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BODY

Composite Use of CFRP, Steel and Aluminum

LIGHTER DOOR MODULES
Made of Organic Sheet for Stricter Crash Requirements

GREATER RANGES
of High-performance Vehicles Due to Better Charging Power

MORE SAFETY
in Autonomous Driving with an Evaluation by Maximum Entropy

/// INTERVIEW Seiichi Hirano [UACJ] **/// GUEST COMMENTARY** Marco Philippi [Audi]

The Emperor's New Hybrid

Dear Reader,

After carrying out careful investigations, German government advisors and ministers repeatedly assured us that the product was of very high quality and that the project was making very good progress. "It's excellent," everyone said. And so the cabinet approved even more funding on a large scale for the promising program. Finally, the electrification concept was presented personally by the head of government to the speechless and astonished people of the country. "But he has nothing on!" a little child cried out at last. In Hans-Christian Andersen's folktale "The Emperor's New Clothes," it is initially just one single voice which highlights the problem that is so obvious to everyone.

How does this bring us to plug-in hybrids? Well, the voices that have been expressing more than just moderate criticism of the ongoing state subsidies for this technology have recently become louder again. A persuasive example is a study that was commissioned by the emperor, sorry the federal government, from the Institute for Energy and Environmental Research (ifeu), the Oeko Institute and the NGO Transport & Environment. The results, which were published in mid-January under the title "Too often in combustion engine mode: plug-in hybrids put transport sector's climate targets at risk," show once again that the hoped-for effects of hybridization are likely to be barely noticeable or even completely non-existent.

As the experts explained, one of the reasons for this is that the current boom in electrified cars in Germany involves mainly large plug-in hybrids, more than three quarters of which are registered as company cars. As they primarily use their combustion engines on their daily journeys, they emit much more CO_2 than the calculations of German greenhouse gas emissions in 2030 were previously based on. The calculations showed that, in the light of market forecasts, an increase of up to 4.3 million t of CO_2 emissions can be expected in the transport sector from plug-in hybrids in 2030.

Why is the hybrid currently so popular with company car drivers in particular? The answer is breathtakingly simple. In order to boost sales of the wannabe EVs, the tax on hybrids in private use is only half the amount of the tax on cars with diesel and gasoline engines. As the fuel costs are almost always paid in full by employers in Germany, it makes absolutely no difference to the employees whether or not their cars are running in electric mode. The stories of hybrid cars being handed back at the end of their lease with the charging cable still in its packaging will therefore come as no surprise.

Frank Jung
Editor

BODY

Composite Use of CFRP, Steel and Aluminum

© Porsche

Hybrid designs are being used more and more frequently in body development to compensate for an increase in car weight. This is because additional comfort and assistance systems as well as lithium-ion batteries are making cars heavier and heavier. To counteract this, not only steels and aluminum but also plastics such as CFRP are being used. For greater lightweighting effects, multi-material and modern sensitive design methods are required.

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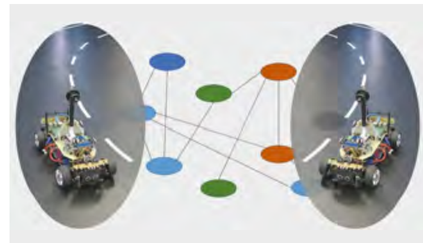
36 Door modules with innovative carrier material can help meet crash test requirements. Brose uses carrier plates made of continuous glass-fiber-reinforced thermoplastics.

© Magna

56 To achieve greater ranges for battery electric vehicles, Magna is investigating how to shorten the charging process by increasing the charging power to 400 kW, for example.



© UAS Esslingen

62 The Fernuniversität in Hagen and the UAS Esslingen are developing simulation concepts based on maximum entropy to better evaluate safety in autonomous driving.

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Messring | **Company Headquarters Started Operation**

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New building complex in Oberpfaffenhofen (Germany) offers 7200 m² of office and hall space

Messring has moved into its new corporate headquarters on the Air-Tech Campus in Oberpfaffenhofen (Germany). The site has 7200 m² of office and hall space and provides the 150 employees with modern workplaces 5 km from their former location. The highlight of the complex is the large hall including the company's crash test facility and two sled test facilities. They are used not only for pre-assembly of customer orders but also for internal and external tests from research and development projects. In addition, there is sufficient space in the crash hall and on the open-air site for tests in the field of active safety, which are becoming increasingly important for Messring and involve the validation of (partially) automated driving functions.

CTS | Kistler | **Cooperation in the Development of Dummies**

The Kistler Group and CTS have agreed to collaborate on the development of realistic substitutes for the human body. The combination of a biofidelic crash test dummy and precise measurement technology offers greater possibilities for crash tests, product development, operational training or the modeling and reconstruction of dynamic processes. The first jointly developed model, called Primus, has bones, ligaments and joints that are modeled on those of humans. Equipped with Kistler's technology, the combined evaluation of precise measurements and real damage provides very accurate test results, for example for accident reconstructions, expert reports and insurance cases, or for obtaining certifications.

© Kistler

Mirko Dobberstein (Managing Director CTS), Peter Schimmelpfennig (Managing Partner CTS), Lars Hannawald (HTW Dresden) and Jens Wolking (Business Driver Vehicle Safety, Kistler) (f. l. t. r.) have jointly advanced the biofidelity crash test dummy Primus

Faist | **Acquisition by Paguasca**

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Faist headquarters in Krumbach (Germany)

Paguasca Holding in Zug (Switzerland) has acquired the entire Faist Anlagenbau Group, which is headquartered in Krumbach (Germany), and its subsidiaries. Faist is an expert in industrial sound insulation and, with its Acoustic Systems business unit, supplies acoustic measurement and test rooms as well as aeroacoustic wind tunnels for customers in the automotive sector, among others. The owner family led by Michael Faist has decided to sell the company, which has been in existence for almost 120 years, and Faist himself is retiring for personal reasons with the goal of enabling the Anlagenbau Group to continue to grow and to secure the sites and jobs. "We are pleased to have found a buyer in Paguasca, who aims to further develop the Faist Anlagenbau Group," said Faist.

HZDR | Rovak | **Start-up for Electrode Production Founded**

The Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and the company Rovak have jointly launched the start-up NorcSi for the production of silicon electrodes for future battery generations. The silicon anode from the new company based in Halle/Saale (Germany) is created in a physical process of coating and thermal treatment using flash lamps and laser annealing. Plans call for industrial use of the anode and integration into existing battery production chains within a few years. The goal is to install the new anodes in high-performance batteries as standard in two years. The patented technology is said to increase the energy density of today's lithium-ion batteries by more than 40 %, replace conventional graphite and thus significantly extending the range of e-vehicles.

© NorcSi

Commissioning of the flash lamp system in February 2020: Dr. Marcel Neubert, Georg Ochlich, Udo Reichmann, Dr. Charaf Cherkouk (f. l. t. r.)

ATZ/MTZ Group | **Gutzmer Joins Liebl as Editor in Charge**

© Schaeffler

Peter Gutzmer

On January 1, 2021, Prof. Dr.-Ing. Peter Gutzmer became Co-editor in charge of the magazines ATZ, MTZ, ATZelectronics and ATZheavyduty. He will also provide support for the ATZlive conferences. Gutzmer, who is well known in the automotive industry because of his roles as associate lecturer and honorary professor at Karlsruhe Institute of Technology (KIT) and as former board member of Schaeffler AG over many years and also as a result of his many other activities, will be working alongside Dr. Johannes Liebl, who has been Editor in Charge for the last ten years. "ATZ and MTZ have been prominent information and communication platforms for technical and engineering issues in the automotive and powertrain industries over a period of more than 120 years. The opportunity, after more than 40 years of professional experience in this field, to help to shape these media as part of a competent team during a time of major global change and against the background of the shift toward connected and sustainable mobility is very attractive," says Gutzmer describing his new challenge. Liebl is enthusiastic about the appointment of his expert colleague. "I am pleased that Peter Gutzmer, who I have known for a long time, will be joining the Springer Nature team and that we will be able to share our workload in these uncertain times. This will give me the freedom to spend more time with my family in the future." Both editors in charge will work closely with the Editor in Chief of the ATZ/MTZ Group, Dr. Alexander Heintzel.

NEVC | Easelink | **Partnership for Charging System in China**

© Easelink

Easelink Managing Director Hermann Stockinger (left) and the Managing Director of NEVC Yuan Chengyin

The National New Energy Vehicle Technology Innovation Center (NEVC) in China and Easelink in Austria have signed a memorandum of understanding to make the Matrix Charging automated conductive charging system the leading charging technology in China. The solution from the Graz-based company includes the integration of charging technology into the parking space surface. NEVC is supported by companies such as the car manufacturers Baic, BYD and Geely, as well as Valeo and the battery developer Catl, among others. Thanks to close cooperation with the Chinese government and industry, NEVC is expected to play a major role in determining how e-vehicles will be charged in the future.

IMPULSES

Dr. Johannes Liebl
Editor in Charge
ATZ | MTZ | ATZelectronics | ATZheavyduty

Systems Thinking

Germany can only secure its strong position as an export nation in global competition if progress is made on the key social issues of mobility, climate protection, energy, security and health. The climate protection targets set in Paris are thus coming into even sharper focus. National and international markets require an open approach to technology in order to meet mobility and transportation needs.

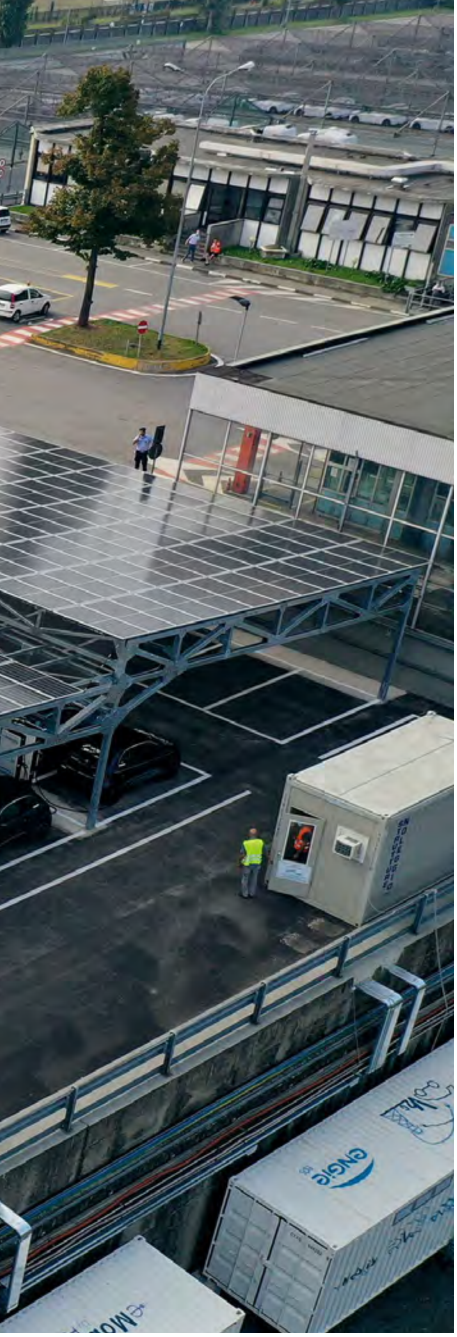
Electrified drives and efficient car and commercial vehicle engines in a system network with new fuels are key technologies for CO_2-neutral individual mobility with low emissions. Demanding test cycles under real driving conditions are tightening the legal requirements and call for new and holistic approaches in all disciplines.

The electrification of powertrain and chassis in a vehicle with several electrical voltage layers and different degrees of networking leads to increasing complexity. In order to master this complexity, current expert knowledge is no longer sufficient. An understanding of functional interactions in the overall vehicle is becoming a criterion for success.

One key to building this understanding is system simulation. It helps to understand the highly interconnected interactions in a virtual vehicle and thus promotes systems thinking. In addition, the ATZ/MTZ Group supports companies with its magazines and events in building up the necessary knowledge. Systems thinking thus becomes a driver for innovations and further expands our competitive advantages in global markets.

The Car as an Energy Storage System

Mobility in Germany is undergoing a period of disruptive change with the move toward electrification, hydrogen and synthetic carbon-neutral fuels. Most people are familiar with these developments, but fewer are aware that electric cars can help to stabilize the power grid by acting as temporary energy storage facilities. Over the past ten years, more than 50 pilot projects of different sizes involving bidirectional charging have been successfully completed in locations all over the world.



© FCA

Until now, Germany has focused on one-directional charging of its electric cars and on setting up the necessary charging infrastructure. Not all electric cars come as standard with an inverter, as the example of the new Citroën ë-C4 demonstrates. It appears that the subject of Vehicle-to-Grid (V2G) is not being taken very seriously in Europe.

LEGISLATION IS NEEDED

Germany's mobility and energy policy is closely aligned with that of the EU and has highly ambitious goals. It represents the most radical restructuring of the automotive industry since the invention of the motor car by Gottlieb Daimler and Carl Benz 134 years ago. The Plug-in Hybrid Vehicle (PHEV) is often seen as a transition technology on the road to pure electric mobility. Whether or not that is the case will soon become clear, but PHEVs, with their 6- to 15-kWh batteries, already offer an additional benefit. This view is not shared by all experts, disregarding for the moment the subject of bidirectional charging and charging in general. The result has been disagreements about the right route to take and about whether synthetic fuels and hydrogen can and should play a prominent role in personal transport.

The batteries of electric cars have huge potential for use as buffers for the power grid. The possibility of bidirectional charging is there, but none of the car manufacturers seem prepared to make the option widely available in their vehicles. In technical terms, it is not a problem. The obstacles are legislative and regulatory in nature. While international standards form the basis for the work of the automotive industry, the energy sector is generally governed by national regulations. A large number of market players, with every car owner becoming a power station operator, would make energy management very complex, particularly in Germany. In the Netherlands cars can already make smart, bidirectional use of charging stations, but in Germany this is not yet the case.

WHAT IS THE POTENTIAL OF V2G?

The V2G process is regarded as promising but not absolutely essential. However, it could transform the energy industry in the future. No one has yet explained how a power grid that can no longer rely on nuclear or coal-fired power stations will be able to maintain its stability when millions of additional electricity consumers appear on roads all over the world. V2G can make a very important contribution in this respect.

Italy is the European pioneer in the field of V2G and by the end of 2021 aims to set up the world's largest project on the Fiat Mirafiori site, which will consist of 350 charging stations for up to 700 electrified cars. The goal of this unique pilot project is to stabilize the supply of electricity in cities by using electric cars as buffers in the form of storage facilities outside the power grid. The technology will allow the vehicles to share energy with the grid and will transform them into a potentially valuable resource for the national grid in Turin, which is operated by Terna.

This technology is not new, but it has never been used on a large scale. The FCA project aims to introduce a new approach to energy worldwide and to turn Italy into the market leader for intelligent energy supply systems. This approach is based on the simple fact that cars are stationary for up to 95 % of the time and offer huge potential for use as decentralized energy storage facilities while they are not being driven.

The European Commissioner for Energy, Kadri Simson, has given the project her blessing and is confident that V2G will become widespread in Europe. However, she cannot put in place regulations that would require other countries to launch projects on a similar scale and would make V2G a part of everyday life in Europe in the near future. She can only issue recommendations.

In contrast to the situation in Italy, Germany's red tape has so far prevented the widespread use of the technology. In Germany V2G will always be possible in small niche markets, "but an attractive market for customers and carmakers is being blocked by the regulations," says Markus Rosenthal from the German Energy Storage Association (BVES).

CARS AS FREQUENCY REGULATORS

In response to the question of what benefits electrified vehicles could offer apart from their function as mobility service providers, Michael Danzer, holder of the Chair of Electrical Energy Systems at the University of Bayreuth, has identified three key scenarios. One of these is the balancing market, which regulates the difference between what is produced and consumed. Here it is important to ensure that the 50 Hz frequency of the grid is always maintained. If too much electricity is fed in, the frequency increases, while if the supply is too low, the frequency falls. The balancing market is responsible for making permanent adjustments.

Even with artificial intelligence, the planning process will never be perfect

© FCA

Bidirectional charging columns on the premises of the FCA plant in Mirafiori (Italy)

and there will always be a certain difference. Until now the large coal-fired and nuclear power stations have been able to support the grid. However, with the move to wind and solar energy, the difference will not necessarily increase, but storage facilities are urgently needed to enable the balancing market to function effectively in the future.

The second scenario is aimed at industrial firms with electric fleets. For these "it would be possible to bring the electric vehicles together in a regional group in a certain district of a city or in a business park. Not all the vehicles will be there, but some will always be parked and they can be used for energy management purposes," says Danzer.

THE ELECTRIC CAR AS THE CRITICAL POINT

The problem with bidirectional charging is not the charging post but the car. Modern AC charging stations can charge in both directions, but the car must support the charging process. "If all cars had bidirectional charging activated and we could communicate with them, we could do as much charging in both directions as we wanted," says Dieter Ebinger from Enisyst, a company in the Stuttgart area that specializes in connecting energy systems in the smart grid with its intelligent measurement and control systems. The potential for doing this in Italy is very high. "If only 5 % of all the cars on Europe's roads were electrified in 2030, they could revolutionize the power grid and play a decisive role in balancing the European energy markets," says Carlalberto Guglielminotti, CEO of Engie Eps. This situation still seems to be a long way off, but one thing is clear: charging stations are springing up everywhere like mushrooms. There are currently 35,000 official charging points in Germany and the number of public fast chargers had doubled to 3600 by the end of 2020. Despite this, the German government is continuing to increase its support for the charging network and making more and more funding available. According to Ebinger, the large number of charging points currently being installed in public spaces does not represent a viable model for the future. Because of his background in electrical engineering, his view is that there should be something similar to fast charging filling stations at assembly points where cars could be charged very quickly. "Most of the charging processes will take place at work or at home."

ITALY PLAYS A PIONEERING ROLE IN THE INTERNET OF ENERGY

In the meantime, in Italy data is being collected to identify the best form of interaction between energy companies and vehicles, because the bidirectional technology can only function efficiently if the car and the charging infrastructure speak the same language. A communication protocol that has been standardized with the use of AI should be in place by the end of 2021.

"The Italians are pioneers in the world of smart meters," says Danzer, who firmly believes in the importance of electric cars for buffering power. "The energy system of the future will always be linked with a communication system, the Internet of Energy. But in Germany this is a long way off."

Enisyst has identified one key factor. "In rural areas, everyone will install their own charging post, but in cities this will definitely not be possible," explain Ebinger and his colleague Dr. Dirk Pietruschka. "I believe that V2G will have a big role to play in the field of self-generated energy, which will allow everyone to optimize the system to meet their own requirements," says Ebinger. The two experts regard self-generated energy as a huge market, where V2G will become increasingly important. The scenario involves producing electricity during the day with your own photovoltaic system and storing excess capacity in your car battery. In the evening you will be able to use the stored energy to meet your own needs.

A sample calculation illustrates the huge storage capacity available in largely immobile electrified cars. After 2035, when no more new cars with combustion engines can be registered, the market penetration of electric cars could reach 50 %. If you take an average battery capacity of 50 kWh and work on the assumption that in 2035 around 40 million cars will be registered in Germany – according to the German Association of the Automotive Industry (VDA) the current figure is 70 million – this gives a storage capacity of one billion kWh (or one terawatt hour). Even if 20 million of these vehicles are not available for storage purposes because they are being driven, you only need to deduct a maximum of 10 % from this figure. This leaves 900 million kWh available, which will provide significant support for the smart grid.

AVOID OVERWHELMING DRIVERS WITH TOO MANY CHANGES

Calculations of this kind are affected by three major limitations. The first of these is that the charging infrastructure is not yet designed for this type of use. In addition, the cars do not have the necessary software for bidirectional charging. The third problem is the subject of the warranty for the service life of the car batteries. For the batteries to provide the power grid with the necessary flexibility, they will need to be charged and discharged more frequently and this will reduce their service life.

In addition to the need to find a legal solution to the warranty issue, Danzer has identified another reason why carmakers are currently ignoring the question of bidirectional charging. “Everyone is still discovering how mobility with battery electric cars will work. The manufacturers do not want to bring another uncertainty into the equation in the form of a bidirectional charging post, which would set a process going that is not under their control.”

BATTERY SERVICE LIFE AND BIDIRECTIONAL CHARGING

Most people will be familiar with the concept from their smartphone. The storage capacity of the battery reduces after a few years because of constant use and charging processes that are not always ideal. However, there is not yet enough information available about the use of V2G with cars over a period of several years. The normal eight-year or 160,000-km warranty for the battery of a BEV or PHEV only covers one-directional charging.

The subject of the warranty is an important one. Who is using the batteries? Who will take responsibility if they are overloaded and if they suddenly start to malfunction, for example? “There is a lot of uncertainty in this area and the manufacturers want to build up confidence among consumers and drivers in order to persuade them to move to electric vehicles,” says Danzer. To sum up, the warranty problem is currently the biggest obstacle in the path of a publicly available V2G system.

The concern remains that the lifetime of the batteries in electric cars could suffer as a result of more frequent charging and discharging and the manufacturers are taking this seriously. “We need more experience of this and some flagship projects with positive results in order to permanently overcome these reservations,” says Pietruschka.

