control signals from earth would take 33 to 53 minutes to arrive, the torpedo-shaped submarine would have to be able to operate autonomously.

1939

Westinghouse presents the first humanoid robot Elektro at the New York World’s Fair.

1942

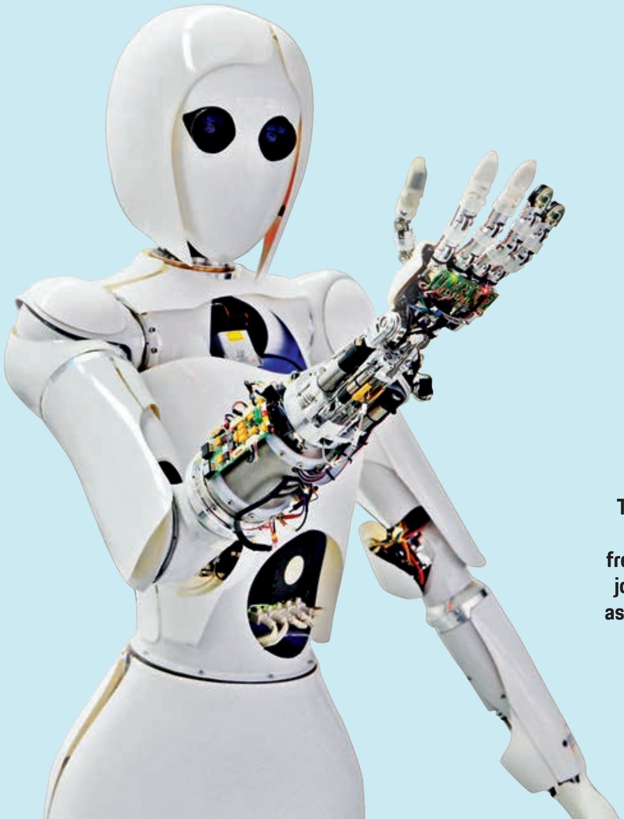
Isaac Asimov presents his “three laws of robotics.” Among other precepts, they state that a robot may not harm a human being.

“For me an autonomous vehicle is a robot I can drive.”

Prof. Frank Kirchner

It’s no wonder, then, that the research group in the “space city” of Bremen has been working intensively on topics such as sensor technology, actuator technology, and artificial intelligence. But the results they achieve do not only benefit aerospace applications—Kirchner also places great store by the transfer to other fields, for instance for robots that have to maneuver independently in dangerous environments. He is also following the development of autonomous driving avidly, from his own very particular perspective. “For me an autonomous vehicle is a robot I can drive,” says Kirchner.

And there are, indeed, many commonalities. Both autonomous vehicles and robots on distant orbs must perceive and analyze their surroundings and use that information to make intelligent decisions. Of course on the moon and Mars there is no road traffic with traffic lights, traffic signs and cars and pedestrians suddenly popping out of nowhere. Nevertheless, even Kirchner’s robots have to deal with dynamic conditions such as sandstorms and tornadoes on Mars or starkly changing light conditions on the moon.



32

The AILA robot system has 32 degrees of freedom, including seven joints per arm. It serves as a platform for research in the field of mobile manipulation.

Orientation without maps

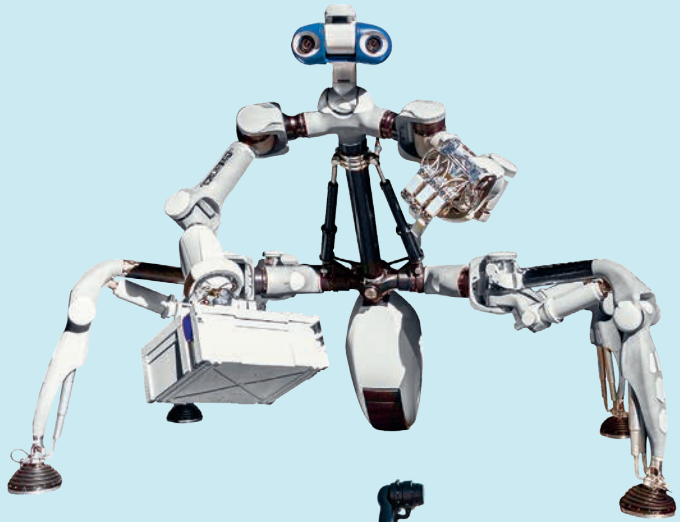
In contrast to autonomous vehicles, however, there are no maps of the terrain for their missions. “At one meter, the resolution of satellite images is still too poor,” explains Kirchner. “As such, the robots must build their own maps of their environment and locate themselves within it." To cope with that reality, the researchers developed the SLAM algorithms (Self Localization and Mapping), probability-based methods for orientation in unknown terrain. "It all started with navigation in sewage canals," recalls Kirchner. "It was a very simple environment, which allowed us to test the new approach there very effectively." From the mid-1990s, the SLAM algorithms were also used in open terrain and in buildings. The first applications for the self-localization of autonomous vehicles emerged about 15 years ago.

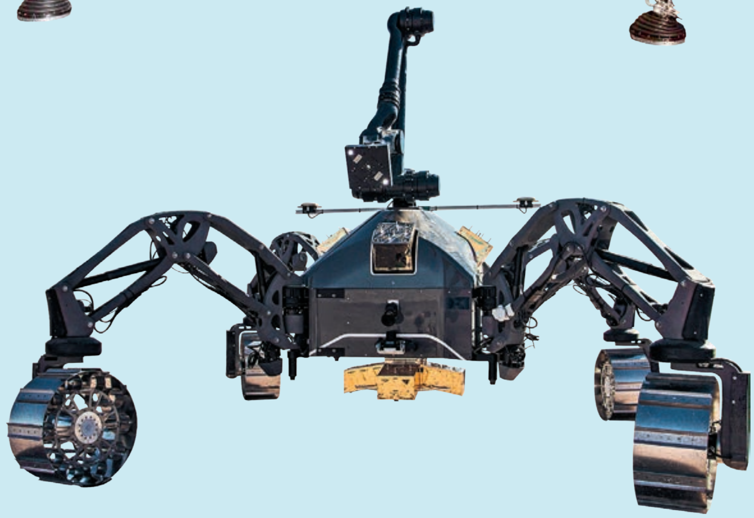
Autonomous vehicles should continue to learn while in use

The basis for the SLAM algorithms is object recognition in dynamic situations, which was also an early focus of the robotics experts. The challenge: The technology must function reliably even when the camera is moving and the ambient conditions change due to weather and changing light conditions—factors that apply as much on Mars as on Earth. "In robotics, object recognition has gained a great deal in terms of maturity and robustness," says Kirchner. "The underlying mathematics is the same as in cars today." But the transfer is by no means a one-way street. Robot developers have benefited significantly from the smartphone boom of recent years that has made inexpensive video cameras commonplace. And with the continued exponential performance gains with microprocessors—a phenomenon known as Moore's Law, with considerable impetus from the automotive industry—, their creations are becoming increasingly intelligent.

Based on his own research, he knows how complicated it is to steer a car through road traffic without human intervention. Kirchner himself has ridden in two test vehicles and was "very impressed." As a highly engaged observer of the development, he naturally has a few ideas of his own on the subject. "Autonomous vehicles should learn during their use phase," he suggests. "One buys a vehicle with basic experience and it continues to develop itself along with the other vehicles on the road." It would be a collective learning experience—just as with the collaborative robots that are now gaining a foothold in industrial manufacturing processes: They have to get along with a variety of different people and therefore share their individual experiences with each other, for instance via a cloud.

"Today, with autonomous driving we pay too much attention to the individual algorithms—but we've known them for a long time already, in some cases since the 1950s," says Kirchner. "What's more important is the organization of knowledge. They key is to network the individual components of knowledge with each other—for instance through collective learning. The vehicle must be a system that learns throughout its life." And to do so, it should also dream from time to time: Kirchner's team is working on the EU project Dreams4Cars, whose mission is to improve the safety of autonomous vehicles. Like mind's-eye pictures or dreams, the control software continually replays real traffic situations in a simulation environment, testing alternative reactions and thereby preparing itself for exceptional circumstances. It will be interesting to see what ideas from the Bremen-based robotics experts eventually make their way from the moon to Earth.





6

The robot Mantis has six extremities and was inspired by the insect of the same name (above).

Sherpa is a rover with an active suspension that can adapt to different terrain and obstacle situations (below).

Prof. Frank Kirchner is one of the world's leading experts for autonomous space and underwater robots. He is the campus spokesman for DFKI Bremen and heads the Robotics Innovation Center with its over 100 employees.

More stability: The sensors recognize the acoustic properties of different surfaces and alert the driver to wet roads.