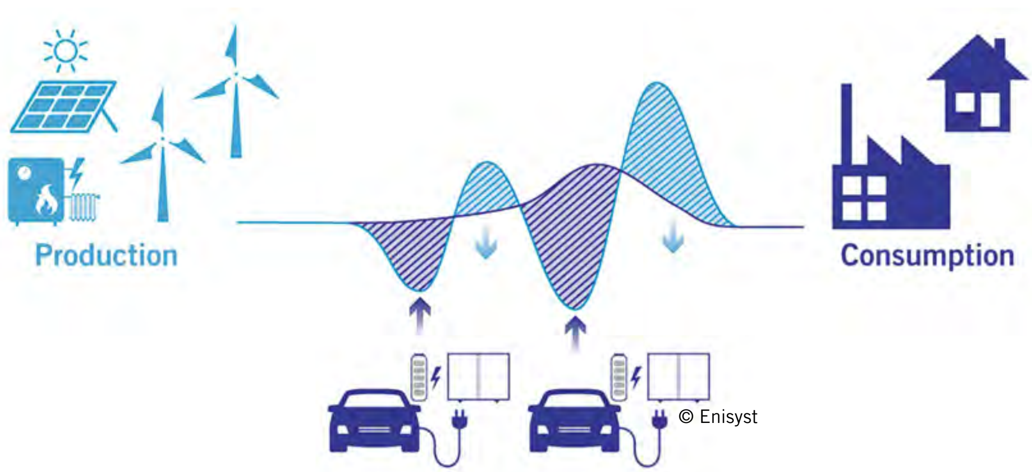
FCA is taking an optimistic approach to bidirectional charging. From an overall perspective, the cars parked on the company’s site can be transformed from a disadvantage to a financial advantage. In the foreseeable future, these benefits could also be available to fleet managers, as Roberto Di Stefano, head of e-mobility at FCA, suggests. The car’s function as an external provider of grid stability services could be financially beneficial for car owners who have a bidirectional wallbox at home.

“We want to show our customers that V2G works,” explains Lodovico Cavazza Isolani, e-mobility program manager at FCA and head of the project. For this reason, he and Di Stefano are pushing for the rapid introduction of legal regulations to allow V2G technology to be extended to fleet management in the near future, with the aim of reducing the operating costs of the cars.

FLAGSHIP PROJECT AT MIRAFIORI PLANT IN TURIN

The team in Turin do not believe that the batteries will wear out more quickly. But equally if a battery is not used for a long period, chemical processes can take place that cause it to deteriorate and reduce its performance. A compromise needs to be found. Extensive research is underway in this field in Italy together with a search for a business model that allows everyone involved to benefit financially.

The faster wear and tear on the battery is counteracted by the claim that it is always discharged to a level that is battery-friendly, but this has not yet been proven. For example, if the battery is



The batteries of electric vehicles can be used as buffer storage for regeneratively generated energy with V2G discharged to maintain the frequency of the power grid, this results in very fast cycles, in other words, rapid charging and discharging. Many people believe that this is a critical problem and are concerned that it will have negative effects on the service life of a car battery.

"Private car users may not want their batteries to be used frequently, because they will probably worry that the batteries will not last as long as a result," says Pietruschka. But they might take a different view of this if they can use the batteries to supply their own house. Making their battery available for the public grid "may be a step too far for many people," comments Pietruschka. At Fiat's Mirafiori plant, at its French partner Engie Eps, which is responsible for decentralized energy generation, and at the Italian power grid specialist Terna, the mood remains optimistic, including with regard to public acceptance of the scheme. To increase acceptance, many other projects are needed, like the ones in Mirafiori and Wüstenrot, that promote bidirectional charging.

WÜSTENROT: SMART2CHARGE IN RURAL AREAS

Smart2Charge in the municipality of Wüstenrot in Germany's Heilbronn district is a V2G project being run by Stuttgart University of Applied Sciences (UAS). Pietruschka has set it up with funding from the German Federal Ministry of Economics. In addition to the municipality of Wüstenrot, the other participants are Enisyst, the company that belongs to Pietruschka and Ebinger, Oxygen Technologies from Freiburg and Mitsubishi Motors Germany, plus Castellan AG, which specializes in system solutions for electric mobility.

Only a few cars, manufactured by Nissan and Mitsubishi, currently allow bidirectional charging. As the municipality of Wüstenrot already had a very good relationship with Mitsubishi Germany, the choice was a simple one. The company made its PHEVs available for the project and the cars will be used in electric mode only. The combustion engine will function exclusively as a range extender to generate electricity in an emergency. Of course the capacity of the PHEV battery is not as big as that of a BEV battery. "The battery size is perfectly adequate for our project," says Pietruschka. In Japan by contrast, the engine is also used as an emergency generator. This means that PHEVs have the advantage that the electricity generated by the engine can be used as a power supply for a house in an emergency, such as a natural catastrophe.

The motto "act local, think global" also applies to the bidirectional charging technology, which needs to be introduced first in a local area of a manageable size. It is also crucial that players from different organizations can work well together, including car manufacturers, automotive industry suppliers, energy and technology companies, private transport providers, such as fleet operators, and municipalities.

ENERGY COMPANIES BLOCK V2G

Power generation companies also have an interest in the stability of the grid. However, they are not in favor of the idea of districts that are largely independent and only need a little electricity from the grid every now and then. This is precisely the objective of the project in Wüstenrot.

In addition to the factors described above, the obvious financial concerns of the energy suppliers also have to be taken into consideration. Districts of this kind can also provide useful services for the grid by using electricity when there is an excess available. The car batteries would enable the system to be managed much more flexibly. The entire cell, as a district like Wüstenrot is referred to in terms of the power grid, can interact with the grid. Energy generation companies have the opportunity to earn from decentralized models by investing in systems of this kind themselves.

© University of Bayreuth

Prof. Michael Danzer
Holder of the Chair of Electrical Energy Systems at the University of Bayreuth and Director of the Bavarian Center for Battery Technology

2 QUESTIONS FOR ...

What is your assessment of the potential of V2G?

Danzer_ I believe that over the next few years and decades a giant fleet of battery storage units will become available. This fleet will have huge potential but will be standing around unused. It is not only in Mirafiori that people are thinking seriously about how a business model can be set up on the basis of this battery capacity and what economic benefits it can offer.

Is bidirectional charging more than just a marketing gimmick?

Danzer_ In the near future there will always be places where excess electricity is generated from wind and solar energy and places where there is not enough electricity available. We need to balance out these energy flows. Larger storage capacity in the grid would be the ideal way of doing this. This is why it makes sense to bring in electric vehicles.

© Mitsubishi Motors

The Mitsubishi Outlander PHEV is one of only a few models already suitable for bidirectional charging

That is exactly what Terna is doing in Mirafiori, where V2G is regarded as a win-win situation for everyone involved.

SIMULATION MODELS OF BIDIRECTIONAL CHARGING

To be able to determine more precisely what happens when a large number of electric cars suddenly move into a district, Stuttgart UAS has created simulation models of the power grid to investigate different scenarios relating to the increase in electric vehicles. "We want to discover when problems occur in the grid and how bidirectional charging of cars can counteract these problems and ultimately avoid the need for the expansion of the grid," explains Pietruschka.

Another subject of the research at Stuttgart UAS is acceptance. "We want to know what the residents think about this and our aim is to involve them in the whole process." One objective is also to set up an electric car sharing scheme in Wüstenrot. This is much more difficult in a rural area than in a city. But even in cities these schemes are not yet cost-effective. "We are investigating how we can organize this with the help of the residents and maybe even encourage them to invest in the system, run it themselves and also take part in it."

Municipalities are involved in the project as well as private individuals and another important group is tradespeople. The four levels of the Wüstenrot V2G project are municipalities, private households, tradespeople and the carsharing model. This goes beyond the concept in Mirafiori.

Ebinger and Pietruschka, who have been working in the field of renewable energy for several years, believe that V2G "is achievable in the foreseeable future." One requirement for everything to function smoothly is that the grid operators invest billions of euros in better power lines after the phase-out of coal.

To give electric mobility a helping hand in general terms, the German Association of the Automotive Industry (VDA) is calling for the electricity used for charging to be exempt from the renewable energy surcharge in Germany. The idea behind this is another nail in the coffin of diesel cars and has been described in these terms by VDA president Hildegard Müller who said: "Electricity for charging cars must be cheaper than diesel." But what if the electricity stored in the car is used in the car owner's home? The major obstacles to V2G remain the many legal issues relating to the warranty for the batteries and the electricity and how it is used.

Susanne Roeder

OPINION

"The charging infrastructure in Germany will have undergone significant changes in five years' time, partly because Volkswagen, which is focusing exclusively on electric vehicles and strongly promoting them via the VDA, has discovered that it can use the energy sector's business model in its subsidiary Elli (Electric Life). V2G will play a role in all of this and will attract attention to this option. However, the question is whether too much emphasis is being placed on the heavily subsidized battery electric vehicle sector. Given fair competition in the form of technology neutrality, hydrogen, fuel cells and synthetic fuels will also have made significant progress by then."

Dr. Susanne Roeder
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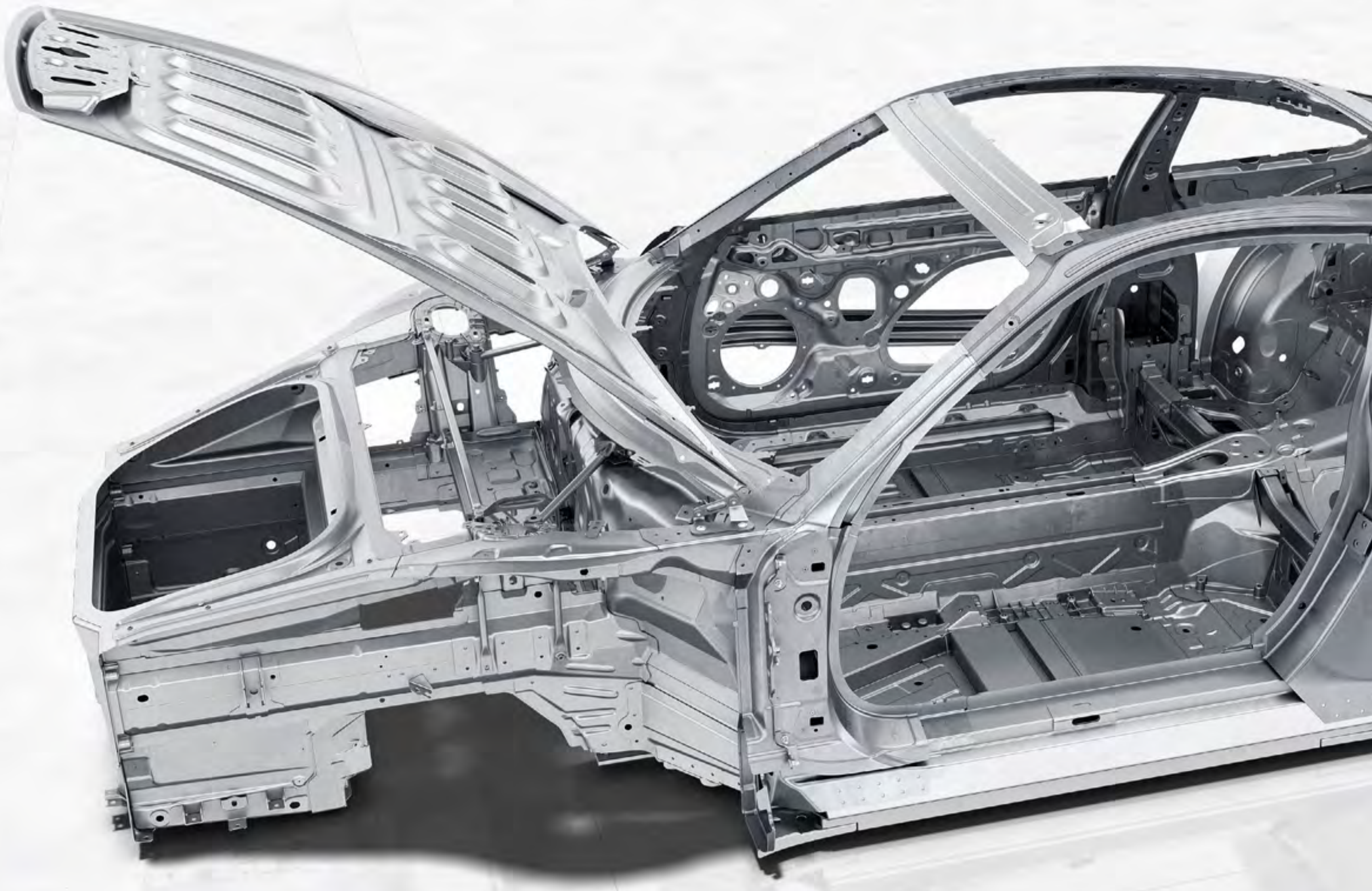

BODY

Composite Use of CFRP, Steel and Aluminum


© Porsche

Alfred Wilm was a highly qualified metallurgist in one of the leading research institutions in the German Reich at the start of the last century. He was a member of the freemasons' lodge known as "Teutonia zur Weisheit." But one of his most important discoveries was the result of the forgetfulness of his apprentice, who left an aluminum casting sample next to the furnace over the weekend. On the Monday, the material proved to be much stronger than it had been on the Saturday. Three years later, Wilm applied for a patent for his lightweight alloy which became a huge success under the name "Duralumin," initially in the field of airships and aircraft.

The product was developed further in Japan and "Extra Super-Duralumin" was created. Nowadays, the Japanese company UACJ is a global supplier of lightweight materials. In the interview, its Research & Development Director and Board Member Seiichi Hirano gives an insight into the applications of different types of material: "UACJ is a specialized manufacturer of rolled aluminum, but we are advancing research and development of composite techniques".

In the past, composite materials of this kind were of only limited interest to Chinese car manufacturers. However, during the development of the electric Changan Eado ET model, a multi-material architecture was used. The design resulted in a body shell with 100 CFRP components, an additional aluminum frame and a steel core. The body shell was over 30 % lighter than a steel equivalent. The prototype underwent the China-NCAP 2018 tests and was awarded five stars.

Because vehicles are highly complex systems, the departments involved in the development process cannot act independently of one another. What each department does influences all the others. The extent of this interaction can vary. It can also affect the requirements of other disciplines in both a positive and a negative way. However, the strength and the nature of the influence cannot always be predicted. But there is now a tool that can identify these connections: the global sensitivity matrix, which is described in detail by Porsche.

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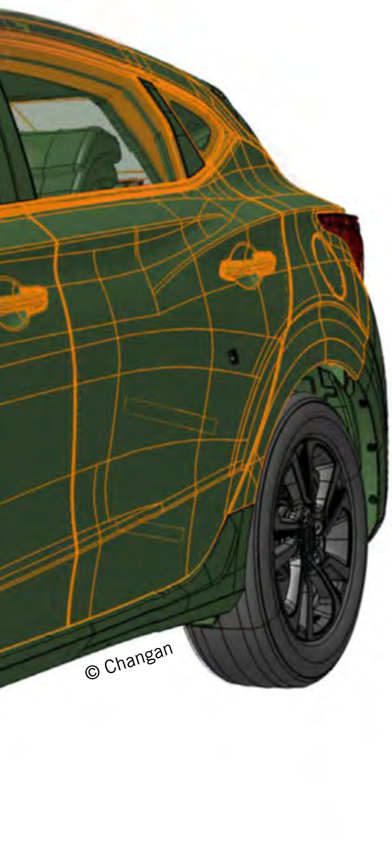
Composites (multi-material structures) like Fiber-reinforced Polymers (FRP) offer the potential to reduce mass and improve vehicle performance and battery electric range, especially important in Battery Electric Vehicle (BEV) applications. From raw material to finished product, a capable supply chain is critical to realize high-volume vehicle applications of FRP composites. Historically, given the limited demand for FRP composites in the Chinese market, Chinese automotive OEMs did not allocate resources to the development of FRP composite parts. This resulted in a lack of know-how across the industry and only limited availability throughout the manufacturing value chain.

The Eado ET compact car project, with one of its foci being on structural composite application, was initiated by Changan to close this gap and accelerate the development of a capable FRP composites supply chain in China. For a



First Body-in-White Made from Composites for a Chinese Electric Car

Forward Engineering and the subsidary KDX Design Center developed a CFRP-intensive body-in-white for the Chinese automotive OEM Changan. This multi-material structure obtained a five-star rating in the China-NCAP assessment (CNCAP 2018). Thus, the Eado ET passenger car is China's first battery electric vehicle with extensive applications of carbon fiber composites, aluminum and steel in safety-critical structures.

realistic project scenario, a five-star China-NCAP rating and a weight reduction of 30 % compared to the identical steel-based vehicle, the Changan Eado, was defined as target. These goals could only be achieved by an FRP dominated multi-material layout for the Eado ET and a focus on integral component design. In order to enable the rapid succession of project milestones, a development method accelerated by simulation (simulation-driven design) had to be chosen.

MULTI-MATERIAL CONCEPT FOR BODY-IN-WHITE STRUCTURES

For the Eado ET, the entire Body-in-White (BiW) structure together with its doors and hoods primarily consists of two modules: The upper body (passenger compartment) is made mainly from Carbon-fiber-reinforced Polymer (CFRP) which was strengthened with high/ultra-high-strength steel. The lower frame is made entirely from aluminum, **FIGURE 1**. This structure layout allows Changan on the one hand to use this aluminum frame as a common platform for the CFRP upper body (premium lightweight design version of the Eado ET) and for the steel upper body (high-volume version). On the other hand, this utilizes the advantages of aluminum for BEV structures by providing an ideal protection and mounting platform for the battery housing and other chassis and powertrain components.

The vehicle front and rear ends are defined as main deformation zones for energy absorption during a crash. Here, the favorable crash characteristics of aluminum enable it to absorb the peak energy in a crash case and transfer the loads into the backing structure. For passenger safety, the passenger compartment of the BiW requires higher rigidity and allows only smaller defor-

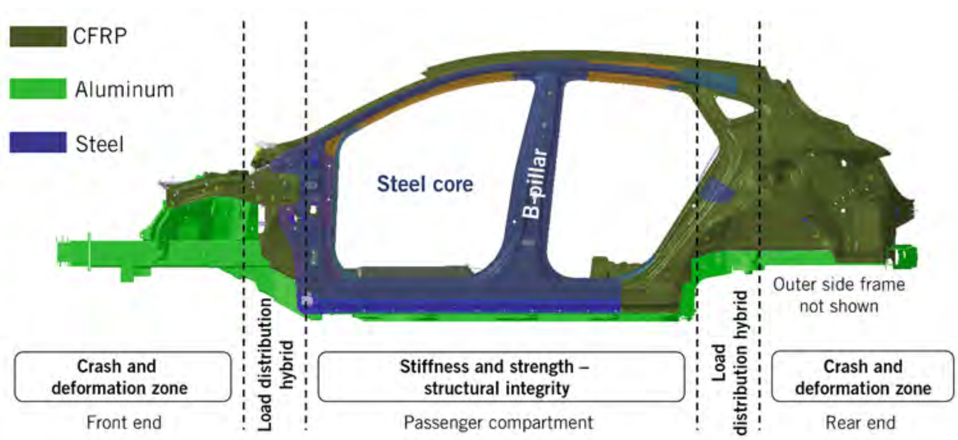
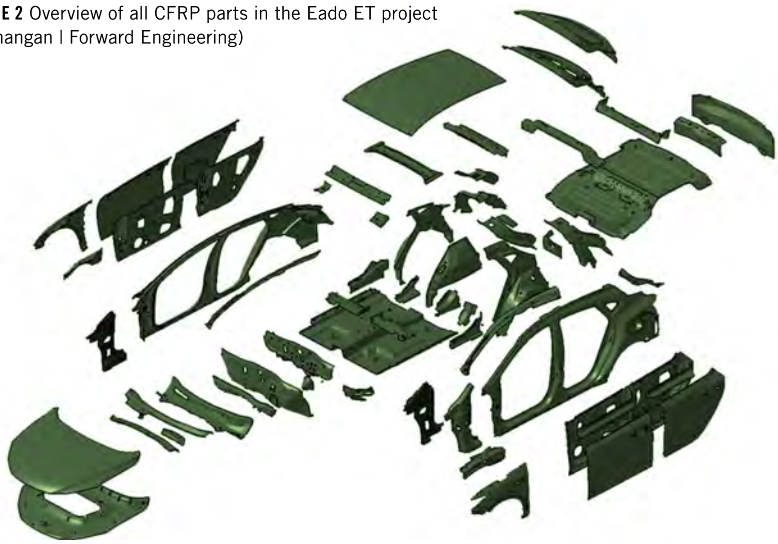


FIGURE 1 Multi-material concept of the passenger car Eado ET from Changan (© Changan | Forward Engineering)

FIGURE 2 Overview of all CFRP parts in the Eado ET project (© Changan | Forward Engineering)



mation. Here, the carbon fiber has more advantages in terms of its excellent stiffness/strength properties. Especially in areas with high loads and clear load direction, this fiber composite material can utilize its anisotropy advantages best. In case of a side crash, the vehicle structure needs to withstand the barrier intrusion and absorb the intrusion energy by keeping the structural integrity intact. The brittle CFRP material is not ideal for such peak energy absorption. To overcome this, a material combination of CFRP and steel was created. This so-called steel core structure was embedded into the CFRP side frame in order to combine the benefits of both materials.

The steel core is the primary structure for the B-pillar and acts as a reinforcement in the areas of roof frame, A-pillar and side sill. The typical ductile properties, combined with the good performance of the used ultra-high strength steel, are best suited to absorb and transfer the impact energy into the surrounding structure in a very limited deformation space.

It would take a much higher effort to achieve this if a 100-% CFRP concept was used. The lower aluminum frame would need to be created much stiffer and the outer side frame would require a redesign. These changes would prevent the use of the existing seat belt arrangement and the use of other important interior carry over parts in the new vehicle.

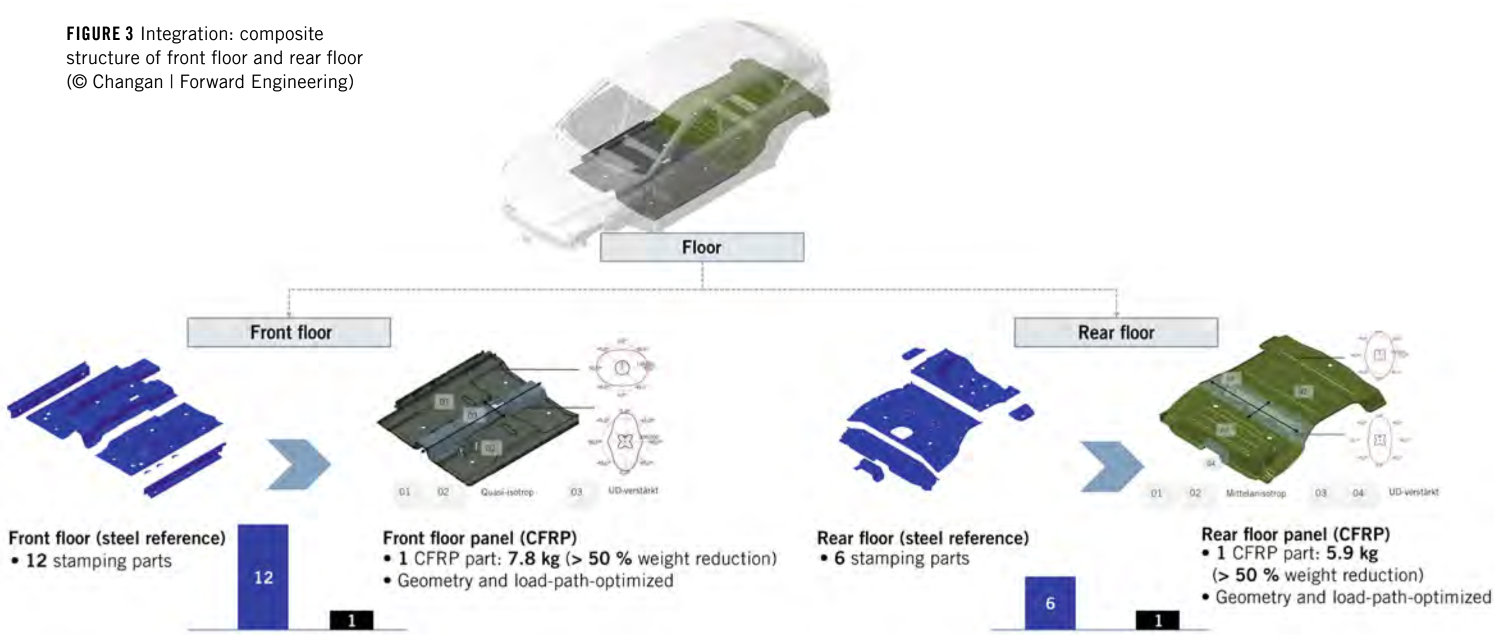
FRP-DOMINATED UPPER BODY, DOORS AND HOODS

The upper body, the four doors and the two hoods (in front and rear) are mainly composed of FRP. To realize the FRP value chain, a variety of locally produced materials (four resin types ranging from fast curing to normal prepreg resin as well as three textiles/semi-finished products) and technologies (HP-RTM with preforms, WCM, PCM, prepreg, Vacuum Assisted Resin Infusion (VARI)) were considered for the composite body structure. In the design phase, all parts were designed with technologies suitable for high-volume production processes. An equivalent VARI process was used for the manufacturing of most of the prototype parts for functional validation due to its cost and time efficiency. The main composite and CFRP parts are shown in **FIGURE 2**.

PART COUNT AND WEIGHT REDUCTION THROUGH INTEGRATION

The extensive use of FRP not only makes the vehicle structure lighter, but also allows to make it more integrated. The

FIGURE 3 Integration: composite structure of front floor and rear floor (© Changan | Forward Engineering)



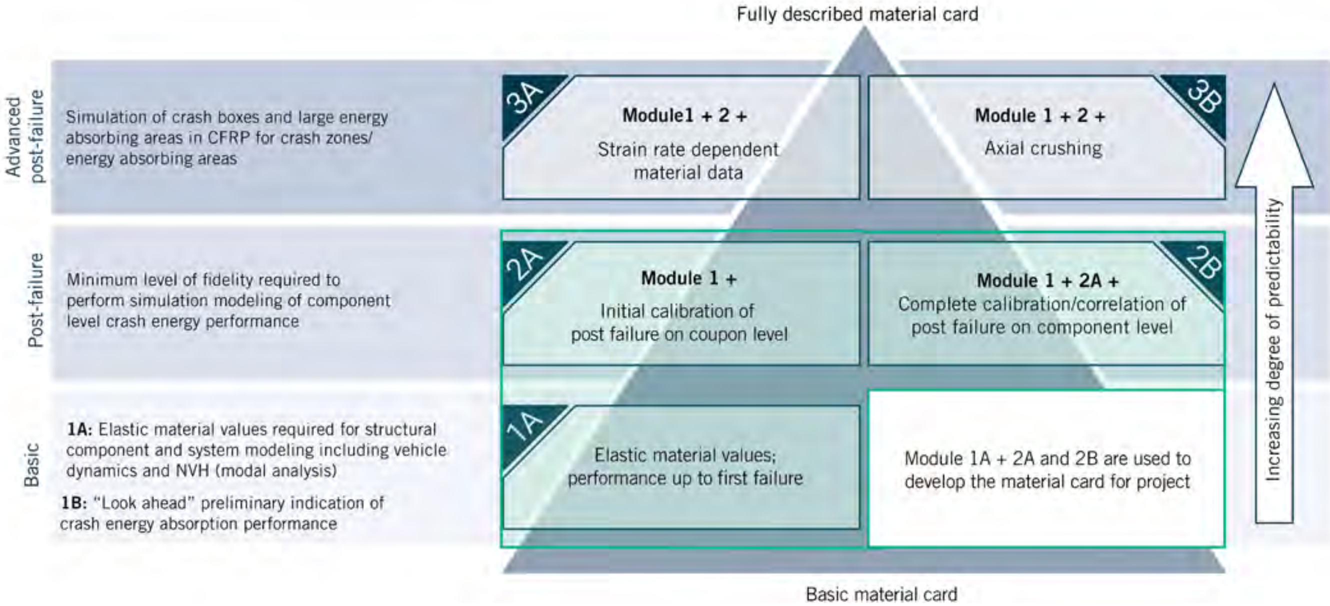


FIGURE 4 Modular approach of material characterization according to [1] (© Forward Engineering)

composite upper body integrates various functions (regarding occupant safety, global/local stiffness, local attachment points, NVH/comfort) by using adhesives as well as easier sealing due to less joining steps while reducing the part count significantly. For example, the entire floor structure, **FIGURE 3**, is composed of two integrated CFRP parts – the front floor and the rear floor. The front floor integrates twelve metal parts and reduces the weight by more than 50 % (7.8 kg for CFRP front floor). At the same time, the geometry and fiber orientation were optimized. The middle tunnel area was reinforced using unidirectional fibers in lateral direction to improve the stability of the body during a frontal crash and to increase the global bending stiffness. For the rear floor in similar, the FRP design substitutes six metal parts while reducing the weight to 5.9 kg which is more than 50 % less compared to the steel reference. In addition, local reinforcements are applied in transverse direction in the second seat row area (C torsion ring) to support the global BiW torsion.

The part count was significantly reduced in the shown integrated design despite using a lot of cost-efficient carry-over steel parts. There were over 577 BiW parts in the steel reference vehicle, of which 159 are carried over to the composite intensive solution. The remaining steel parts (418) have been reduced to 100 CFRP body parts, the steel core and an additional aluminum lower frame as a common platform. As a result, over 30 % weight reduction from 469 kg (steel reference) to 322 kg (Eado ET project) for the entire BiW was achieved.

SIMULATION-DRIVEN DESIGN AND BUILDING BLOCK APPROACH

The keys for the successful development of this fast track project were the tailored simulation-driven design and the building block approach. This was forced on the project by the need to concurrently develop the component geometry while creating validated material cards for the required CAE simulation.

Given the limited available project time and the requirement for more than ten different material cards (combinations of different materials, technologies and grammages) in a first step, Forward Engineering has classified similar material cards depending on the predefined production process and fiber volume content, which allowed reducing the number of tests by keeping a reasonable accuracy of the material cards and still covering the variation of technologies. In the second step, the load conditions of the different BiW zones (crash relevant, strength or stiffness dominated) were analyzed to assess the level of demand for material cards for each part. This could be best described as a modular approach of material characterization, **FIGURE 4**. Based on this specific material card development strategy, a full characterization (1A, 2A and 2B) was carried out for the materials in crash-related zones while some post-failure assumptions were made for the less critical material cards (only 1A or 1A + 2A tested).

On the basis of such a material card development, a wide range of calculations and hardware tests starting from coupon/plaque level, over component/sub-system level to system/vehicle level were conducted to further improve the predictability on different load cases for the vehicle, especially for investigations for the crash load absorbing areas. The concurrent building block approach, **FIGURE 5**, with iteration loops ensured that both the cost and performance objectives were met by testing on a number of less expensive specimens. Simultaneously, a plausible data base could be built at different complexity levels of the development.

FIVE STARS IN CHINA-NCAP CRASH TEST BY VALIDATION TEST

For validation purposes, hardware tests were carried out by Changan. While meeting the targets of stiffness and strength requirements, the vehicle successfully achieved the required five-star crash test rating according to China-NCAP 2018 regulations. The validation regimen contained a full width frontal impact, a frontal offset impact

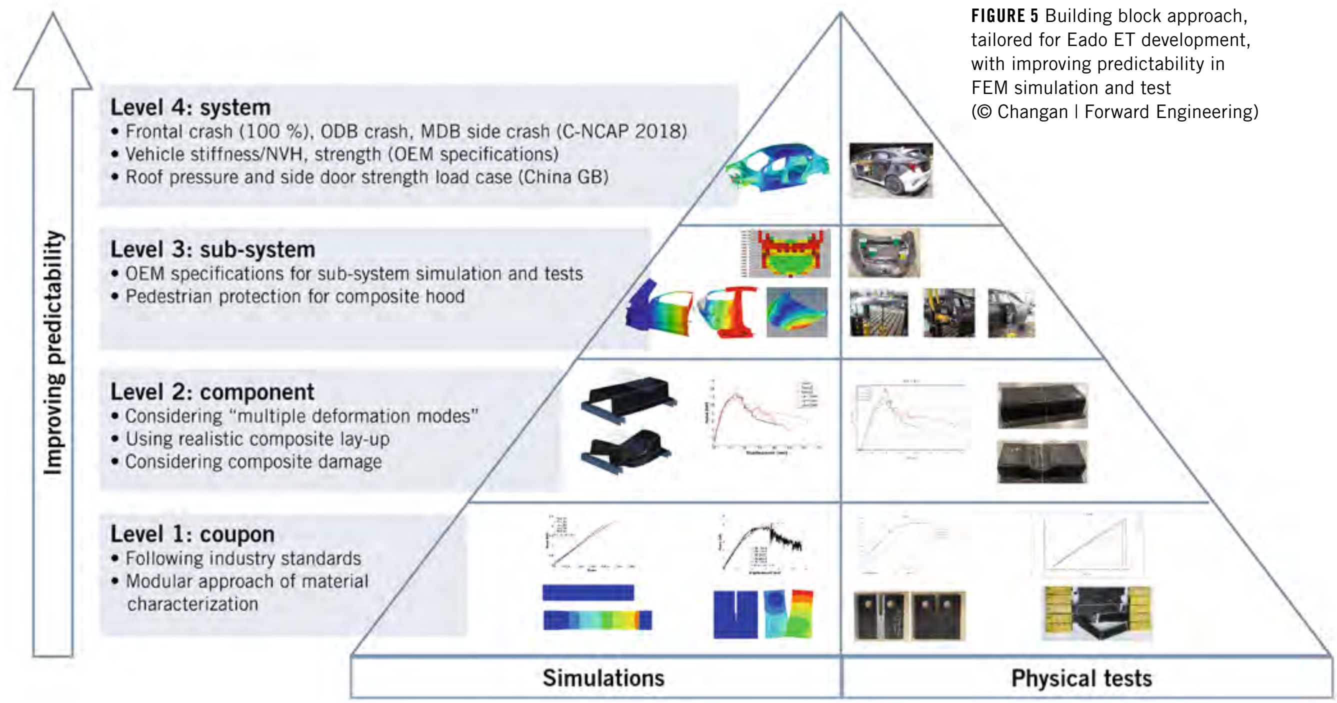


FIGURE 5 Building block approach, tailored for Eado ET development, with improving predictability in FEM simulation and test (© Changan | Forward Engineering)

with the Offset Deformable Barrier (ODB) and a side impact with Mobile Deformable Barrier (MDB). The results of FEM simulations and crash tests also showed a good correlation with a maximum deviation of about 6 %.

As laid out in the structural concept, during the ODB test, the aluminum frame absorbed the main energy and the FRP passenger compartment provided sufficient stiffness to hold the aluminum structure in place. Consequently, the intrusion in the front wall was controlled well and the passenger compartment structure could keep a very good structural integrity. The peak acceleration was below 35 *g*. The test curves correlated well with the FEM simulation result, **FIGURE 6**, thanks to the validated material cards. Similar results and behaviors could be observed from the front crash with a full-width rigid barrier which is generally less critical than the ODB load case.

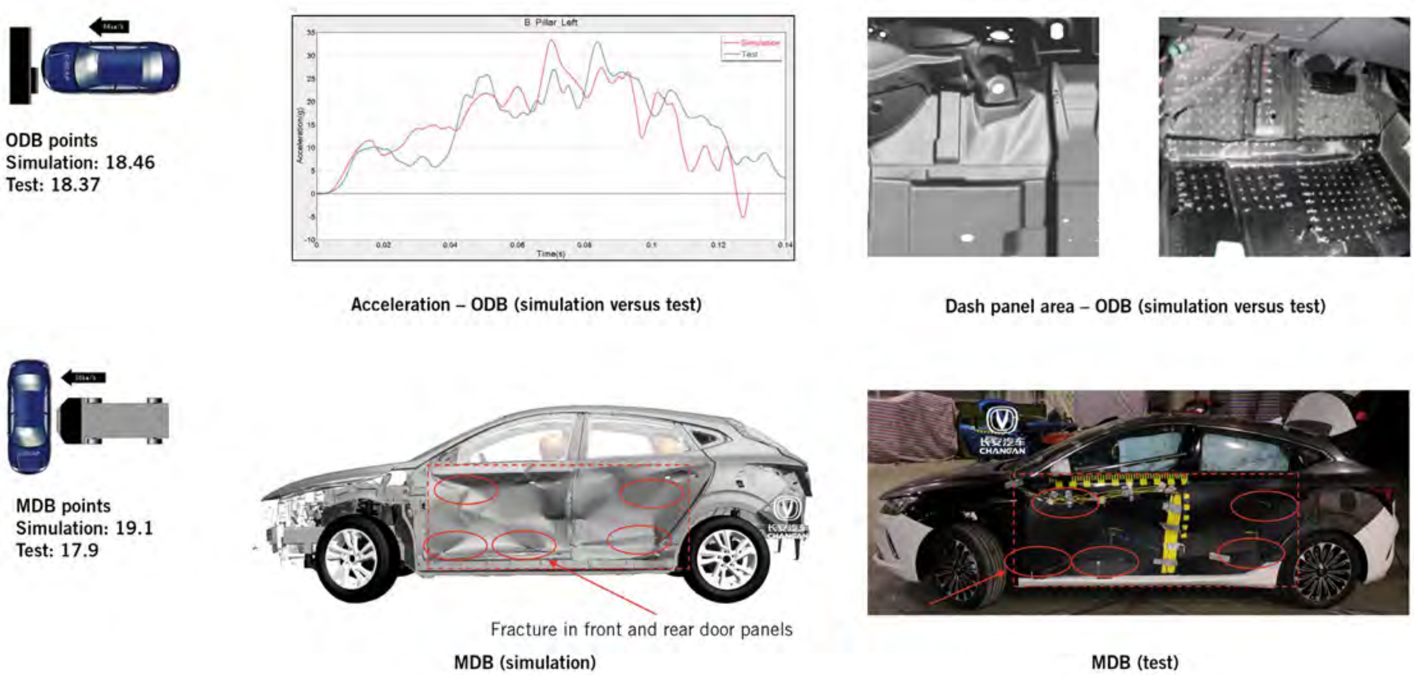


FIGURE 6 Result comparison of ODB and MDB crash with point score (simulation versus test) (© Changan | Forward Engineering)

Thanks to the multi-material steel-core concept and the remaining steel beam in the door structure, the vehicle could absorb the MDB side impact energy. The deformations were within the allowable limits and its structural integrity remained intact. The simulation accurately predicted main damages on the front and rear door panels. The difference (simulation versus test) in the point score (19.1 versus 17.9) is mainly in the rear door upper area (chest), as the crash test dummy (SID-IIs) chest was more heavily compressed than the simulation predicted. Several post-crash analyses have been performed to analyze the reasons in detail as well as to propose optimized solutions. A better correlation is expected for the official tests later at the China Automotive Technology and Research Center (Catarc) in Tianjin (China).

CONCLUSION AND OUTLOOK

All project and technical targets could be met within the given time frame. The BiW of the Changan Eado ET was developed using a composite-intensive multi-material architecture. The high integral design lead to a BiW (including doors and closures) with only 100 CFRP parts, an additional aluminum frame and the steel core. As a result, the weight of the BiW was reduced from 469 to 322 kg which is more than 30 % compared to the steel reference vehicle. The Eado ET prototype was validated by Changan with a five-star rating, according to the China-NCAP 2018 regulations.

Last but not least, 100 % of the FRP parts and technologies were sourced in China. The initial goal of the project was clearly demonstrated. The composite value chain in China moved a big step forward and was confirmed ready for major large-scale manufacturing. A batch of prototype vehicles is delivered to Catarc for official crash-test certifications by the end of 2020. The most promising multi-material structure concepts are expected to be transformed into high-volume production applications at Changan Group.

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"We can reduce carbon emissions by using sustainable aluminum"

The development of aluminum application technologies is a continuous engineering process to minimize carbon footprint and passenger car weight. Seiichi Hirano, Member of the Board of the UACJ Corporation, a Japanese aluminum components supplier with the world's third largest production capacity, talks in the ATZ interview about the properties that give aluminum advantages over steel and CFRP in terms of CO_2 emissions, as well as which expertise was used in the Mazda MX-5.

ATZ _ Hirano-san, the UACJ Corporation is a company with a long history in aviation. When was it established?

HIRANO _ Well, today's UACJ was born in 2013 through the business integration of Sumitomo Light Metal Industries Ltd. and Furukawa-Sky Aluminum Corp. But our research and development began 100 years ago with the investigation on aluminum alloys for aircraft. In 1936, Dr. Isamu Igarashi, an expert of the Research Division of Sumitomo Metal Industries, Ltd., which is where our roots lie, developed Extra Super-Duralumin, ESD for short. Thanks to the invention of this lightweight and high-strength material, the performance of aircraft has improved dramatically since then, and ESD still contributes to the development of the space and aviation technology to this day.

Where is your research base located?

The R&D division is based in Aichi Prefecture in the central part of Japan, and

Seiichi Hirano, M. Sc., (born in 1959) is Director and Member of the Board of the UACJ Corporation, headquartered in Tokyo (Japan), and has been the Director of the UACJ Research & Development Division since 2020. He received his master's degree at the Graduate School of Science and Engineering of the Waseda University, Faculty of Science and Engineering in 1984. He worked first in Sumitomo Light Metal Industries, Ltd. and then moved to their R&D Center, which is a comprehensive research division for aluminum materials. In 2006, Hirano became the General Manager of the Third Department of the R & D Center, and since then he has taken the same position at several departments. From 2012, he served as the General Manager of the Manufacturing Engineering Department and the Quality Assurance Department. Hirano has extensive experience in aluminum research and development, production technology and quality control in general. He takes a leading role in managing International Conference on Aluminum Alloys (ICAA), a two-year series all over the world, next in 2022 in Toyama (Japan).

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R&D is also carried out in the USA and Thailand. UACJ's R&D Center employs 300 researchers, the largest number in the global aluminum industry.