Ear to the road

Text: Axel Novak

Wet roads make driving a challenge. Porsche has now designed a system for detecting wet carriageways and is adding the system to the new 911 Carrera as a standard feature. With the new WET driving program, drivers gain extra stability reserves whenever desired.

Motorists and other road users often underestimate just how dangerous driving on rain-covered roads really is. Roads that have become slippery from rain cause accidents far more frequently than snow or ice because drivers very often consider wet roads a minor hazard. This is why the new Porsche 911 Carrera comes as standard with an innovative system that detects wet carriageways and alerts drivers to them. Drivers can then opt to activate the WET driving program, which makes tailored adjustments to many of the vehicle's systems to improve road stability on wet surfaces. “The idea behind the WET driving program is to make driving a high-performance vehicle on wet or slippery roads easier,” says Yves Billet from Porsche AG's engineering department for chassis mechatronics. “This isn't about increasing performance but about improving stability even on difficult road surfaces.”

The system is a world first and comprises meticulously designed technology and the intricate interplay of sensors and control unit. WET mode starts off with technology that uses acoustic sensors to detect spray water whirling around in the front wheel arches. Several steps are necessary: To identify the road conditions, the electronics first need to restrict the frequency range of the raw analog sensor signal—the range needs to supply an optimum signal-to-noise ratio for reliable distinction between "road is wet" and "road is dry." After initial analog processing, the sensor signal is converted to digital. The system can now derive specific characteristic values that unmistakably indicate wet or dry conditions. Additionally, the windshield rain sensors are considered by the system. These sensors use optical technology to trigger wiper response to water droplets on the windshield. Their data are used to double-check signal plausibility. But, because roads can stay very wet even when rainfall has already stopped, the wheel arch sensors remain the primary deciding input.

Rain mic
A piezo sensor is bonded to the reverse of the circular element. When impacted by water spray, it acts like a diaphragm. The piezo sensor responds to even the slightest deformation by supplying a corresponding voltage.

Test drives and certification trials all over the world

Developing wet road detection faces its greatest challenge in the sensors. They need to be strong enough to withstand the rigors of daily use in a sports car and at the same time be sensitive enough to reliably identify road conditions at any time—regardless of road properties or climate zone. Attuning the suspension control systems also required a huge effort of coordination to obtain the characteristics for optimal driving on wet surfaces.

Because they wanted to feed the system's algorithms with as many surfaces' acoustic profiles as possible, the design engineers conducted many test drives and certification trials all over the world. The sensors encounter particular difficulties when dealing with gravel roads or loose chip-seal. "And then there are the added acoustic effects when driving at very high speeds, for example increasing rolling noise or wind noise in the wheel arch," Markus Gantikow, head of Porsche AG's suspension mechatronics department, explains. "We needed to work out the ideal sensitivity for every circumstance."

Unique approach

Porsche's wet road detection system uses a method of detection fundamentally different from that of any other system. Some of them use surround view cameras in the door mirrors, radiator grille, or vehicle rear to watch for a certain tire spray pattern. By adding signal patterns from tire monitor systems or acceleration sensors, the on-board computer can identify the road conditions. Other systems rely on optical sensors to evaluate the light reflected by the road surface.

World first: Acoustic sensors in the front wheel arches detect turbulent water spray.

While these methods also deliver good results, they usually remain prototypes or lab equipment for testing that, because of cost, weight, or design, are unsuitable for incorporation in a Porsche.

When designing WET mode, Porsche engineers benefited from previous work undertaken during the mid-1990s. Back in the day, there was a European research program called Prometheus (PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety). Its aim was to develop new assistance systems. Europe's governments wanted to improve efficiency, ecological impact, and safety in road traffic. As part of the research program, Porsche devised a concept for wet road detection but the prohibitive costs of computing and memory capacities prevented its realization. "Lots of us really loved working on it back then," Dr. Michael Unterreiner, who is an engineer with Porsche AG's advanced development team, remembers. "But actually realizing the functions wasn't possible at the time."

The new Carrera S models

CO_2 emissions (combined): 205 g/km
Consumption urban: 10.7 l/100 km
Highway: 7.9 l/100 km
Combined: 8.9 l/100 km
Efficiency class: Germany: F
Switzerland: G

Stability reserves in difficult situations

Today, cutting-edge microchips and software enable WET to act as a fully fledged driving program. As such it is capable of adjusting a variety of control systems to affect vehicle behavior. Once it detects a wet road, it prepares the response behavior of Porsche Stability Management (PSM) and Porsche Traction Management (PTM). At the same time, the driver is informed that the road is wet. He or she can then opt to manually switch to the WET driving program, which is a standard feature. WET mode neither activates nor deactivates automatically.