So you have no research and development activities in Europe? How do you get local information from there?
The development of Japanese cars, which have won many awards in Europe, is being carried out in Japan and is supported by UACJ's R&D Center in Aichi Prefecture. We have established UACJ Extrusion Czech s.r.o., a manufacturer of extruded aluminum for heat exchangers in the Czech Republic, and UACJ Elval Heat Exchanger Materials GmbH in Düsseldorf (Germany), a company that sells aluminum for heat exchangers. Currently, we do not have a research base in Europe, so we respond appropriately to requests from Europe in Japan. And via correspondents, we collect information on European automobile technologies daily and feed it back to our research activities. I think a research base in Europe will be a future issue.

What kind of research is being done? Which lightweight design approach do you follow, especially for body panels?
The UACJ R&D Center develops products that are built on accumulated basic research on aluminum alloy design, strength, formability, corrosion resistance, etc. For automobiles, UACJ has developed Japan's first aluminum alloy sheet for body panels and has contributed to the weight reduction of Japanese automobiles. Currently, we are working on improving the properties of 6000-series aluminum alloy sheets for body panels. Our newly developed alloy features excellent formability, strength resulting from paint-baking, corrosion resistance and surface quality. UACJ is also at the top level in the world in the development of bright aluminum alloy sheets with excellent brilliance and various functional pre-coated aluminum alloy sheets. These products also have some applications as automobile parts.

"An aluminum research base in Europe will be a future issue for us"

Multi-materialization is expanding in the body structure of automobiles. What kind of characteristics do you think make aluminum alloys superior to steel?
UACJ is a specialized manufacturer of rolled aluminum, but we are advancing research and development of composite techniques with CFRP and steel, etc. For example, there are joining techniques that use adhesion and friction stir welding. Due to advances in joining techniques between different materials and differential thickness joining techniques, a lightweight composite body structure centered on steel has been developed, and the all-aluminum structure is now limited to high-end vehicles. Aluminum can take advantage of its good characteristics, such as shock absorption and thermal conductivity. For these excellent properties, aluminum cannot easily be replaced by other materials, as steel has the advantages of steel, and resin has the advantages of resin. We believe that multi-materialization is an opportunity to expand the range of aluminum adoption through collaboration, rather than competition, with steel.

You make the point that aluminum, steel materials and, increasingly, plastic composite materials, push each other in lightweight design efforts. What do you take into account when it comes to calculations for sustainability of these material groups?
In the design of a composite body structure, reduction of weight as well as improving crash safety and increasing vehicle dynamics are important issues. Structural materials are currently selected based on their strength properties,

lightweight potential, and prices, but sustainability has become more important than ever. In recent years, it has become increasingly considerable to reduce the CO_2 and environmental load at the disposal and recycling stage of life cycle assessments, and from now on, I think that citizens and users will take the initiative in selecting cars with the right materials. The aluminum material has excellent recyclable properties, and a low environmental impact during the recycling process. As a material manufacturer, we regard social responsibility and sustainability as most important aspects, and strive to reduce our environmental load at the diverse production stages.

The powertrain is becoming more electrified. How will you handle that? Are you involved in supplying electrode materials and battery housings, too?
The batteries installed in the powertrain are important for electrification. Therefore, UACJ manufactures aluminum foils as well as sheet, extruded, forged, and processed products. These foils are used as an electrode material for batteries, and they are a very important material for which there is no alternative with current technology. In addition, extruded aluminum shapes have optimum characteristics as a structural

"We created a thin-walled hollow shape for bumpers"

material for battery housings due to their impact resistance and heat dissipation. Batteries are getting bigger and heavier to extend the driving range. We are proposing the use of extruded aluminum shapes. They are lightweight and can be made into various cross-sectional shapes.

The purpose of using electric vehicles is mainly based on environmental regulations such as reduction of CO_2 emissions. What are the advantages of using aluminum?
The benefits of using aluminum are its light weight, and also its high recyclability. Compared to refining aluminum from ore (bauxite) to make aluminum ingots, the energy required to recycle a product into aluminum ingots is only 3 %. In Japan, the public and private sectors are jointly developing more advanced recycling technology. This technology is called "upgrade recycling" that removes impurities and produces high-purity recycled aluminum ingots. By widely using and recycling rolled aluminum products, we can reduce carbon emissions and contribute to the realization of a sustainable mobility society.

What kind of product innovation do you think will be possible in the next two years or the next 20 years in aluminum technology?
UACJ has accumulated know-how by focusing on basic research, such as development of rolled aluminum products, and based on this know-how, we established our "Mobility Technology Center" in Aichi in October 2019, which is a department specializing in the development of automotive parts. This center promotes the development of innovative aluminum applications. In addition, when we can establish a low-cost cyclical upgrade recycling technology with a low environmental impact, the barriers using rolled aluminum will be eliminated, and the use of rolled aluminum products will explode. I think innovation will occur in the structure of mobility itself.


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UACJ regards social responsibility and sustainability as most important aspects, and strives to reduce the environmental load of aluminum in all manufacturing steps, states Hirano

How do you address the problems of corrosion resistance and electrical conductivity in composite materials made with steel (iron) and aluminum?
UACJ's R&D Center has been engaged in research on corrosion mechanisms in the field of heat exchangers for automobiles for more than 40 years, and we have accumulated a wide range of know-how in preventing galvanic corrosion. Joining steel and aluminum parts is often used in current car body structures, so it is important to protect the joint parts from moisture, which is a corrosive factor, in the joint parts, and to verify the effects of deformation due to the differences in expansion coefficient. For example, we have developed a mechanical joining process with insulators to avoid electrical connections, and also designed a sealing structure that prevent moisture in the parts after joining, in combination with adhesives.

UACJ manufactures the body and chassis components of the current Mazda MX-5 made of aluminum. For which of these com-

ponents is a lightweight design concept particularly important? Which properties of aluminum are advantageous in production and joining processes?

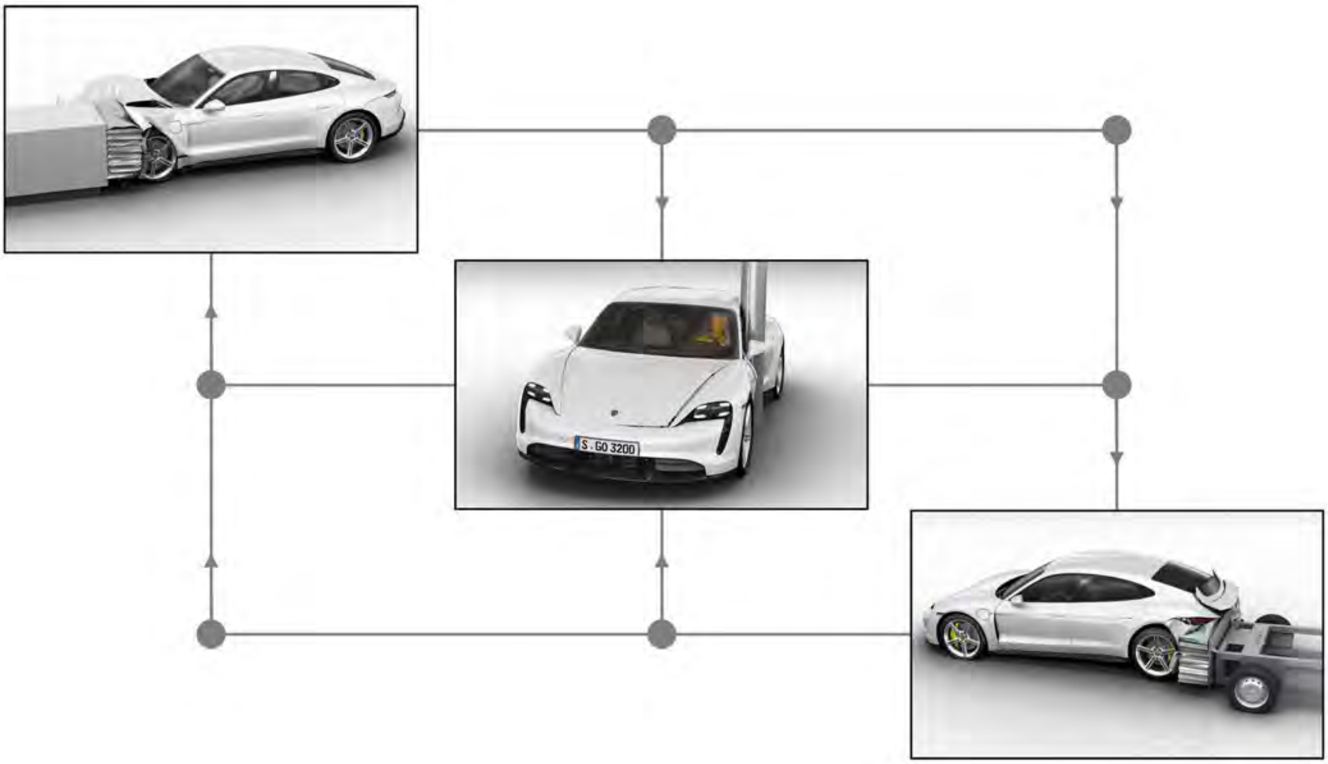
A typical example of the lightweight design of the MX-5 is the 7000-series aluminum alloy front bumper. The bumper is an important strength member for shock absorption in the crushable zone, and it is also the member farthest from the center of gravity of the vehicle, so weight reduction is also important to reduce the yaw moment of inertia. Based on these required performances, we developed alloys and extrusion processes, and realized the production high-strength, thin-walled hollow shapes for bumpers using 7000-series aluminum. This newly developed alloy also has an excellent weldability and is the most suitable one for lightweight and highly rigid welded structures.

Which methods and tools do you use to design your aluminum sheets, for example to better determine the influences of load cases on other areas?

When using aluminum sheets for body panels, it is well-known that they have less elongation than steel sheets. At UACJ's R&D Center, we perform CAE-based press forming simulations to predict material cracks and wrinkles during pressing. The results are used to develop press die shapes that create beautiful body shapes, and improve material properties. Similarly, we are pursuing the use of the lightest and most efficient materials by applying topology optimization technology. For example, we are developing lightweight and high-rigidity aluminum panel members with differential thickness joining of thick and thin sheets. Including these technologies and the concept of sensitivity analysis, we would like to contribute to improving the crash safety performance and rigidity of the vehicle body and the degree of freedom in design for the future.

Hisano-san, thank you for this interesting interview.

INTERVIEW: Michael Reichenbach



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Due to the high complexity of the full vehicle system, the specialist disciplines involved in the development process must act in close coordination as their actions influence each other. These couplings can be strong, weak or negligible and can influence the requirements of other disciplines in a positive or negative direction. The strength and direction of the influence are not always predictable due to the complexity. However, there is a tool for identifying these interrelationships: the global sensitivity matrix proposed by Sobieszczanski-Sobieski [1]. It identifies coordination paths and interactions and promotes the development speed and quality, since individual actions can always be assessed in a global context.

BASIC IDEA OF A GLOBAL SENSITIVITY MATRIX

Assuming that in vehicle development there is a shared vector of design variables $\vec{x}_{\text{global}}$ and discipline-specific design variable vectors $\vec{x}_{\text{local},i}$ with whose variation the disciplines bring their requirements to the target. The vector of all design variables used in the development process is as mentioned in Eq. 1:

Eq. 1 $$\vec{x} = \left(\vec{x}_{global}, \vec{x}_{local,i}\right)$$

Here is $i = 1, I$ (here, I denotes the number of disciplines involved).

Using **FIGURE 1** and three disciplines, the basic principle of the sensitivity matrix is explained exemplarily. The influence of the requirement values of the discipline Y_1 on the other disci-

Global Sensitivity Matrix for Vehicle Development

Passenger car development processes are becoming increasingly complex. Many professional disciplines are involved, which are connected to each other via the design variables. Using the example of the design of a body-in-white with regard to side crash, stiffness and front crash, Porsche, the Universities of Wuppertal and Leiden and divis intelligent solutions show how a global sensitivity matrix on metamodels is used to analyze the interactions and to interdisciplinary optimize the design targets.

plines Y_2 and Y_3 can be described by $\partial Y_2/\partial Y_1$ and $\partial Y_3/\partial Y_1$.

The requirement values usually have no causal relationship, but influence each other via the changed design variables. $Y_1 = Y_1(\vec{x}, Y_2, Y_3)$ is then reduced to $Y_1 = Y_1(\vec{x})$. The disciplines are thus indirectly coupled by the design variables. The strength of the influence of the design variables on the respective requirement values can be described with $\partial Y_1/\partial\vec{x}$, $\partial Y_2/\partial\vec{x}$ and $\partial Y_3/\partial\vec{x}$.

They represent thus the sensitivities of the respective design variables to the requirements. If for example discipline 1 needs to change one or more variables from the shared design variable vector $\vec{x}_{global}$, which is sensitive for all disciplines, all other disciplines will be affected by this decision. Depending on the number of affected disciplines and the strength of the influence in a positive or negative direction on the requirements of these disciplines, it can be decided whether the variable change is useful. At least discipline 1 is sensitized that it has to inform all other disciplines about these changes. Using discipline 1 as an example, it would also be conceivable to first use the local design variables $\vec{x}_{\mathrm{local},1}$, since these variables are only sensitive to discipline 1. In addition, the possibility arises that discipline 1 performs decentralized optimizations with these local design variables in order to generate the best possible result with these restrictions. If this result is not sufficient to fulfill the requirements and the use of globally sensitive variables is necessary, the sensitivity matrix can be used to select relevant load cases for a multidisciplinary optimization [2].

PROCEDURE FOR BUILDING UP THE SENSITIVITY MATRIX

The sensitivity matrix is built out of a database based on approximation models (also called metamodels) that estimate the global behavior and thus the relation between design variables and requirement values. Design variables can be for example shape, thickness or material changes of components. The requirement values are determined from simulations or expe-

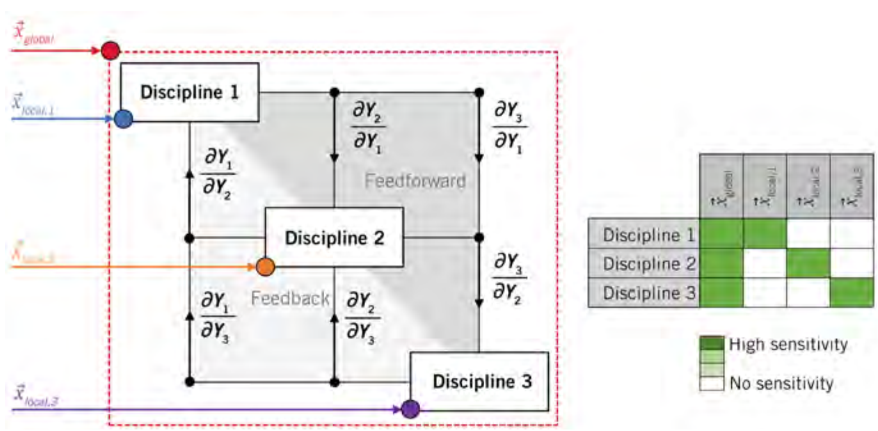

FIGURE 1 Global sensitivity matrix according to Sobieszczanski-Sobieski [1] (© Porsche)

riments. In order to approximate the relations globally, that means in the entire design space, many simulations or experiments are necessary. In the best case, a Design of Experiments (DoE) is used to generate strategically well-distributed samples (design variable configurations) in the design space, which are then evaluated in the simulations or experiments. The generated table serves as basis for approximation models, such as Gaussian processes or neural networks (for example a multilayer perceptron).

In case of variable changes, simulations or experiments are no longer required, since the evaluation is now performed on the approximation models. Furthermore, the approximation models can be made available to all other departments on a data management server. This enables other departments to understand the requirements and influences without the simulation or testing know-how of the respective department. In addition, global sensitivity analyses can be performed on the approximations to identify sensitive variables. This can be done for example with the Sobol indices [3], which are based on the variances of the approximated requirement values. The Sobol indices are determined with the help of a Monte Carlo study and describe which of the *n* design variables or their interaction and to which proportions cause the variance of the requirement values. Thus each variable has a Sobol index between 0 and 1, where the sum of all Sobol indices per approximated requirement value is 1. The higher the Sobol index of a variable, the more sensitive it is and the higher is its influence on the requirement value. The degree of influence and the direction can then be determined by simple predictions on the approximation models, **FIGURE 2**.

Of course, these statements are based only on approximation models and should therefore always be considered with care. For more reliability in the statement quality, criteria such as low error measure and high correlation values should be fulfilled. The criteria can be calculated by predicting a set of existing samples on the approximation models and comparing them to the real values. This can be done globally over the entire design space or locally in the immediate vicinity of the points of interest for the development. The evaluation

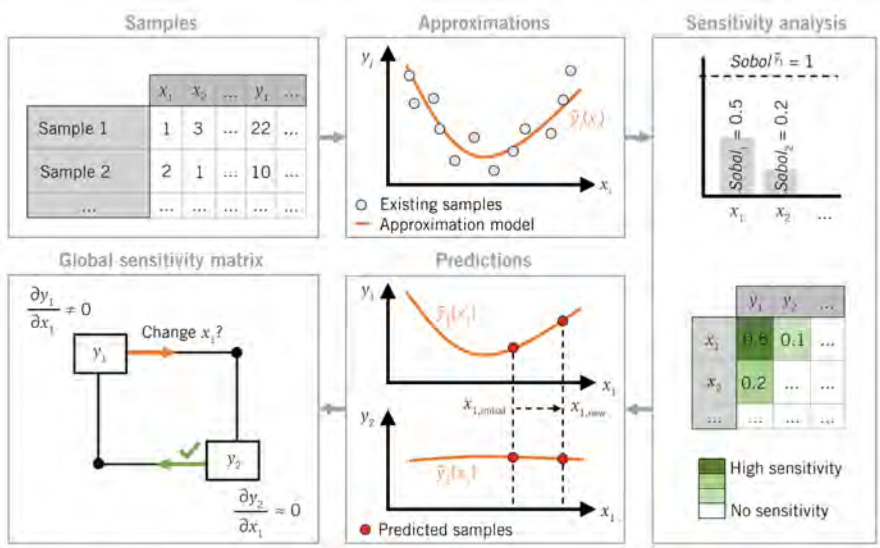

FIGURE 2 Exemplary procedure for building up a sensitivity matrix (schematic) (© Porsche)

of the local confidence helps to obtain an estimate for the reliability of the local predictions based on the approximation models.

SENSITIVITY MATRIX BASED ON A BODY DEVELOPMENT EXAMPLE

The exemplary chosen disciplines of vehicle safety and stiffness both influence the development of the body-in-white. The department, which is responsible for the front crash (F) with full overlap within vehicle safety, is for example particularly interested in keeping the Occupant Load Criterion (OLC), as a simplified model of dummy chest acceleration, as low as possible. The department responsible for the side crash (S) in a pole impact wants to achieve low intrusions in the area of the seat cross member. Both departments are working on the overall goal of keeping the physical strain on the occupants as low as possible. The department that evaluates stiffness (STF) needs high values for global bending to meet its requirements. The design variables for this example are 38 wall thicknesses of the components in the main load paths of the body-in-white, **FIGURE 3**. The variable bounds depend on the different manufacturing processes (deep-drawn sheets: 0.8 to 2.5 mm thickness; hot-formed tubes: 1.5 to 5 mm thickness). As a basis for the approximation models, a DoE with 1500 samples (variable configurations) is performed. The requirement values (OUT_F_OLC, OUT_S_Intrusion, OUT_STF_Mode) are obtained by FEM simulations.

It is now assumed that department S has to make changes to meet its require-

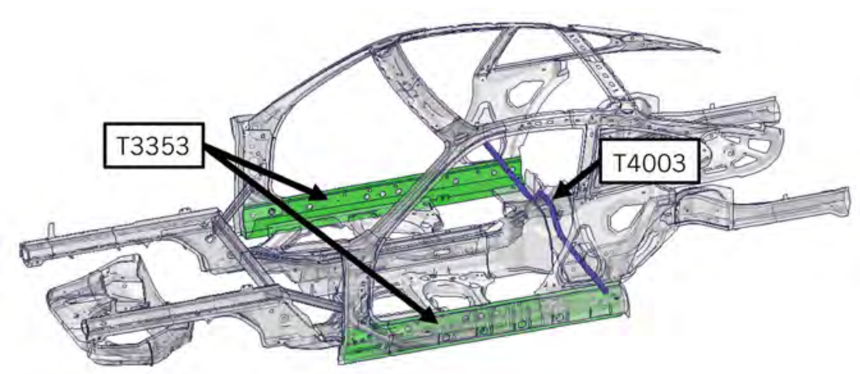

FIGURE 3 38 components of the main load paths of the body-in-white with the investigated points cross tube (T4003, blue) and inner panel of the sill (T3353, green) (© Porsche)


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Requirement value	OUT_F_OLC	OUT_STF_Mode	OUT_S_Intrusion	OUT_Mass
Approximation	Multi-layer perceptron	Gaussian processes	Multi-layer perceptron	Linear model
T2141	0.1762	0.0005	0.0002	0.0029
T2143	0.3197	0.0010	0.0	0.0475
T2151	0.4983	0.0008	0.0	0.0092
T3013	0.0	0.0011	0.0061	0.0854
T3301	0.0023	0.0062	0.0609	0.1448
T3353	0.0028	0.2585	0.1692	0.0990
T3365	0.0016	0.0020	0.0758	0.0143
T3367	0.0033	0.0004	0.0004	0.0943
T4003	0.0009	0.0008	0.6272	0.0668
T4153	0.0026	0.3552	0.0011	0.0170
T4167	0.0033	0.0505	0.0014	0.0047
T4605	0.0025	0.0091	0.0014	0.0570
T4607	0.0002	0.0904	0.0334	0.0602
T4621	0.0016	0.0728	0.0014	0.0103

TABLE 1 Sobol indices of selected variables based on approximation models that were learned with the ClearVu Analytics program of divis (© Porsche)

ment that mean to reduce intrusion. In order to on the one hand keep the coordination effort low, and on the other hand limit the negative influence on the requirements of other disciplines, which are already in the target, department S would like to change only the variables that are solely sensitive for its own requirements. The sensitivity matrix shows that the wall thickness of the cross tube T4003, **FIGURE 3**, not only has the highest sensitivity for it, but also has a low sensitivity for the other two disciplines F and STF. For reasons of clarity, **TABLE 1** shows only those variables that have a Sobol index of at least 0.05 for at least one of the requirement values.