If the driver does activate the function using the button above the center console—or the mode switch if they have the optional Sport Chrono package—PSM, PTM, aerodynamics, the optional Porsche Torque Vectoring Plus (PTV Plus), and the drivetrain's response are adjusted. In the case of the drivetrain, this occurs by flattening out the accelerator pedal's characteristic curve while the transmission controller shifts to higher gears. At speeds of 90 km/h and above, the vehicle also opens its cooling air inlets and extends the rear wing to its performance position to optimize the aerodynamic balance between front and rear axle. When in WET mode, PSM Sport, PSM Off, and Individual driving modes are no longer available, the suspension cannot be set to Sports mode, and the Sport Response button is disabled.

Currently, WET mode is a standard feature in the Porsche 911 Carrera. It adds further to drivers' safety reserves on wet roads and also when driving on slippery snow. "When you're driving on a wet road and in tricky traffic, you need fast and reliable responses," Yves Billet says. "By supplying the right technology, we can assist you in that."

Prepared

The system adjusts the response behavior of PSM and PTM as soon as it detects a wet carriageway.

PSM

Porsche Stability Management provides excellent lane holding and cornering for a high level of active safety when taking driving to the limits.

PTM

Porsche Traction Management ensures rapid and measured force distribution between the front and rear axle.

Get there safely: The new WET driving program makes driving on wet or slippery roads easier.

The light-weight gene

Text: Jost Burger

Weight optimization has always been a top priority for Porsche. The latest Porsche 911 sports the next major innovation in its bodywork: side panels made entirely of aluminum. But why stop there? Other components have also become lighter. Construction of the new sports car also employs innovative joining methods and pursues sustainable production.

Modern car bodies are made of a number of materials. In the past, automotive bodies-in-white were manufactured primarily from cold-worked sheet steel. While still used today, it is widely found alongside aluminum, which weighs less. This mix of materials, also referred to as *multi material design*, first and foremost pursues a reduction in weight: Lightweight design is the catchphrase. It saves fuel and enables a faster start. But there's more to it yet. Together with other technical design features such as rear-axle steering and improved passenger cell stiffness, lightweight construction also improves stability and safety.

Let's take a quick look back at how far we've come: The 2004 model of the 911, the type 997, still had a body made entirely of steel. Its successor model in 2011, the type 991, had an underbody and roof made of aluminum. The new type 992 sticks with the aluminum underbody but the engineers also cut the share of steel down to less than half—it now barely scratches 30 percent. At the same time, the amount of aluminum increased once more, taking lightweight construction another step further.

Not even 30%

is the share of steel in the new 911. It was more than twice as much in its predecessor.

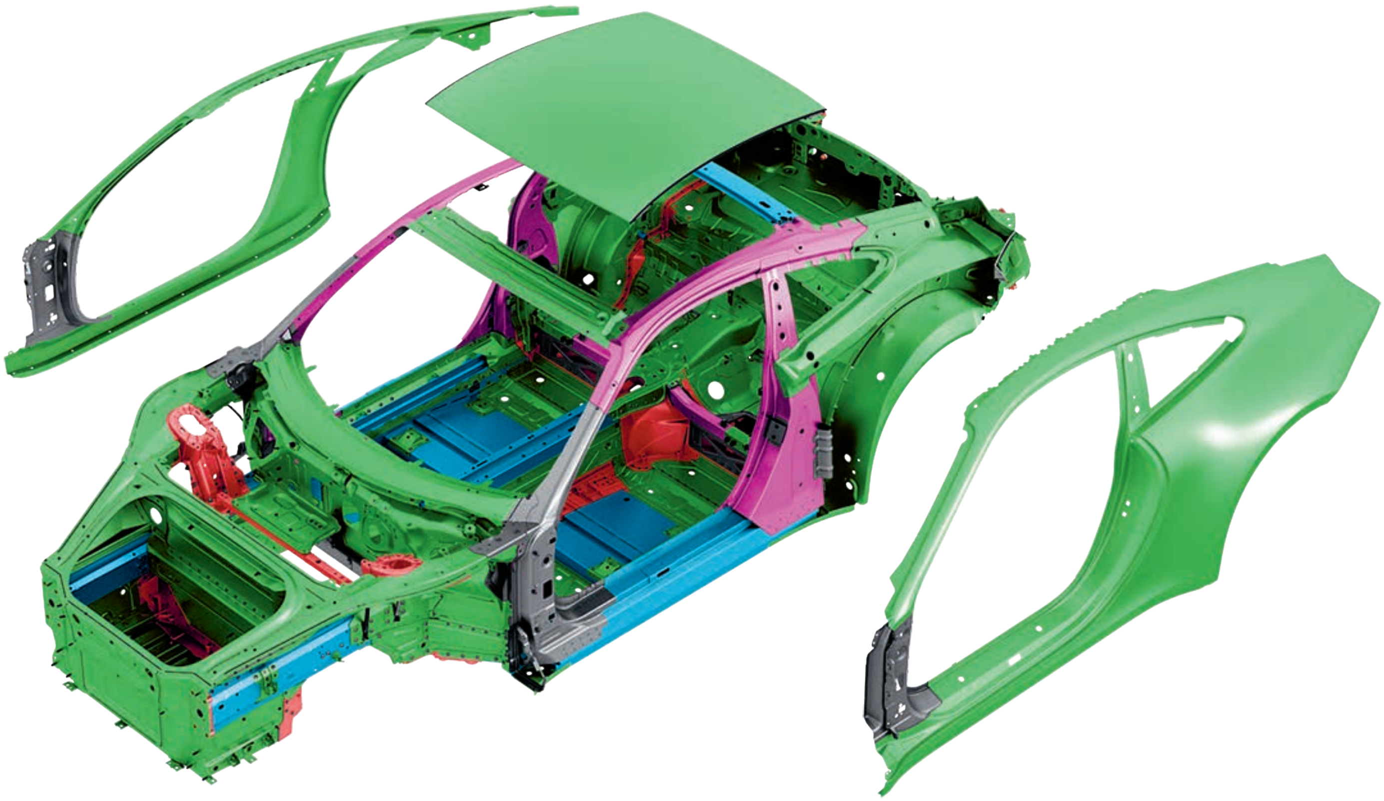
Power-to-weight ratio: the lower the better

It should be noted, however, that lightweight by no means needs to equate to lighter and ever lighter. The essential aspect is the ratio between mass and engine power, referred to as the *power-to-weight ratio*. Expressed in kg/kW, it is calculated by dividing mass by maximum drive output. The lower the value, the better. Another look at the 911's history shows us that the sports car always pursued this trend. It's a history of constantly dropping power-to-weight ratios.

Lightweight construction at its most beautiful: The new 911 is made to a large part of aluminum to save weight.