Based on the current state of development, department S makes predictions on the available approximation models to determine the direction and magnitude of the variable change. **FIGURE 4** (left) shows the normalized requirement values depending on the T4003 variable change. The requirement values are min-max-scaled to the respective value range of the solution space (results from the DoE). This offers an overview of all requirement values at the same time, and additionally allows to estimate the degree of influence depending on the solutions possible so far. In addition to that, the local confidences with a best-case scenario of 1 can be plotted for each requirement value. The calculation of the confidences (reliabilities) is based on [4].

Department S must conclude that although the variable is globally very sensitive and causes a significant improvement in relation to the value range, this potential applies primarily to smaller values of T4003 (1.5 to 2.5 mm). A wall thickness increase from the existing state of development, **FIGURE 4** (red line), does not provide a significant improvement. For this reason, department S decides to perform the same investigation with the inner panel of the sill (T3353, **FIGURE 3**). However, this variable, which is the second most sensitive for department S, also influences the stiffness, **TABLE 1**. When looking at **FIGURE 4** (right), though, it becomes clear that increasing the wall thickness has a positive effect for both departments. The OLC increases only negligibly. Since the local confidence is the worst of all requirement values, department S should inform department F about any changes.

In order to reach the target, department S thickens the inner panel of the sill from 1.5 to 1.9 mm and predicts an improvement in the value range of 5.09 % (compared to the forecasted initial design). At the same time, department S predicts that the stiffness improves by 6.84 % and the OLC declines by 0.36 % in the respective value ranges.

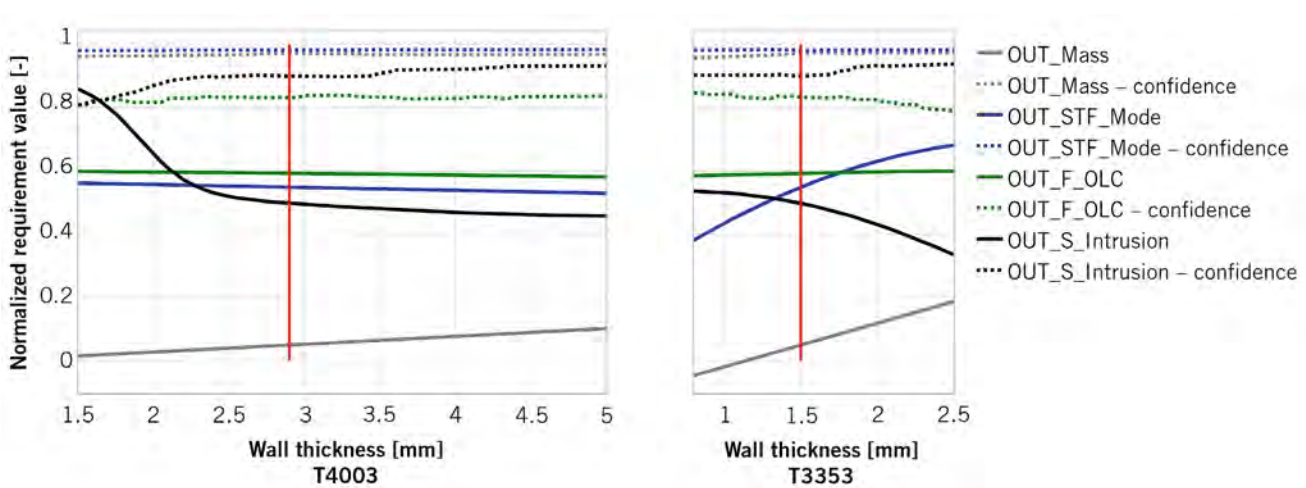

FIGURE 4 Normalized requirement values depending on the T4003 (left) and T3353 variable change (right) (© Porsche)

Upon request of department S, department F provides feedback that this deterioration is not a problem. With this knowledge each department can now perform a verification simulation. After this verification, department S even achieves an improvement in the value range of 7.38 % compared to the FEM-calculated initial design.

Although the improvement in stiffness of 6.09 % is slightly less than predicted, department STF is nevertheless pleased about the additional security in the target fulfillment. To compensate for the 5.51 % increase in mass in the value range, they also plan to adjust one or more variables that are only sensitive to their own requirements. Department F gives feedback that after verification, there was even an improvement of the OLC of 1.11 % in the value range.

CONCLUSION AND OUTLOOK

Even with the advantages of a sensitivity matrix being undeniable, its creation requires many samples and is therefore expensive. In the case of the presented example in body development, 1500 samples (variable configurations) and thus 1500 FEM simulations per load case are used as the basis for the approximation models.

In a next step of method development for the global sensitivity matrix, it will have to be examined by how much the size of the DoE (and therefore the number of simulations required) can be reduced without losing significant accuracy of the approximation models and therefore generating valid statements. Furthermore, it has to be investigated to what extent already existing simulations can be used. However, it is extremely difficult to obtain information from partly non-parameterized simulations. While information such as changes in material and wall thickness can be extracted easily, the retroactive extraction of changes in geometry and joining technology is much more complex and will still pose great challenges to the automotive industry.

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Rimac | IAV | **Electric Sports Car with a 1408-kW Powertrain**

© Rimac

The Croatian sports car manufacturer Rimac Automobili and the Berlin-based engineering specialist IAV are cooperating on the development of the C_Two electric hypercar. Alongside other components, IAV is testing the heart of the new vehicle, the 1408-kW electric drive system, with the aim of achieving series production readiness and certification in 2021. Four independently operating permanent-magnet electric motors and all-wheel drive provide a top speed of 412 km/h and a powertrain torque of 2300 Nm, accelerating the car from 0 to 100 km/h in less than 2 s. A speed of 300 km/h is reached in just 11.6 s. The lithium nickel manganese battery with a capacity of 120 kWh is said to allow a range of 550 km according to WLTP. The car is equipped with eight cameras for its ADAS features, including front stereo vision, lidar system, six radar units, and twelve ultrasonic units.

Magna | Fisker | **Electric SUV with Single-chip Radar**

© Fisker

Magna and Fisker have confirmed that they are working together to develop driver assistance systems for the Fisker Ocean electric SUV, which is expected to be launched at the end of 2022. This represents an important expansion of the EV platform sharing, vehicle engineering, and manufacturing cooperation that the two companies announced last October. They say that their cooperation is aimed at developing unique ADAS features and a suite of software packages based on a scalable domain controller architecture.

In addition to using cameras and ultrasonic sensors, the ADAS package includes digital imaging radar technology. The system, which is called Icon Radar, was co-developed with the technology start-up Uhnder, and is claimed to be the first digital imaging single-chip radar solution for the automotive market.

Hyundai Motor Group | **Rear-wheel Drive BEV Platform**

Hyundai Motor Group, which includes the brands Hyundai, Kia, and Genesis, has developed a dedicated platform for Battery Electric Vehicles (BEV) with rear-wheel drive and 800 V technology. The Electric-Global Modular Platform (E-GMP) forms the basis for the Group's next generation of electric vehicles and will be used in the Hyundai Ioniq 5 in 2021. According to Hyundai, the platform has a modular design and a high level of standardization, thus enabling it to be used in sedans as well as in SUV and crossover models. Enhanced ride comfort and handling stability are ensured by a five-link rear suspension system and an integrated drive axle, which consists of drive shafts, wheel bearings and wheels for power transmission. The energy density of the battery, which is integrated into the floor between the front and rear wheel axles, will be approximately ten percent higher compared to Hyundai's existing EV battery technology.

© Autoneum

Autoneum | **Lightweight Trunk for Electric Cars**

The front trunk for electric cars produced by Autoneum provides more luggage space and helps reduce weight. This multifunctional component made from Ultra-Silent is especially lightweight because of its textile fibers and is intended to replace the heavy plastic solutions consisting of several individual components that are common in electric cars today. The new trunk will reduce the weight of an electric car by 3 kg and its sound-absorbent textile materials will improve the vehicle's acoustics.

© Walki

Walki | **Insulating Skins**

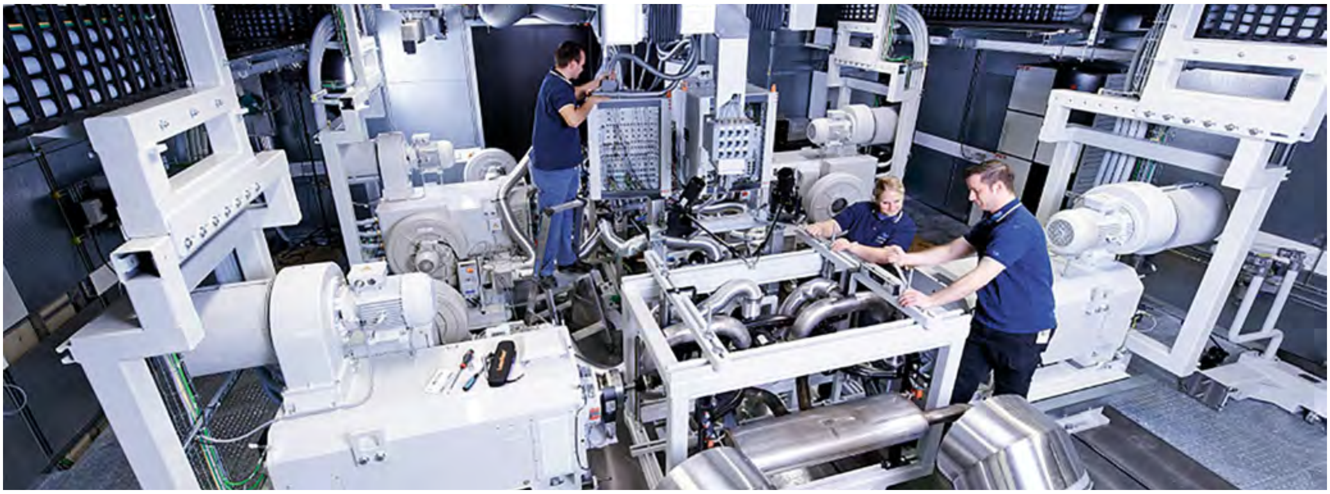
The lightweight, flame-retardant, sound-insulating vehicle skins developed by Walki will help to reduce the environmental impact of all types of vehicles. The skins are made from multifunctional, thermo-formable materials that always form a structural component of an item of interior or exterior trim. Skins can be found in every area of vehicles including engine covers, hood trims, underbody shields, roof linings, wheel arch linings, carpets and trunk floors.

© Tenneco

Tenneco | **Mercedes AMG with Electronic Dampers**

The sixth generation of the Mercedes AMG Black Series features Monroe Intelligent Suspension multi-stage adjustable damping using CVSA2 technology, which was developed and manufactured by Tenneco's DRiV division. It enables the driver to select different damping modes. The core component of the system comprises two lightweight semi-active dampers equipped with two externally mounted electro-hydraulic valves that independently control rebound and compression. The dampers adjust within milliseconds to respond to changing road conditions.

FVV | **Research on Efficiency**



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Four university research institutes have investigated on behalf of the Research Association for Internal Combustion Engines (FVV) to what extent the efficiency of internal combustion engines in hybrid powertrains can be increased. In a hybridized mid-range vehicle, the spark-ignition engine developed within the research project already used 42 % of the energy that is bound in the fuel. Further investigations showed that the overall efficiency can be enhanced to approximately 46 % by using new fuels, such as methanol that is produced from renewable resources. At the end of the project, the researchers examined the potential of lean engine operation, which is operation with a high excess of air. The results showed that engine efficiency can be increased by two to three percentage points over a wide range of engine characteristics. This means that an efficiency of 50 % is within reach.

© Huf

Huf | **Optimized Kick Sensor**

The automotive industry supplier Huf has imroved its kick sensor for operating the tailgate and sliding doors. The power consumption of the new sensor is half that of the previous version and the weight around 20 % less. In addition, it is much more compact than its predecessor. Its height has been reduced by a third, which means that it will fit not only in all rear bumpers, but also in side sills. As a result, it will be possible to open electric sliding doors with a foot movement. The housing also offers better protection against dust, dirt and weather.

© Fischer

Fischer | **Automatic Charger Socket Cover**

Fischer Automotive has developed a fully automated cover for the charging socket of the Xpeng P7 battery electric sedan produced by Chinese car manufacturer Xiaopeng. The cover can be opened with a key, a voice command or the controls in the vehicle's cockpit. Every car has one charging port on the left-hand side and one on the right for one large and one small battery with different charging speeds. The drive and locking mechanism is operated by two actuators, and the mechanical and electronic components are fitted into a very small space.

© Vibracoustic

Vibracoustic | **Decoupling Solution for eCompressors**

Vibracoustic has launched a decoupling system for electrically driven compressors (eCompressors) fitted to modern battery-electric and plug-in hybrid vehicles. The design of the bearing and mounting assembly is aimed at improving the thermal management of the battery and at the same time compensating for excessive noise and vibration from highly loaded eCompressors. By conducting comprehensive elastomer simulation and testing, for example to determine the ideal rubber compound, the company was able to design the rubber components for minimum wear and maximum service life.

Simet | **Process for Reducing Weight**

© Simet

Simet, a company based in Turin (Italy), specializes in the surface treatment of metals and has developed a process to reduce the weight of vehicle bodies by means of thermal and chemical coating removal and chemical etching. The company has been working on this concept, which uses an environmentally friendly method of chemical milling, since 2017. The process is known as Green Etching and involves immersing the material in a chemical bath to reduce its thickness evenly and consistently. After the initial etching stage, the components undergo two washing phases, another immersion to inhibit the process and two rinse phases. During the experiments with the process using aluminum components, the company identified a number of other benefits, which included improvements in the roughness, the appearance and the corrosion resistance of the surface. However, the mechanical and technical properties of the material remained unaffected.

© Volkswagen

Volkswagen | **Autonomous Charging Robot**

Volkswagen Group Components has presented its prototype of a mobile charging robot, which is started via an app or Car-to-X communication and enables fully autonomous charging of vehicles in restricted parking areas, such as underground car parks. It independently approaches the vehicle to be charged and communicates with it, from opening the charging socket flap to connecting the plug and decoupling it. The entire charging process takes place without any human involvement whatsoever. In order to charge several vehicles at the same time, the mobile robot moves a trailer as a mobile energy storage unit to the vehicle, connects it up, and uses this unit to charge the battery of the electric vehicle. In the meantime, the robot can go to other electric vehicles and charge them in the same way. Once the charging service has ended, the robot independently collects the mobile energy storage unit and takes it back to the central charging station.

Organo Sheet Door Technologies for Tougher Crash Standards

© Brose

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Door modules with innovative carrier materials help to meet stricter crash test guidelines while saving weight and costs. The possibilities offered by the carrier plates made of continuous glass-fiber-reinforced thermoplastics, so-called organo sheets, used by Brose are promising.

The Insurance Institute for Highway Safety (IIHS) is one of the world's leading institutions for vehicle safety assessment. Accordingly, the industry is watching with great interest for adjustments to the IIHS test criteria. The next milestone will be in 2023, when vehicle flanks will have to withstand over 80 % more energy in a side impact than before. Against this background, car manufacturers are not only examining the design of their bodies but also the door structures used. Brose frequently receives one question from customers: Is it possible that door modules have a negative impact on the test results? After all, a more or less generous hole is cut in the middle of the door and covered with a plastic panel.

The short answer: No, the use of such door systems does not adversely affect the crash values – on the contrary, door modules can even enable new approaches in dealing with the new test procedure. For a detailed explanation, the authors first take a look at the classic structure of door modules, then consider the requirements of the new test system and finally analyze the possibilities offered by the use of innovative carrier materials.

PRE-TESTED SYSTEMS FOR UNCOMPLICATED ASSEMBLY PROCESSES

The door module principle has been used in the automotive industry for decades: At the end of the 1980s, Brose was the first supplier to combine the most important functional components of the vehicle door into one system.
In the conventional construction of

side doors, many individual components must first be assembled on a door assembly line. With the modular construction method, however, the OEMs receives the system as a pretested unit from the supplier, **FIGURE 1**. It can be inserted into the door frame with just a few hand movements. The more functions of the door are integrated in the module, the less additional work has to be carried out until the side door is attached to the body. Various equipment variants are already implemented at the supplier and, if required, are made available just-in-sequence, which means in line with the customer‘s production cycle.

The advantages of the modular design become even clearer the more functions are integrated on the unit carrier. In addition to fastening elements, for example for the cable harness, the window regulator rails in particular can be implemented directly in the plastic carrier. As a result of this measure, the system can do without Bowden cables, which improves efficiency by at least 10 % and allows the use of smaller motors.

DOOR MODULES IN A SIDE CRASH

Even with the adapted IIHS system, the basic criteria for lateral crash testing will remain unchanged. In addition to the effects on the dummy, the speed and depth of the intrusion on the side of the vehicle, the opening behavior of the side airbags and potential splintering are evaluated. First of all, the key factor for the test result is the structural integrity of the body, and in particular how the B-pillar, roof sills and floor assembly are designed. Secondarily, the A- and C-pillars as well as additional reinforcements are included in the evaluation. Inside the door, only the hinges, the lock as well as the sill cover and the side impact beam are relevant. The interior area of the door, in which the module is located, only plays a minor role. Therefore, the decision for or against the modular design has only minimal effects on the test result of the vehicle.

Nevertheless, there are basic requirements for crash-compatible door modules, for example from European legislation on type approval: The doors must not open during the test but must be able to be opened after the impact. A further challenge is the interaction between door module and interior door panel. The paneling serves as a partition between passenger and module, which must not be broken through even in the event of an accident. For this reason, measures such as adapted layout and positioning of the components in the door during design ensure that assembly parts cannot become projectiles and that no sharp-edged fragments break off from the carrier plate.

In the future, however, vehicles will have to be able to withstand crash loads at a higher level in the event of a side impact. According to the announcements of the IIHS, mass and impact velocity of the barrier will increase. The energy input will change from 290 kN before to 530 kN – the increase of more than 80 % mentioned at the beginning. In addition, a barrier with less ground clearance and higher compressive stiffness in the lower third will make the test more realistic. This results in high loads, particularly in the lower half of the vehicle side wall, which impact on the sills, the B-pillar connection, the door and the side impact beam. A further consequence is a higher penetration depth at the doors as well as a rolling motion of the hit vehicle. Especially the B-pillar is exposed to high loads.

Vehicle manufacturers have to react to the increased requirements with adjustments to the vehicle body. Even if door modules are not directly affected in a side crash as shown, they can still support OEMs in this task. The possibilities are particularly promising when using carrier plates made of continuous glass-fiber-reinforced thermoplastics, so-called organo sheets.