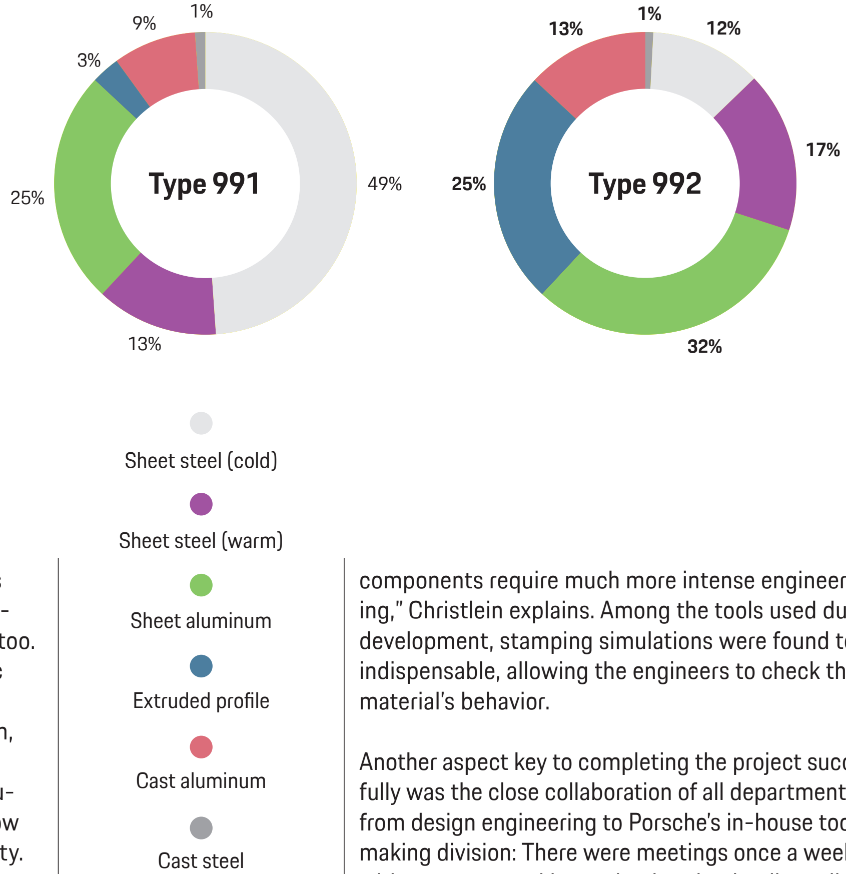
The new Carrera S models

CO_2 emissions (combined): 205 g/km
Consumption urban: 10.7 l/100 km
Highway: 7.9 l/100 km
Combined: 8.9 l/100 km
Efficiency class: Germany: F
Switzerland: G



Material concept

More aluminum, less steel: the quickest way to describe the material composition in the new 911 (type 992). The side panels, for example, are for the first time made entirely of aluminum, cutting their weight by twelve kilograms.



The lower power-to-weight ratio in the new 911 is not solely due to its more powerful engine. Uncompromising lightweight design played a major part, too. "Lightweight construction lies in Porsche's genetic heritage, we always had weight optimization right there at the top of our agenda," says Jens Christlein, head of body structure engineering at Porsche AG. Making the new 911's side panels entirely from aluminum was a logical step, then. The side panels now weigh twelve kilograms less, with no loss of stability. Designing them was quite the challenge for everyone involved. Compared with steel, aluminum offers less favorable material properties. "It's far more prone to tearing through tensile deformation. This means the components require much more intense engineering," Christlein explains. Among the tools used during development, stamping simulations were found to be indispensable, allowing the engineers to check the material's behavior.

Another aspect key to completing the project successfully was the close collaboration of all departments from design engineering to Porsche's in-house toolmaking division: There were meetings once a week, with everyone working on honing the details until all design and quality requirements were met. In some cases, the specialists needed to find their way to the ideal, millimeter by cautious millimeter. "The art lies in taking the vastly emotive look of the new Porsche 911 and adding lightweight design to form a unit," says Christlein. It took all of the engineers' decades of experience—and true grit: From start to production maturity, the process took more than two years.

Beside the aluminum side panels, a range of additional innovative lightweight design techniques and methods are used for the new 911. Increased use of high-pressure die-cast parts, for example on the front spring strut mounts and rear tunnel housings, offers greater freedom in designing the body-in-white, because you can vary the parts' geometry more easily. They also make it possible to combine multiple functions in a single component. Examples include integrated bolting lugs or reinforcement ribbing, which in classic sheet metal designs require multiple components—which both make production more difficult and add weight. The benefits gained from die-cast parts in the new 911 increase even further by using lightweight aluminum to make them.

The new 911 also uses a greater share of aluminum for its extruded profiles, for example in the front and rear side members. According to Christlein, "Geometry and boundary conditions permitting, extruded aluminum profiles are an excellent way to produce highly complex profiles at low tooling costs." To meet the different requirements—load resistance being just one—the material is used at varying thickness.

Sustainable production: combining heat treatment and painting

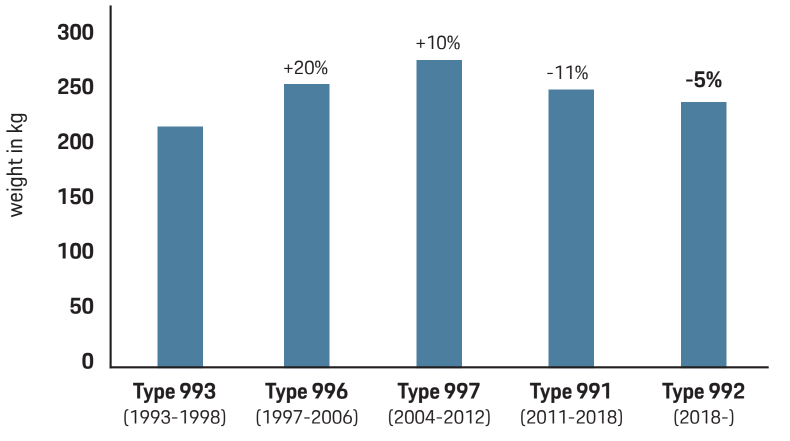
Another innovation succeeds in making production of the 911 more sustainable. Heat treatment for the cast parts is now combined with the painting process. After casting, cast parts need to undergo heat treatment to acquire the desired material properties. "When they're fresh from the mold, they don't have the ductility we need, for example, which determines their deformation in a crash," Christlein explains. This makes heat treatment the actual trick in producing cast parts. It also takes lots of time and energy. In manufacturing the new 911, Porsche puts the heat energy necessary for painting to double use by simultaneously using it to give the cast parts the required strength and ductility.