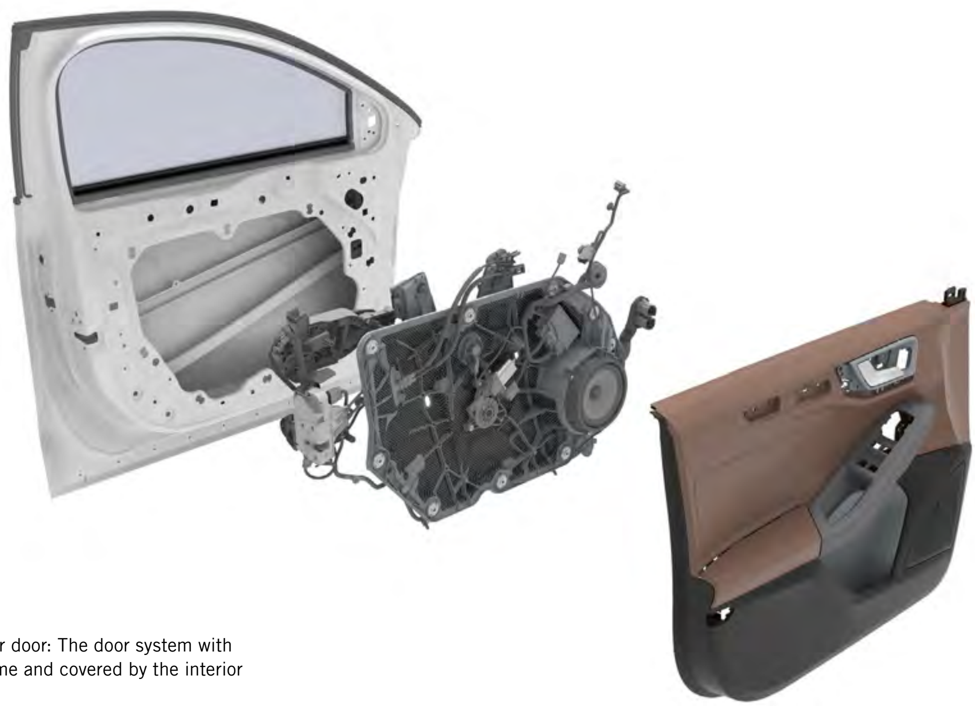


FIGURE 1 Established structure of a modular door: The door system with all components is attached to the door frame and covered by the interior paneling (© Brose)

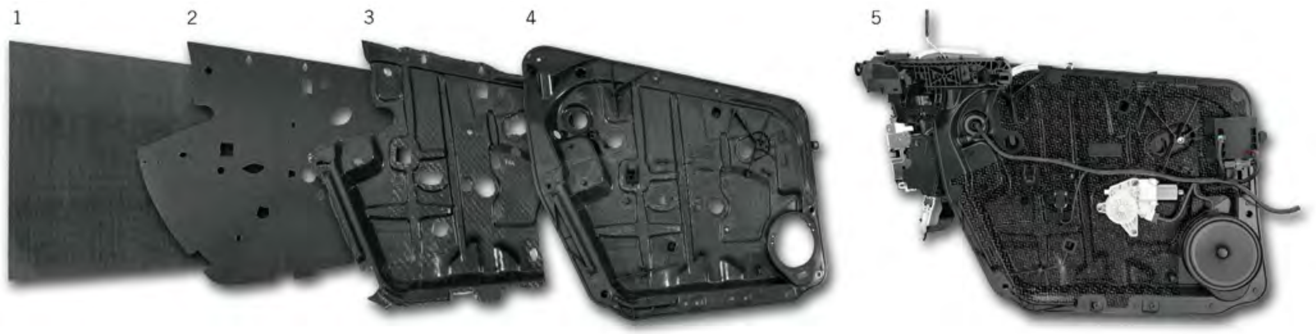


FIGURE 2 The production steps in organic sheet production (from left to right): The sheet (1) is first punched (2) and then softened by heat; in the tool, the carrier plate is formed (3) and back-injected (4) with fiber-reinforced plastic; (5) shows the finished door module with assembled components (© Brose)

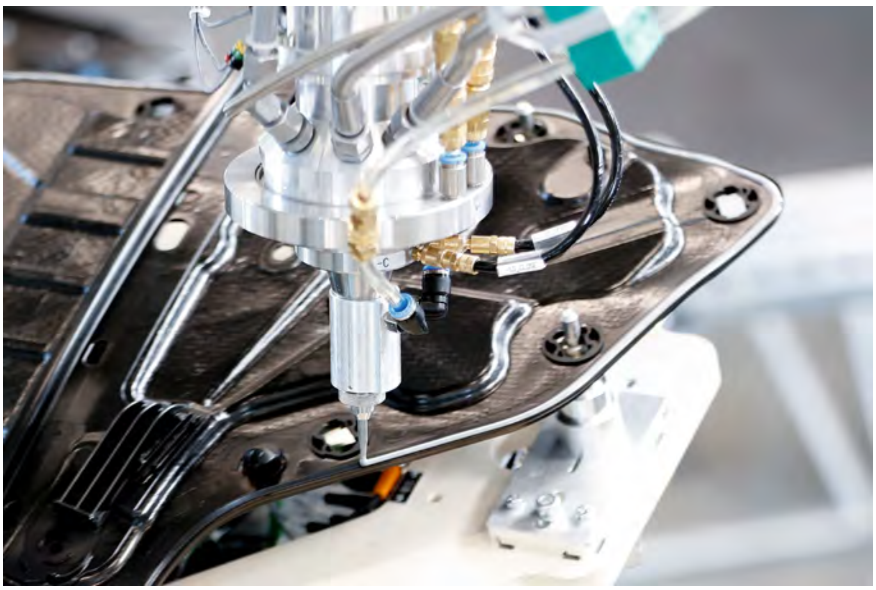


FIGURE 3 Attaching the sealing to an organo door module at the Brose Technikum in Hallstadt: There and in its own crash center, the automotive supplier carries out the validation of the door systems (© Brose)

WEIGHT REDUCTION WITH FUNCTIONAL ADVANTAGES

Organo sheet is an innovative lightweight construction material. It consists of glass fiber fabric embedded in a thermoplastic matrix. When the material is heated, it acquires a soft consistency and can be pressed into the desired shape. At the same time, reinforcements and functional elements made of plastic can be attached by back-injection, **FIGURE 2** and **FIGURE 3**. This process is carried out in a conventional injection molding machine using appropriate tools.

Brose has been manufacturing door modules made of organo sheet in large series since 2018. Compared to conventional plastic door systems made of PP-LGF30, this results in a weight advantage of 45 % or up to 2 kg per vehicle – and with better crash behavior. The carrier made of fabric-reinforced plastic absorbs up to four times more energy and is correspondingly more robust. In addition, much more stable connections to the body are possible, as holes are made during the forming process to protect the fibers. Organo sheet has already proven its suitability as a material for a safety-relevant structural component – namely in a foldable rear seat shelf, which Brose has been supplying for the Land Rover Discovery since 2016. Injection-molded elements such as a ribbed structure and screw bosses made of glass-fiber-reinforced polypropylene increase rigidity and provide interfaces for add-on parts. Compared to the conventional steel version weighing around 4 kg, the loader also saves around 40 % of the weight.

It stands to reason that the advantages of organic sheet should be exploited when dealing with the new crash requirements. On the one hand, the weight saved can at least partially offset the additional weight by necessary reinforcements in the body. On the other hand, it is worth taking a closer look at the possibilities of functional integration, for example of crash elements. This category distinguishes between paddings and pushers. A crash pad works like a cushion: it absorbs the incoming energy and transmits it with a time delay. Such elements are mainly used at the beginning of the crash process to influence the dummy movement. In addition, so-called pushers can transmit the force to connected objects during the collision. Classically, such elements are found in the area of the B-pillar. They transmit the loads of the side impact with strong intrusion to the seat structure, for example. Considering the new challenges, the integration of pads and pusher elements directly into the aggregate carrier or as an assembly part on the door system is feasible. This way, the additional safety precautions do not result in new assembly steps on the manufacturer‘s line, as the complete module is placed in the door with a single action.

EVOLUTION TO A STRUCTURAL MODULE

Further areas of application emerge when the system limits of the door modules are extended so that they also take over static structural tasks in the door. This development was unthinkable before the use of thermoplastic fiber composites with their superior material properties. In the future, the door body shell can be designed in such a way that

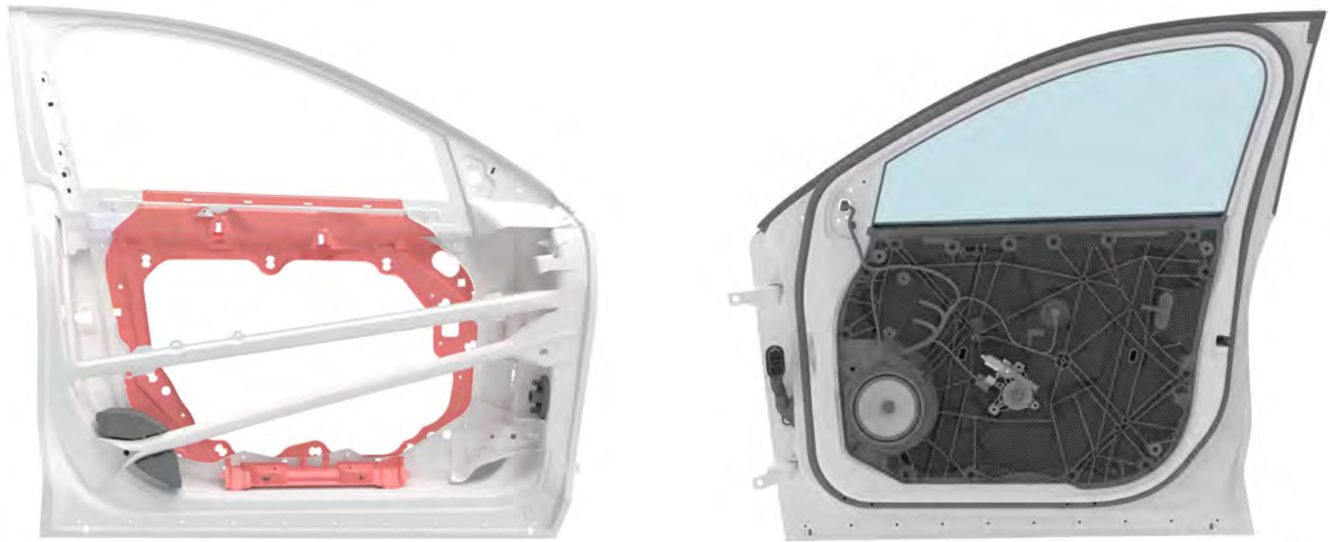


FIGURE 4 Replacing large metallic areas (left, in red) with the structural module enables additional weight savings of around 1 kg per door (© Brose)

it only achieves its full rigidity in combination with this so-called structural module. As a result, it will not only be possible to significantly enlarge the cut-out in the inner part of the door, **FIGURE 4**, but also to omit complete components such as metallic reinforcements, crash pads or pushers. Their function is then assumed by the structural module. In addition to the obvious weight loss, this procedure also brings significant cost advantages for the manufacturer, as in addition to the components, the corresponding tools and joining processes are no longer required.

The extended structural modules have already been fully validated at Brose, **FIGURE 5**. The new approach enables weight savings of more than 4 kg per vehicle compared to standard organo sheet metal modules, which are already lightweight. Compared to a conventional door design, the difference is as much as 8 kg. It is important to note that this innovative approach requires the vehicle manufacturer to involve the supplier in the development process at an early stage. After all, the simulations required to design the body can only be carried out with the aid of precise data on the structural module and its connection to the door. Although this coordination may seem unusual at present, it is the only way to achieve the greatest possible advantages in terms of crash behavior and weight – and at lower cost.

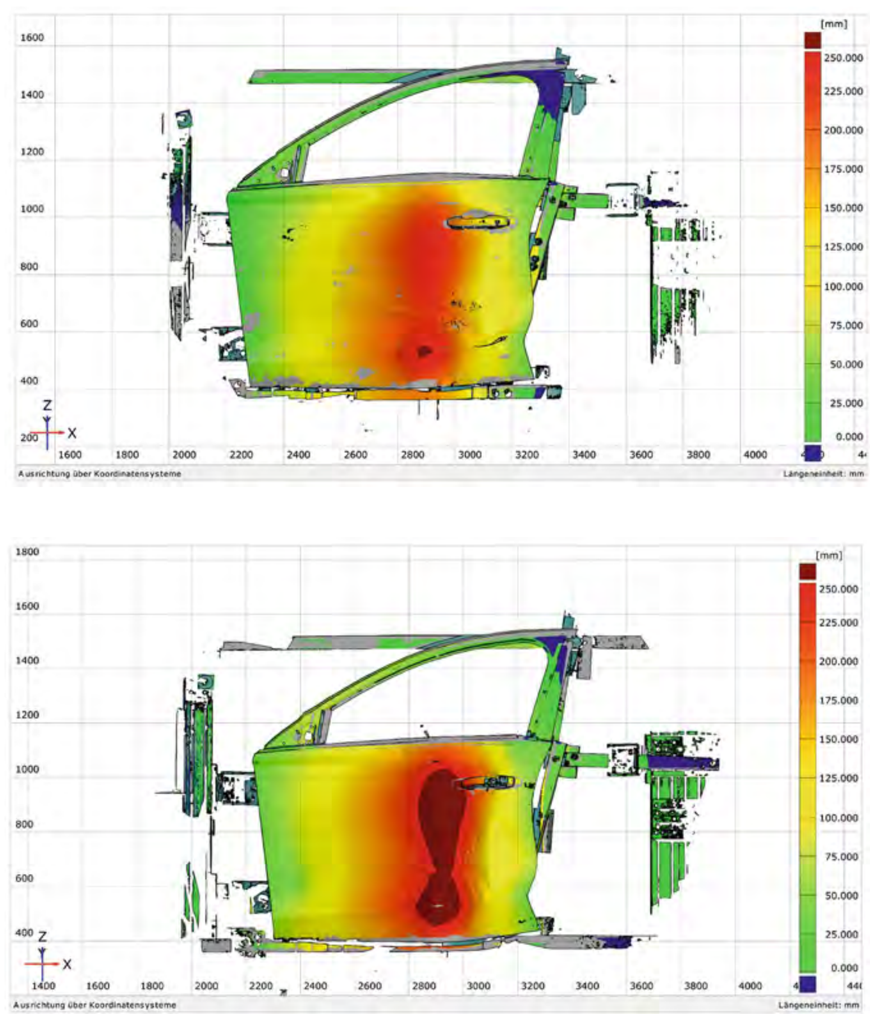
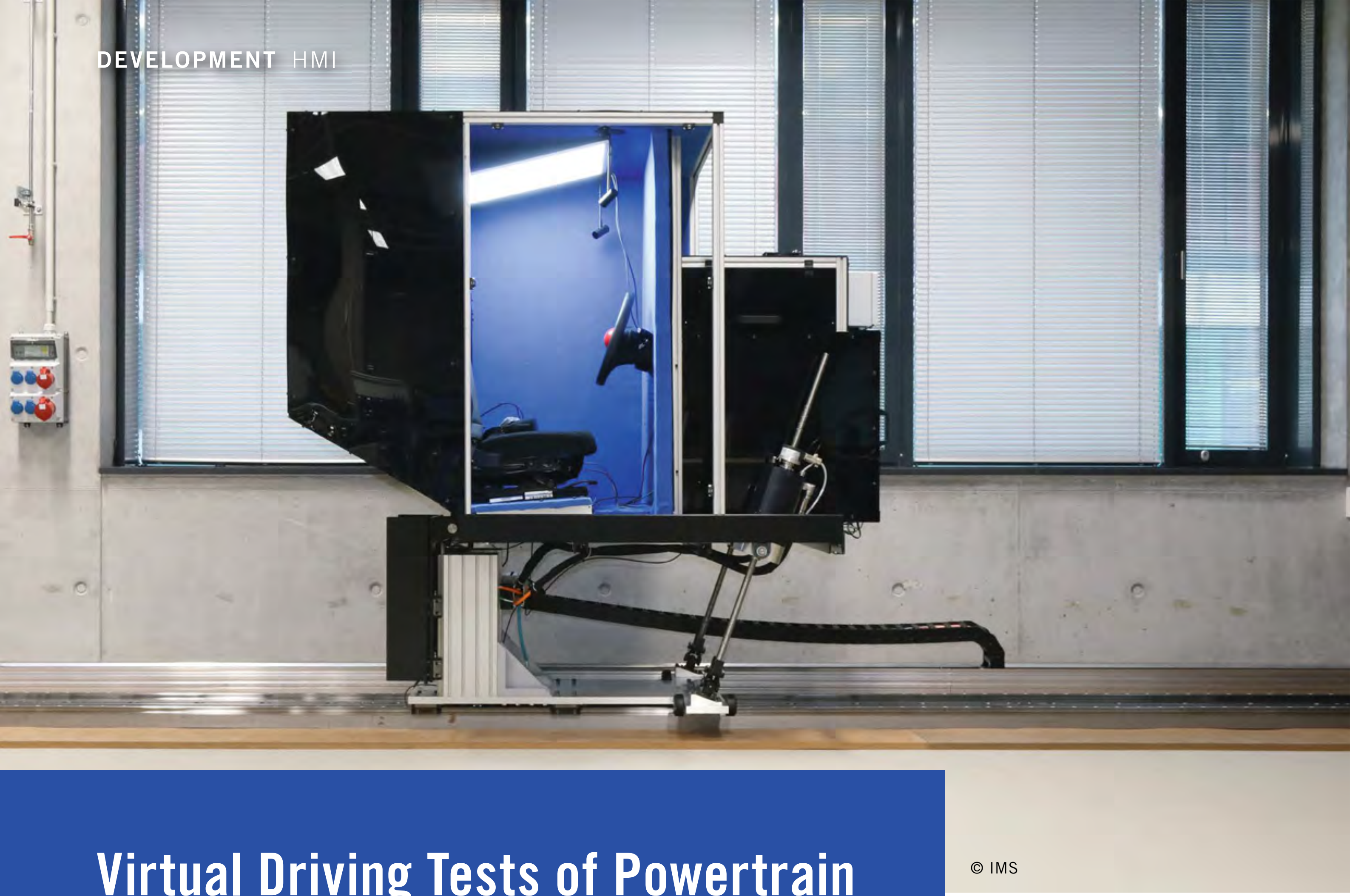


FIGURE 5 Structural modules can also have a positive effect on crash results: In this pole crash, the depth of penetration of the door with a structural module (top) was 35 mm less than that of the series door with the conventional large module (bottom) (both made of organic sheet) (© Brose)



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Virtual Driving Tests of Powertrain Systems in the Driving Simulator

The subjective evaluation of driving maneuvers in the early stages of development is a challenge. At TU Darmstadt, a special driving simulator was developed to address this task. The results obtained show how subjective driving impressions of test subjects can be examined and evaluated early on.

At the Institute for Mechatronic Systems in Mechanical Engineering (IMS) at TU Darmstadt, a longitudinal dynamic driving simulator was developed that is used to investigate human perception (human factors) in the context of the Vehicle 5.0 research network [1]. The focus of the studies carried out with the so-called Driveception is on longitudinal dynamic driving maneuvers such as launch or gear shifting processes with conventional and electrified drives. Driving simulators offer the following advantages:

- high reproducibility due to identical, controllable test conditions
- high variability of the test design
- specific investigation of factors influencing human perception
- neutral, brand- and model-independent test environment
- reduction of time and costs.

The Driveception enables studies on the subjective evaluation of driving dynamics and comfort in early development stages, when no vehicle is available at the time, **FIGURE 1**. In addition, the scope of testing and application of prototype and development vehicles can be transferred to the driving simulator. Thus, the extended investigation possibilities contribute to increasing the technical maturity of vehicles while taking subjective criteria into account.

MOTION SYSTEM

The new simulator is characterized by a compact and cost-effective design. The test subject sits in a cabin, which is located on a longitudinal dynamic motion system. The motion system

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consists of a gearless linear drive, which translationally accelerates the entire setup. In addition, the combined movement via a lifting actuator and two parallel-acting hollow shaft motors allows the cabin to rotate (inclination θ) about a point of rotation at the level of the test subject‘s equilibrium organ [2], **FIGURE 2**.

A Motion Cueing Algorithm (MCA) enables the optimal split of the acceleration into a high-frequency component, which is represented by the linear motion, and a low-frequency component, which is generated by the inclination of the cabin [3]. Consequently, the acceleration perceived by the test subject is composed of a part of the horizontal movement and a part of the gravitational acceleration directed in the longitudinal direction of the test subject, which results from the inclination of the cabin. Due to the combined longitudinal and rotational motion, perceived accelerations of more than 5 m/s² can be achieved.

HUMAN MACHINE INTERFACE

The test subject can use the accelerator and brake pedal as interfaces to the Driveception, **FIGURE 3**. For example, the active brake pedal can be used to simulate and subjectively evaluate different pedal feelings by means of different dis-

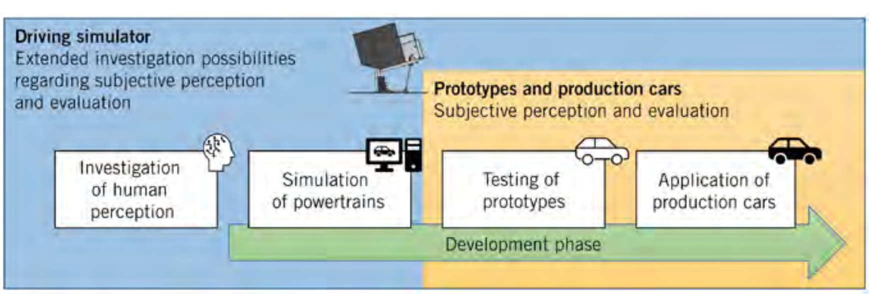

FIGURE 1 Extended investigation possibilities for the subjective evaluation of human factors in vehicle development (© IMS)

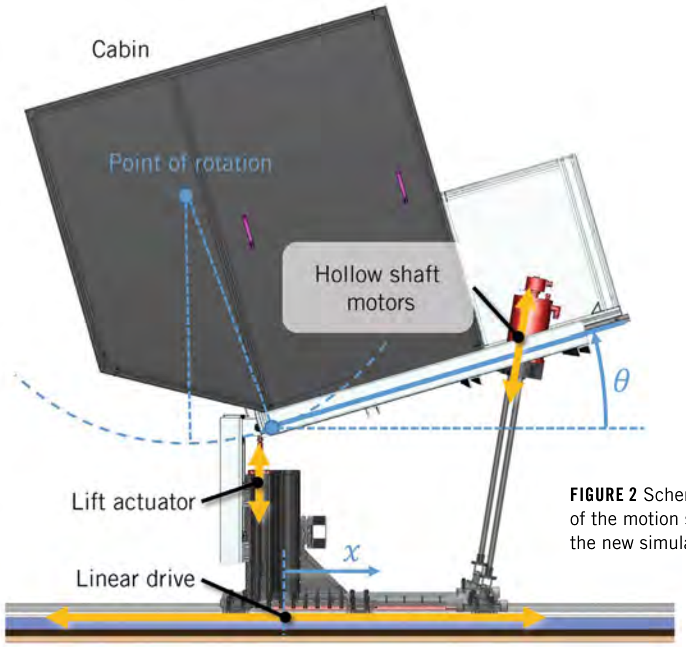

FIGURE 2 Schematic structure of the motion system of the new simulator (© IMS)

placement-force characteristics. For further interaction, manual gear shifting can be performed with the standard steering wheel-mounted shift paddles.

The virtual reality in the Driveception creates a multimodal sensory impression of a real ride. For the visual sensory stimulus, the test subject is presented a virtual vehicle interior and environment via a virtual reality headset. The acoustic stimulation is achieved by reproducing driving noises via noise-cancelling headphones. For this purpose, speed- and torque-dependent engine noise and speed-dependent wind and rolling noises are extracted from measurement data and synthesized for the corresponding driving situation in the Driveception. To provide haptic feedback, shakers under the driver's seat, on the accelerator pedal and on the steering wheel can also generate situation-adapted vibrations.

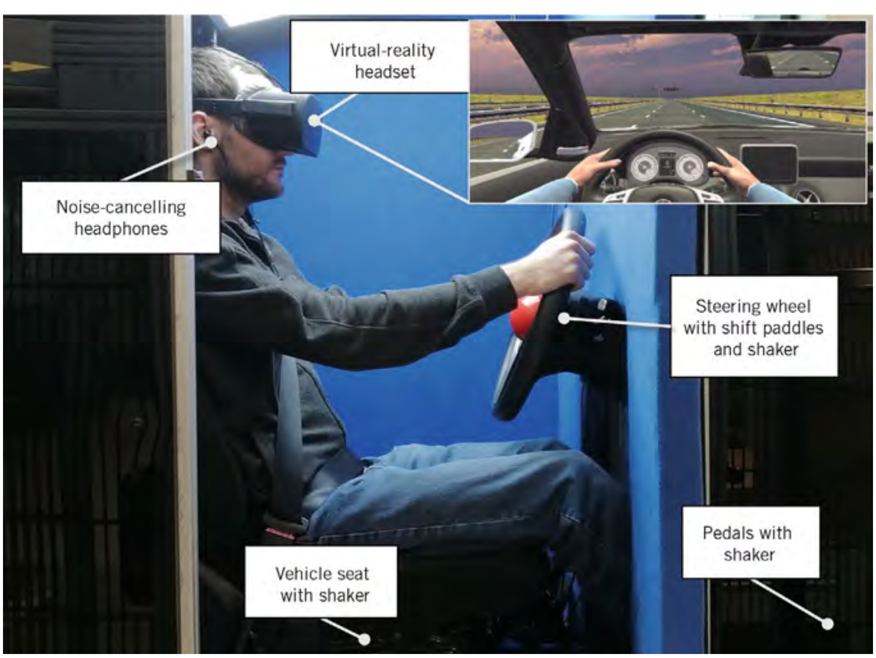

FIGURE 3 Human machine interfaces in the Driveception (© IMS)

VALIDATION STUDY ON THE SUBJECTIVE PERCEPTION OF ACCELERATION

Within the scope of a validation study, subjective acceleration impressions in the Driveception and in a series-production car are compared with each other. For this purpose, test subjects are asked to act as passengers and evaluate three acceleration maneuvers of different intensity in both test environments. Since the test subjects do not actively influence the driving action, a high focus on the evaluation of motion perception is ensured. In addition, to reduce the influence of engine and ambient noise, noise is played via the noise-cancelling headphones. Performing the experiment without active test subject interaction does not require real-time calculation of the acceleration trajectories, so that they can be calculated offline in advance [3].

FIGURE 4 shows the test procedure: At the beginning, the test subjects evaluate a launch process in the vehicle, which is executed several times with a constant Accelerator Pedal Position (APP). This launch process is repeated with an almost identical acceleration profile in the Driveception and is also evaluated. The test subjects perform this sequence with three maneuvers with maximum accelerations of 2.5, 3.3 and 3.9 m/s². After the maneuvers in a test environment, they assess various criteria relevant to drivability such as acceleration strength, jerk and jerking on a scale of 1 (very weak) to 10 (very strong) [3].

The results for the evaluation of the acceleration strength in the three maneuvers show that the test subjects perceive the difference in acceleration strength for different accelerator pedal positions in both test environments, **FIGURE 4**. In addition, the strength assessments also correlate with the increase in maximum acceleration. Furthermore, a statistical analysis shows no significant differences between the evaluations in the vehicle and in the Driveception. In particular, the consistent evaluation of the strongest launch maneuver is noteworthy, since the acceleration of 3.9 m/s² in the limited motion space of dynamic simulators is a great challenge. Overall, the results indicate that in the Driveception the assessment of the acceleration strength can be made in the same way as in the vehicle.

However, the evaluation of the comfort aspects of jerk and jerking do not show a consistent picture. The results show partially high similarities but also significant differences between the test environments. It is noticeable that even the evaluation of the tests in the vehicle does not show the expected trend. No correlation could be found between the assessment of the comfort aspect and the actual characteristics. Therefore, the result suggests that untrained test subjects have difficulty evaluating several drivability-relevant criteria of a complex launch maneuver simultaneously.

SUBJECTIVE EVALUATION OF SHIFTING PROCESSES IN AN ELECTRIFIED VEHICLE DRIVE

In a further study, a driving maneuver recorded in a demonstrator vehicle called DE-REX (two-drive transmission with range-extender [4]) is transferred to the simulator. The DE-REX vehicle uses a dedicated hybrid transmission with two subtransmissions with two gears each. An electric motor is connected to each subtransmission, which is functionally integrated into the transmission and thus takes over transmission functions during

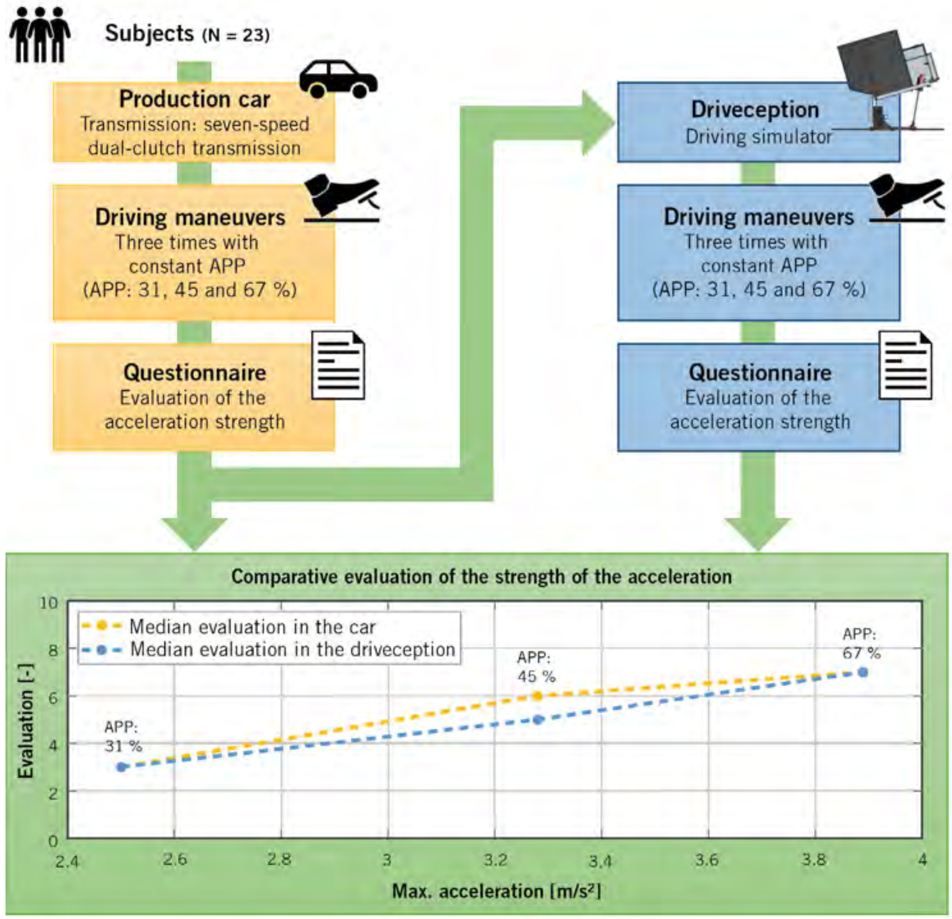

FIGURE 4 Execution and results of the validation study on the perception of acceleration strength (© IMS)

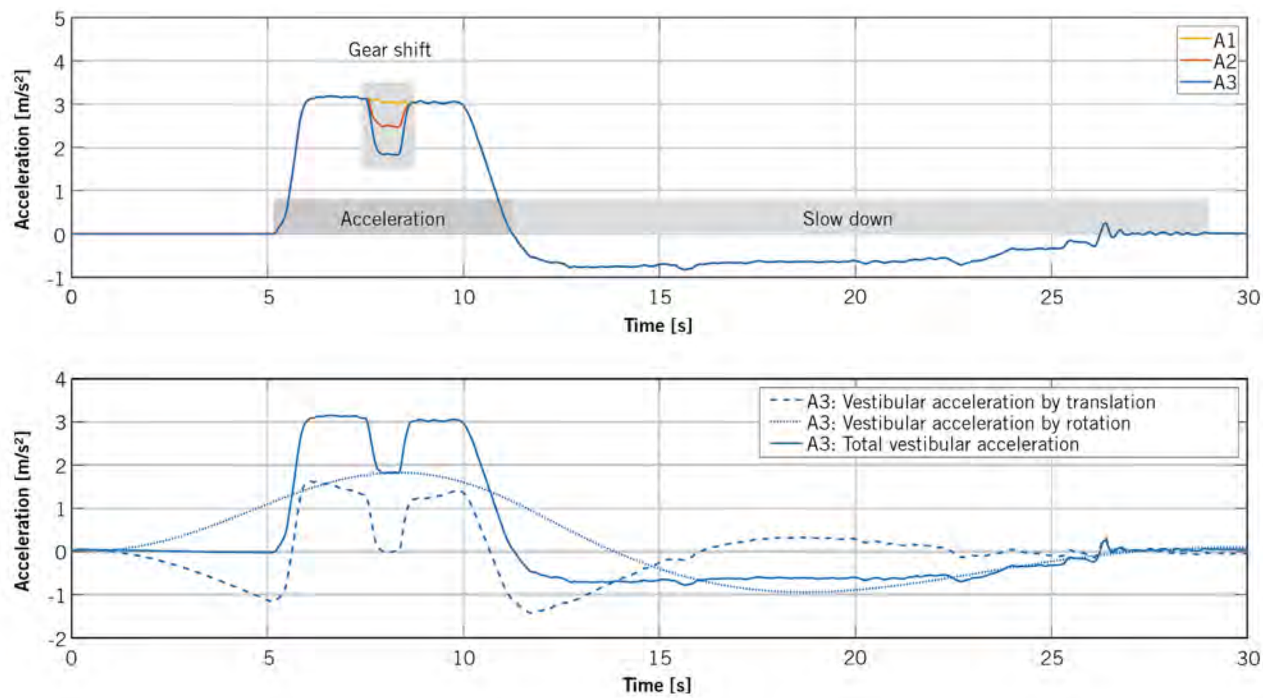

FIGURE 5 Comparison of the application and spliting of the acceleration components by the MCA in test variant A3 (© IMS)

gear shifts. The high level of shifting comfort was shown on the basis of subjective evaluations in the demonstrator vehicle [4].

The aim of this study is to subjectively evaluate three potential application variants of an up-shift in purely electric operation. The driving maneuver consists of an acceleration up to 50 km/h with a constant accelerator pedal position of 80 %. At the beginning, in both subtransmissions the first gear is engaged. At a vehicle speed of about 20 km/h, an upshift of one subtransmission into second gear takes place. Finally, the vehicle is braked to standstill.

In order to compare the three different application variants (A1, A2, A3), the acceleration level – and thus the traction force support – is varied during the shifting process, **FIGURE 5** (top). Starting with a traction force support of 80 % in the DE-REX vehicle in variant A2, the acceleration level is raised (100 % traction force support in A1) and lowered (60 % traction force support in A3). It is expected that an increase in the traction force support will lead to an increase in shifting comfort. Application variant A3 is used to investigate whether a targeted reduction of the traction force support can contribute to increasing the perceived sportiness.

As an example for application A3, **FIGURE 5** (bottom) shows the splitting of the acceleration components by the MCA into the translation and rotation of the driver‘s cabin of the Driveception. It can be observed that the high-frequency acceleration components (for example the decrease in traction force during gear shift) are performed by the translational linear drive. The low-frequency acceleration components are emulated by the rotation of the cabin.

During the test, the test subjects experience the various acceleration profiles A1 to A3 once each time and then evaluate the shifting processes on a five-level Likert scale with regard to perceptibility, dynamics, sportiness, comfort, jerkiness and strength (based on [5]).

The results of the subjective evaluation clearly indicate that, as expected, the shifting process with 100 % traction support in variant A1 tends to be assessed as not noticeable, fluid and comfortable, **FIGURE 6**. However, this driving maneuver is rated as comparatively unsporty. In contrast, the acceleration profile A2, which is based on the current application in the DE-REX vehicle, and application variant A3 are assessed as more noticeable and even more sporty due to the slight decrease in tractive force. The evaluation of the perceived dynamics is classified as difficult by the test subjects for the selected

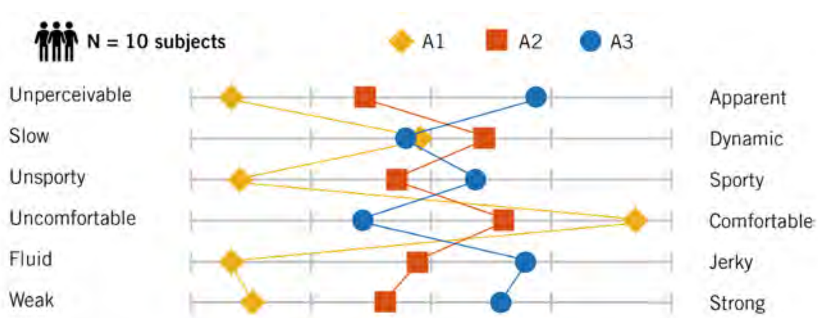

FIGURE 6 Results of the subjective evaluation of the three application variants of the gear shifting process (© IMS)

maneuvers. Therefore, there is a tendency to choose the neutral middle of the Likert scale. In conclusion, if the focus is on a high level of shifting comfort, a full traction support as in variant A1 should be aimed for. For a sporty perception, however, variants with a reduction in traction force during gear shift can also be specifically applied. On the basis of these findings, the new simulator provides the basis for further investigations into the influence of shift-comfort-relevant factors.

SUMMARY AND OUTLOOK

The Driveception driving simulator offers the possibility to conduct focused investigations in the context of human perception in longitudinal dynamic driving maneuvers under reproducible and variably adjustable test conditions. Especially in early development stages without hardware, the driving simulator can provide a valuable contribution to making driving experience perceptible. The results of a validation study show a good transferability of the perception evaluation from the production car to the Driveception. In addition, a study on gear shifting shows how the Driveception can be used for the subjective evaluation of different application variants. The simulator will also be used in the future for further research activities at IMS and in cooperation with automobile manufacturers and suppliers for various proband studies.

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Holistic, Context-sensitive Human-machine Interaction for Automated Vehicles

Situations in road traffic can quickly become confusing due to their high complexity and dynamic development, especially if one does not concentrate. DLR is investigating how this challenge will become more acute by reason of mixed traffic situations with new types of vehicles, new mobility options and increasing connectivity and automation.

Due to the growing complexity, the design of cooperation and interaction and the necessary Human-machine Interface (HMI) will play an even more important role. It is the basis for people in traffic to understand the situation and correctly anticipate the behavior of other road users. This is the only way to achieve acceptance and an adequate level of trust, especially in new technologies such as automation. In particular, traffic safety can only be guaranteed if misunderstandings are avoided in time.

Increasing automation also leads to necessary paradigm shifts in HMI design. One decisive change is that, on the one hand, the role of the driver is increasingly changing to that of a user and the vehicle automation can be regarded as an independent cooperation partner. For example, a bilateral interaction between a driver and a crossing pedestrian will become a multilateral interaction between the automation and the pedestrian, the automation and the driver/user of the vehicle, and possibly in parallel between the driver/user of the vehicle and the pedestrian. From the outside, it may be difficult to tell who is driving the car and who is currently making the decisions. Hence, HMI design is tasked with the prevention of any potential misunderstandings, it

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must ensure a consistent communication within the vehicle and toward other traffic participants, and it should address the new specific user needs that depend on the user and the situation.

SUCCESSFUL HUMAN-MACHINE INTERACTION

Successful human-machine interaction must therefore be designed holistically and context-sensitive, but what does this mean and how can this be achieved? The HMI consists of several channels, especially visual and acoustic channels, but within the vehicle also haptic channels through tactile and kinesthetic interaction. The HMI consists of an inward part through the internal HMI (iHMI) and an outward part through the external HMI (eHMI). In addition, there is both explicit interaction through interfaces such as displays or targeted acoustic signals and an ever-present implicit interaction, which occurs in particular through the dynamic movement behavior of the vehicles. This dynamic HMI (dHMI) must therefore also be taken into account [1].

The concept of a holistic context-sensitive interaction design means that iHMI, eHMI and dHMI must always appear consistent, especially for automated vehicles, and should therefore be designed together in a holistic fashion. It should also take into account the context of the current state of the user as well as the traffic situation and be able to adapt in a context-sensitive manner. Here, too, the aim is to increase traffic safety and ensure an intuitive understanding between man and technology. While a certain situation can be uncritical for a relaxed, attentive driver or road user, it can become critical for a stressed, frustrated or distracted road user and create different HMI requirements.

HOLISTIC INTERACTION STRATEGIES AND DESIGNS

In numerous research projects, DLR has developed holistic interaction concepts together with partners from research and industry. Every interaction concept requires a basic interaction strategy and concrete implementation concepts.

For automated vehicles of the near future, the following interaction strategies seem promising:

- an intention-based interaction strategy, where the planned driving behavior, for example the "intention" of the vehicle, is communicated
- a perception-based interaction strategy that conveys which other road users have been recognized.

As for implementation concepts, numerous studies have shown that the use of LED bands is promising for a holistic HMI for both the iHMI and the eHMI part. These must each be underpinned by a consistently designed vehicle behavior (dHMI).

With the iHMI part of a holistic HMI, the focus is on creating a common understanding of the current driving situation and a predictable behavior of the automation for the user to avoid surprises through automation. Insufficient knowledge about the situation and the intention of the automation could lead to unnecessary or even dangerous interventions by the user. Especially the perception-based interaction strategy shown in **FIGURE 1** offers great potential for use in a holistic, context-sensitive iHMI in complex traffic scenarios with multiple interaction partners [2].

The outward eHMI part serves to ensure safe, holistic and context-sensitive interaction with other road users. The intention-based and perception-based interaction strategies developed in the EU project "interACT," **FIGURE 2**, have been shown to potentially improve safety, acceptance and traffic flow, possibly even before it is actually necessary [3]. Study results show that these HMI concepts are well suited for interaction with pedestrians in an urban context in terms of acceptance and perceived safety [4]. For intention-based HMI design, for example certain blinking sequences indicate planned and current braking or acceleration of the vehicle so for example a waiting pedestrian knows the vehicle intends to stop. The perception-based

FIGURE 1 Perception-based interaction design on an LED light band as iHMI as displayed in VR development toolchain; interaction with several road users when turning left (© DLR)

FIGURE 2 Intention-based (top) and perception-based (bottom) interaction design on an LED band as eHMI on the outside of the vehicle (© DLR)

design indicates where objects have been detected, so for example a crossing pedestrian can see themselves being tracked while crossing and know they are safe.

The dHMI part is represented by the dynamic motion behavior of the vehicle. Within the paradigm of a holistic HMI, the vehicle's movement implements the implicit communication inside and outside the vehicle. Therefore, in this case the actual movement must match the information displayed on the LED band. For example, a vehicle could cause uncertainty for both pedestrians and the user on board if it indicated via iHMI and eHMI LED bands that it has seen the pedestrian and plans to stop but does not actually reduce speed.

CONTEXT SENSITIVITY THROUGH SITUATION AND USER STATE ASSESSMENT

To achieve context sensitivity of an interaction, cognitive and emotional states of drivers or users of automated vehicles are recorded. As addressed in the research projects F-Relacs and Autoakzept, these can be obtained from camera data using machine learning methods based on identified posture, gestures, gaze and facial expressions. In addition, physiological data such as pupil width, heart rate or heart rate variability are used. For example, subjective uncertainty in relation to the prediction of vehicle behavior is characterized by an increase in excitation and a widening of the pupil.