The growing number of different materials used in body-in-white production also increases the number of joining techniques. Hot-formed steel and aluminum provide a good example: Classic spot welding won't work here, which is why friction welding is used instead. Friction welding works by pressing the rivet that will hold two sheets together onto the sheets against a bearing and then spinning it. The heat produced by the friction melts the rivet through the two sheets. Flow-drill screws follow a similar principle: They are driven into the material at high speed, producing heat that makes the material moldable. This way, the screw cuts a thread in which it can be tightened to join two materials.

The latest 911 body-in-white marks the model range's best power-to-weight ratio so far. But the engineers refuse to rest there. They're already considering new lightweight designs, including using materials like magnesium or carbon. In the end, however, adopting them will be a question of cost. But Christlein is adamant that lightweight construction can still be taken a good deal further: "We discuss the material mix in every new project, and arrive at a new conclusion every time, too."

Reversing the weight spiral

In the past, 911 bodies kept on gaining weight. With type 991, the engineers managed to turn it around. Even though type 991 was already a lot lighter, uncompromising lightweight design in type 992 reduced weight further by an impressive five percent.



"We always had weight optimization right there at the top of our agenda."

Jens Christlein, Porsche AG head of body structure engineering

Deeper knowledge

Vehicle electronics

The VDI congress Electronics in Vehicles (ELIV) provides vehicle manufacturers and suppliers an opportunity to discuss the topic of vehicle electronics. Established in the mid-80s, the event today addresses the latest trends and technologies in highly automated driving, smart vehicles, and e-mobility. Besides lectures, there's a specialist exhibition presenting innovations. Porsche Engineering will also be present on October 16 and 17.

ELIV 2019
Oct 16 & 17, 2019, Bonn

The big picture

Slush: techie summit

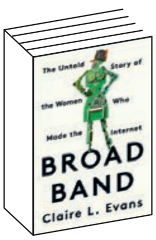
At the Slush conference, startups meet industry giants to discuss the latest trends in software development or digital business models. Want to know what's hot in IT right now? Better be in Helsinki.

Slush 2019
Nov 21 & 22, 2019, Helsinki

Standard reference work

The handbook provides an overview of current driving assistance systems along with the sensors and data processing they require. It is today considered a standard reference.

Handbuch Fahrerassistenzsysteme
[*Driving Assistance Systems Handbook*, German only]
Hermann Winner et al. (editor)
Springer Vieweg 2015



The women who made the internet

It wasn't only men who brought us the IT revolution and the internet. Empowered women such as Grace Hopper played roles just as essential. This book tells their story.

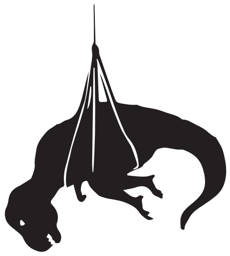
Broad Band
Claire Evans
Portfolio/Penguin 2018

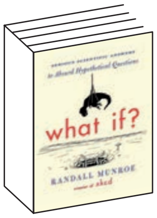
Soft skills for softwarers

Pun intended! This book for software developers is not about programming but looks at essential soft skills for getting along with customers or co-workers. Tongue-in-cheek and all.

Soft Skills
John Sonmez
Manning 2015

For the child in all of us





What if?

For example, what if Earth and everything on it were to suddenly stop moving while the atmosphere retained its speed? This book offers many scientific answers to absurd questions like this. Thoroughly smart and very amusing.

What if?
Randall Munroe
John Murray

Coding for kids

Making coding a game: Tynker is aimed primarily at children—but that shouldn't stop adults from using it, too. Tynker is the leading platform in the field of kids' coding and is used to make programming apps and games a game in itself. Learning programming logic and code language comes as a side effect. Ideally, Tynker will be used by children aged seven or older. But adults might well learn a thing or two as well.

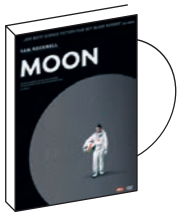
https://www.tynker.com

Find the Porsche!

Engineers at work, sports cars in the wind tunnel, the 24 Hours of Le Mans, or Porsche's cutting-edge production facility in Leipzig: This picture book is sure to kindle your offspring's enthusiasm for the Swabian cult brand and the people who bring it to life. There's so much to see!

Porsche Wimmelbuch
Stefan Lohr
Wimmelbuchverlag 2018

Intelligent entertainment



The dark side of the moon

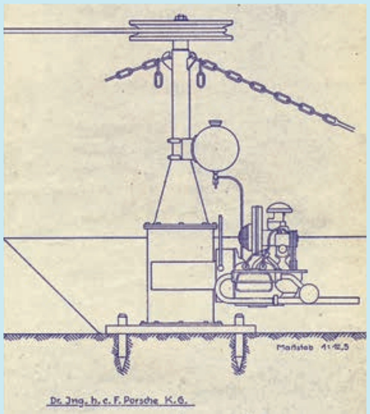
Astronaut Sam Bell (played by Sam Rockwell) is mining helium 3 on the dark side of the moon to supply Earth's energy needs. Nothing out of the ordinary—until he bumps into a clone of himself. A true classic.

Moon
Duncan Jones (director); DVD (Koch Media)

Save Mark Watney

Astronaut Mark Watney finds himself marooned on Mars. He is caught in a sandstorm and wakes from unconsciousness to find himself all alone. Now he needs to use all his scientific skills to keep himself alive—hopefully long enough for the rescue mission to arrive from Earth.

The Martian
Andy Weir
Crown



1945/46

1959

1985

1983

The Porsche airplane engine PFM 3200 takes to the air for the first time. Two years later, Porsche AG's CEO Peter W. Schutz (left) and Head of R&D Helmuth Bott (right) launch it officially.

Skiers in 1945/46 enjoy a Porsche ski lift (top left illustration shows a technical drawing, scale 1:12.5).

In 1959, boat owners were zipping across the water with a Porsche 729 boat engine for the first time (bottom left illustration above).

Design derivatives have a long tradition at Porsche. One—pretty spectacular—example of such is the PFM 3200 airplane engine. In the Allgäu region on August 9, 1983, it took off on its virgin flight in a Cessna Skylane. The 212-horsepower (156-kilowatt) six-cylinder engine was a derivative of the Porsche 911's engine, adapted to airflight requirements by the engineers at the Weissach Development Center. And the engineers wasted no time doing so: Germany's aviation authority, the *Luftfahrtbundesamt*, granted its approval in September 1984, only two years after the project kicked off. The next highlight was no slower in arriving: Less than a year later, in July 1985, a PFM 3200 propelled a Mooney piloted by Michael Schultz and Hans Kampik on its flight around the world, a journey of around 100,000 kilometers. Their voyage included visits to Greenland, Canada, Alaska, Cuba, Chile, the United Arab Emirates, Australia, and Japan.

In developing the PFM 3200, the engineers at Porsche went to great lengths to make flying more economical, environmentally friendly, and safer. Key advantages of the PFM 3200 over conventional airplane engines were its use of regular gasoline, lower noise emissions, and engine control using only a single power lever rather than three. In 1984, the magazine *Flug Revue* wrote of the engine that it would “begin a revolution.” And the engine wasn't even the first Porsche innovation to reach for the sky: All the way back in November 1909, a silver-gray airship took off from near Vienna. It was powered by a 100-horsepower six-cylinder engine—designed by Ferdinand Porsche.

Though they may not have flown as high, there have been many other applications beyond the automobile that have benefited from Porsche expertise over the years. In 1945/46, skiers, for example, were able to enjoy a Porsche-designed lift: Developed for the company Sauter, it consisted of two masts with rope winches and a 25-millimeter thick hemp rope strung between them. One of the winches was powered by a 14-horsepower (10-kilowatt) Volkswagen motor using an extendable coupling and worm gear.

In 1959, the company presented the 52-horsepower (38-kilowatt) 729 boat engine, a derivative of the 1.6-liter four-cylinder engine in the Porsche 356. Porsche's advertising slogan for the prime mover back then: “On every race track and road in the world, Porsche cars zip past, fast and reliable. A Porsche boat engine is fast and reliable, too.” Ferry Porsche himself had a boat driven by the 729 engine.

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DERIVATIVE AND SYSTEM DEVELOPMENT

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