The challenge for a user-oriented system adaptation is to check for factors in the current driving context that explain the physiological and behavioral data collected. After all, innumerable intra- and extrapersonal factors such as thoughts, feelings and moods on the one hand, or obstructions in traffic or incomprehensible system behavior of the automated vehicle on the other hand can lead to very similar patterns. Therefore, characteristics of the traffic and systemic context must also be captured and modeled [5]. The contextual information will be integrated in the information from the user condition assessment and possible causes of the user's current condition such as frustration or subjective uncertainty will be identified. Based on this, a holistic, context-sensitive system adaptation is then carried out, which takes into account the probable causes of the user's condition. As shown in **FIGURE 3**, the HMI consisting of iHMI, eHMI and dHMI is controlled based on an integrated situation model that takes into account the current user state and the current context (and within the selected overall interaction strategy).

CONCLUDING REMARKS

The increasing automation in automobiles is changing the areas of application and usage context of vehicles as well as the interactions and cooperations between different road users and vehicles. As discussed, the technical system of vehicle automation interacts both internally with the user and, potentially in parallel to the user, externally with other road users.

This complex interaction can only succeed if the vehicle's Human-machine Interface (HMI) is conceived and designed holistically. The interface must be able to communicate consistently internally and externally and, above all, in a way that is understandable to all road users. This is the only way to ensure that a mutual understanding of future maneuvers and behaviors does not jeopardize road safety and that people build an appropriate level of trust in the technical systems.

A holistic interface can only be called holistic if it:
- is directed into the vehicle interior and communicates explicitly with the vehicle occupants (iHMI)
- communicates explicitly with the traffic around the ego-vehicle (eHMI)
- implicitly supports explicit communication with the vehicle dynamics (dHMI)
- ensures the consistency of all HMI parts.

The quality of communication of the holistic interface can be improved by making the interface context-sensitive. For this purpose, user states as well as the environmental situation and system states must be assessed and interpreted with the help of artificial intelligence.

More research is needed on holistic, context-sensitive interaction concepts to optimize interaction and avoid possible negative effects. The goal is that technological systems in road traffic can ideally respond to human interaction partners and that interaction on future roads becomes simple, intuitive and safe even in complex situations.

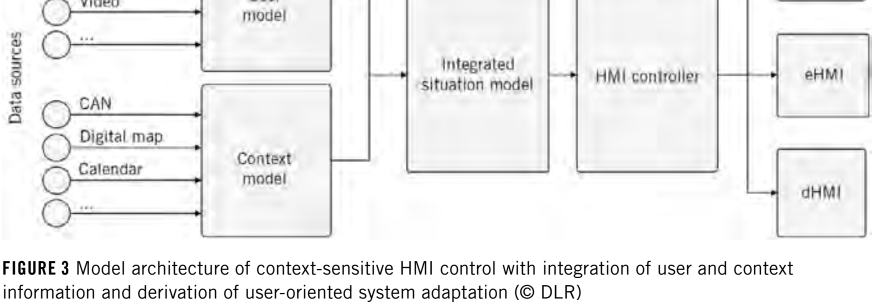

FIGURE 3 Model architecture of context-sensitive HMI control with integration of user and context information and derivation of user-oriented system adaptation (© DLR)

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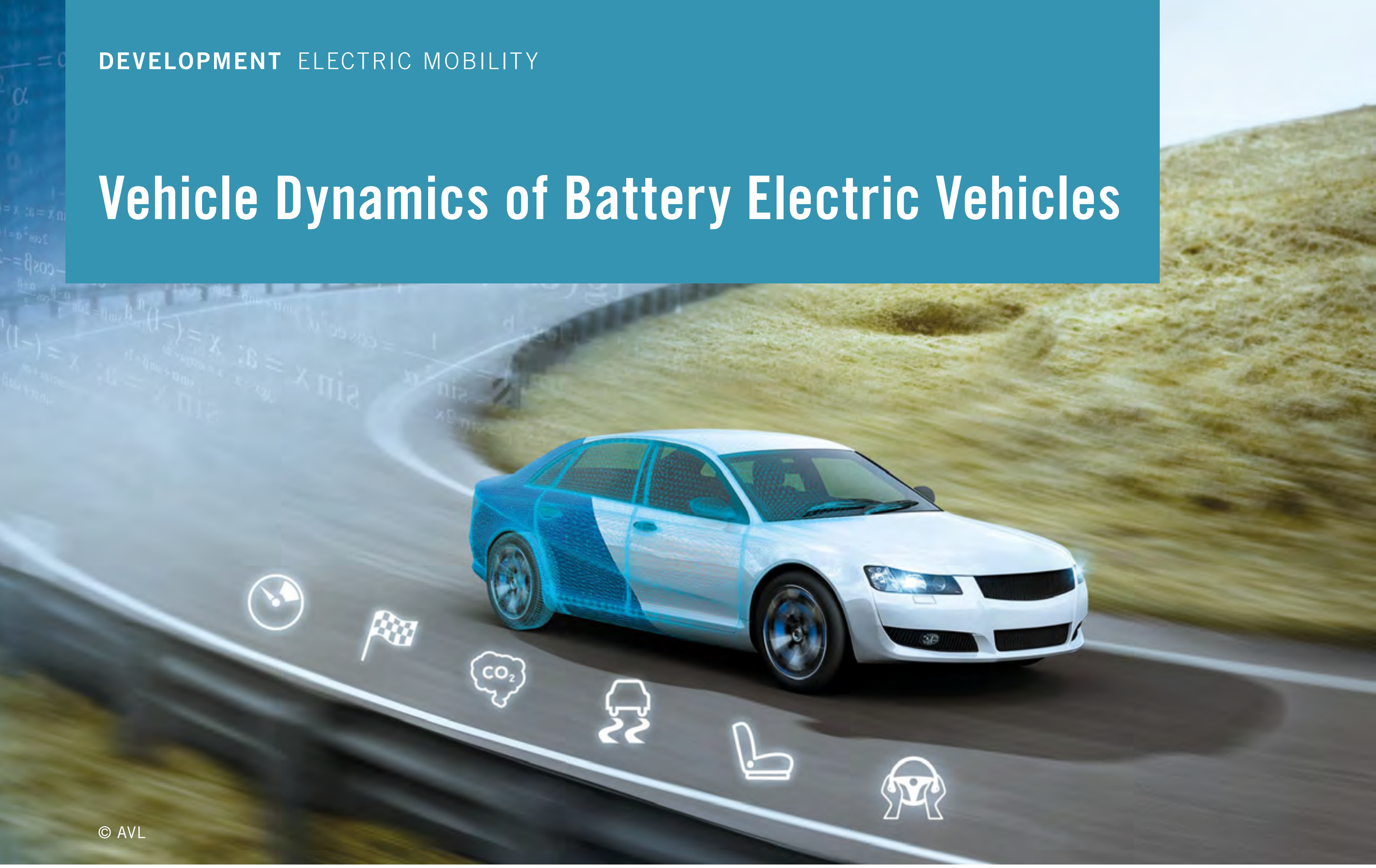
Vehicle Dynamics of Battery Electric Vehicles



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The share of battery electric vehicles in the overall portfolio of vehicle manufacturers will continue to grow in the coming years. AVL presents a method for defining the optimal vehicle concept to ensure both cost efficiency and a reduction of development time.

Stricter limits in vehicle fleet emissions is one of the major reasons of vehicle manufactrurers to enlarge the Battery Electric Vehicle (BEV) share of their vehicle portfolio. OEMs must answer the following questions: What are the customer demands on today's and tomorrow's vehicles, and how do these demands affect the design of vehicle system (for example powertrain, chassis, thermal management system) and their design parameters (topology selection, component characteristics, additional vehicle functions, etc.)? The high number of possible complete vehicle configurations resulting from the combination of electric drive components, their technical characteristics and their complex interrelationships, and the multitude of customer requirements represent a major challenge for OEMs with regard to efficient product development.

In the following, a method for the definition of the optimal vehicle concept is presented which ensures cost efficiency as well as a reduction of the development time. The focus of the method is on the integration as well as automation precalibration of powertrain functions into BEVs by using a virtual environment for overall vehicle testing. This approach does not only allow to consider the influence of the control functions of the different vehicle systems on fulfilment of customer demands and therefore on the system design, but also to generate a basic calibration of the controllers, which previously could only be created when prototypes were available. The reduced time required to calibrate prototype vehicles allows significant cost savings to be realized.

PERCEIVED CONSUMER VALUE

From the multitude of vehicles available on the market, the end customer chooses the one that meets their individual needs best. A common way to determine customer wishes and preferences are customer surveys which show that low running costs and smooth/quiet ride are top-rated customer demands [1]. But what are the possibilities for technical implementation on BEVs in order to meet customer demands in the best possible way and also to stand out from the competition?

Meeting the customer demand of reliability and low operating costs are favored by the smaller number of components in an electrified powertrain compared to a conventional powertrain. By saving on components (for example clutches) or reducing the complexity of individual subsystems (for example by a single-stage electric transmission), the number of possible sources of error is significantly reduced. A possible interpretation for All-wheel Drive (AWD) BEVs, for the customer demand of smooth/quiet ride, can be that the vehicle is easy to control in all driving conditions (including surfaces with low-friction value). Due to the smoother torque build-up of electric motors that are usually combined with single-speed transmissions, fully electric powertrains have a big advantage over conventional powertrains in this area. The implementation of additional powertrain functions – such as selective torque vectoring to individual wheels – makes it possible to improve aspects of vehicle dynamics furthermore. Especially at the limits of vehicle dynamics, thus generating additional customer value.

The identification and evaluation of all relevant customer requirements allows to derive vehicle development targets at vehicle level. In order to break down these development goals into functions and technical specifications, results of technical competitor analysis, such as those recorded in the AVL Global Vehicle Benchmarking Program are used. The results of the activites are the basis for all further development activities on vehicle level. The benchmarking results allow to define target values for vehicle and driving attributes, which in turn enable vehicle positioning and characterization based on objective parameter and criteria. **FIGURE 1** shows an example of a selected number of objectively assessed criteria of a competitor compared to the defined development target. But which characteristics and technical specifications have to be fulfilled by individual subsystems, components, as well as their combinations, to achieve these development targets?

VEHICLE CONCEPT

The wide variety of possible powertrain configurations and functions, subsystems and component characteristics makes it difficult to determine the configuration that meets the defined target requirements best. To identify this configuration as quickly as possible, vehicle simulation is one of the key elements in the feasibility and concept phase. **FIGURE 2** shows the variety of different vehicle configurations under consideration of different technical specifications of the individual subsystems and components. Each grey line represents one vehicle configuration. The influence on selected driving is highlighted for the two BEV vehicle configurations Efficiency and Vehicle Dynamics.

In order to achieve the defined development targets, the correct selection of components as well as to understand how they interact as a system or subsystem is fundamental. This allows to

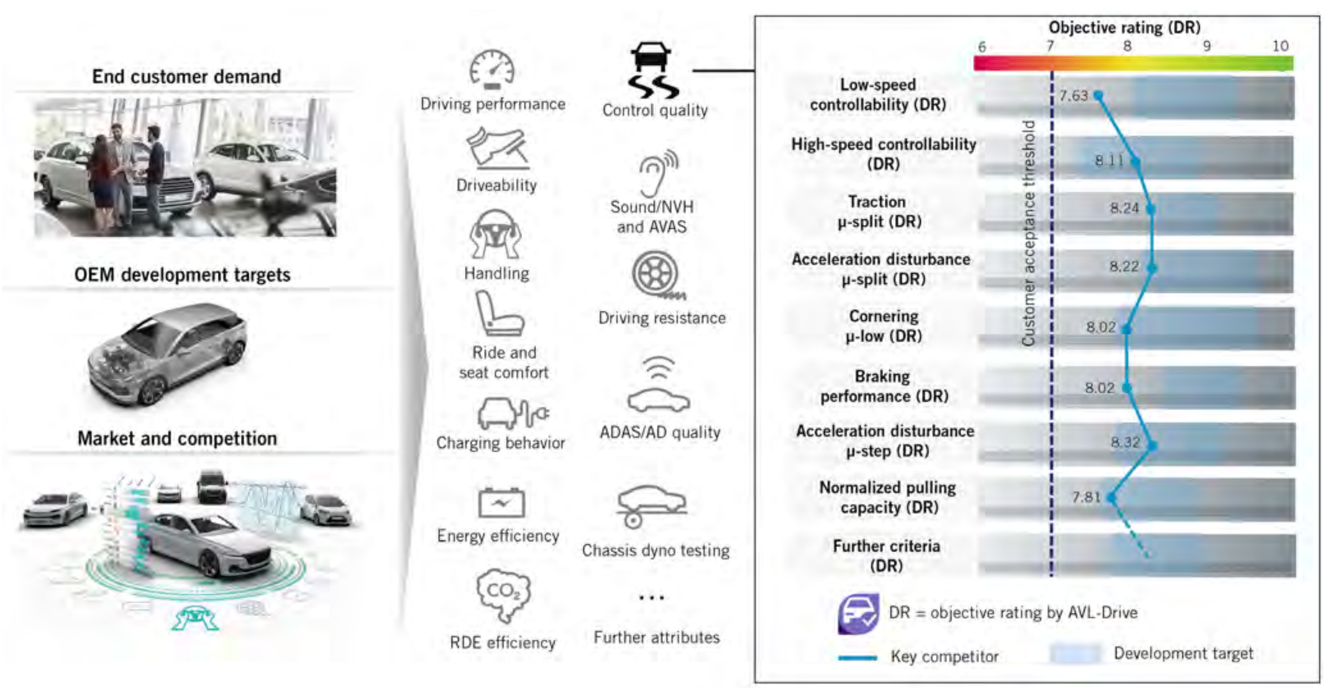

FIGURE 1 Example on translation of customer requirements into vehicle requirements and their related objective targets (AVAS: Acoustic Vehicle Alert System; NVH: Noise, Vibration and Harshness; ADAS: Advanced Driver Assistance System), AD: Autonomous Driving (© AVL)

decide which trade-offs have to be made as well what is the influence on the vehicle behavior. Within all the systems, subsystems, components, functions, etc., the powertrain is one of the major parameters in finding the optimal balance between vehicle efficiency, driveability, handling, and ride comfort. An individual definition and calibration of powertrain control functions (such as AWD control, slip control, etc.) are essential to meet today's customer expectations for energy efficiency and driving dynamics.

VEHICLE DYNAMICS CONTROLLER FOR VEHICLE SIMULATION

To handle the given complexity in a cost-effective way, AVL has developed a new approach for the development of electric powertrain controls. By using automated processes in a virtual development environment a high number of development steps can be carried out to a high level of matury in an early development phase. Due to the functional variability of the electric powertrain, powertrain simulation only is no longer sufficient. In order to adequately reflect all influences and effects on the longitudinal, lateral and vertical driving dynamics, a precise simulation model on the vehicle level (such as AVL VSM) is necessary. The control functions have to be developed specifically for the specification and topology of the powertrain and linked to the vehicle simulation model. Furthermore, the interfaces of input and output variables of the controller software are defined in the same way, as they will be implemented in the real vehicle at a later stage.

Usually, the design of the control algorithms is done in a Matlab/Simulink development environment. The controller software code integrated into the vehicle simulation model controls the electric machine torques/speeds based on the defined input signal from the simulation tool and the respective driving conditions (such as acceleration in a turn, constant-speed cornering, constant-speed straight line driving). An extensive calibration process is necessary to ensure that the interactions between the powertrain and the vehicle are as well coordinated as possible from both a functional and a driving dynamics point of view. The system behavior can be adapted for this purpose by changing calibration parameters.

In order to make the effects of calibration changes provable and visible, the use of objective evaluation methods is recommended. The method can be based on pure physical metrics, or on an objective rating system as used within AVL-Drive. The assessment method is used throughout the entire development process – starting with the target definition, for gap analyses, and at the end as proof of target fullfillment.

In summary, the described combination of development tools is capable of mapping the vehicle behavior under the influence of the powertrain control as well as immediately evaluating overall vehicle simulation results of predefined customer-oriented or performance-oriented driving maneuvers. Typical dynamic AWD use cases, such as driving on gradients, acceleration in curves or cornering at the limit, etc., can be performed virtually and highly realistic.

In addition, these dynamic AWD use cases can be also used to support activities related to functional safety. The existing possibilities of vehicle dynamics simulations support the Hazard and Risk Analysis (HARA) and are furthermore also used for testing fault injection, as well as tests for system robustness and stability in a flexible and very cost-efficient development environment.

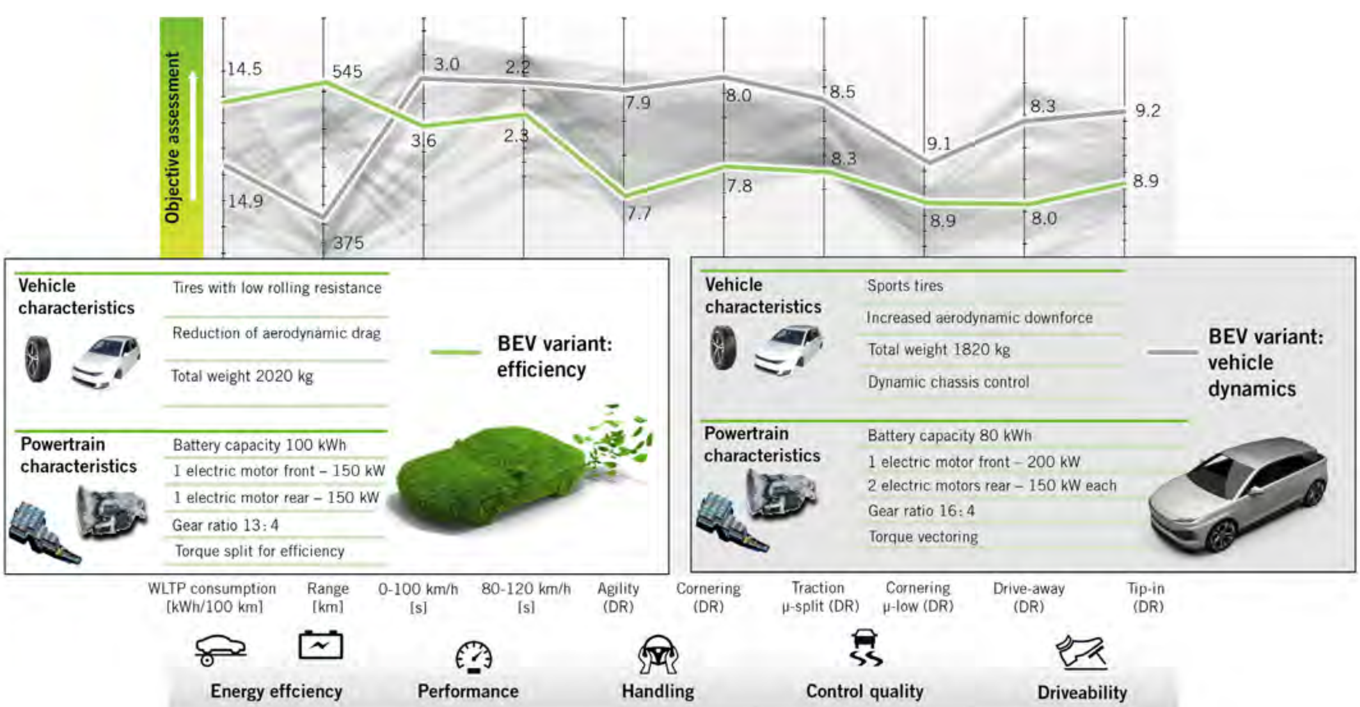

FIGURE 2 Variety of possible vehicle configurations and their influence on selected driving attributes (© AVL)

FIGURE 3 Toolchain for automated assessment and calibration of an AWD controller (© AVL)

AUTOMATED PRE-ELECTRIC CALIBRATION OF VEHICLE DYNAMICS CONTROLLER

A proper calibration of the electric powertrain control functions is the basis for highest possible traction, low wheel slip and safe and stable cornering behavior. It is an enabler for vehicle dynamics customers expect from modern vehicles. But still the highest share of the vehicle operation profile is straight ahead driving at constant speed. The development goal is to operate the electric powertrain as energy-efficient as possible in these typical customer orientated use cases. As electric machines usually have a sweet spot regarding efficient operation, the required torque delivery for constant speed driving needs to be split over the electric machines to approach the complete system's most efficient operating point to guarantee the lowest possible energy consumption and extend the vehicle's range.

To sum up, the electric powertrain control functions need to operate the electric machines highly dynamically when needed, but in a very efficient way in all other driving situations. Basis for such a control is a well working detection of driving situation boundaries such as friction coefficient, gradient, cornering etc. To achieve these contradicting targets, the controller needs to react quickly and accurate based on the given driving situation. For that purpose, a comprehensive calibration of the functions is essential. The major part of the entire calibration process can be done virtually using the toolchain "complete vehicle simulation – powertrain control logic – objective evaluation."

As manual variation of all available calibration parameters and reviewing the effects is still in the virtual environment very time consuming even the success and efficiency of the calibration highly depend on the experience and skills of the simulation engineers. To overcome these restrictions, an automated calibration approach is a logical consequence. As the described toolchain runs automatically but open loop, it is obvious that an extension to a closed-loop optimization is desired.

A Design of Experiments (DoE) optimization software (for example AVL Cameo) can close the optimization control loop. The DoE software calculates sets of calibration parameter variations that are automatically transferred to the controller software code. The simulation of the use cases and the objective evalu-

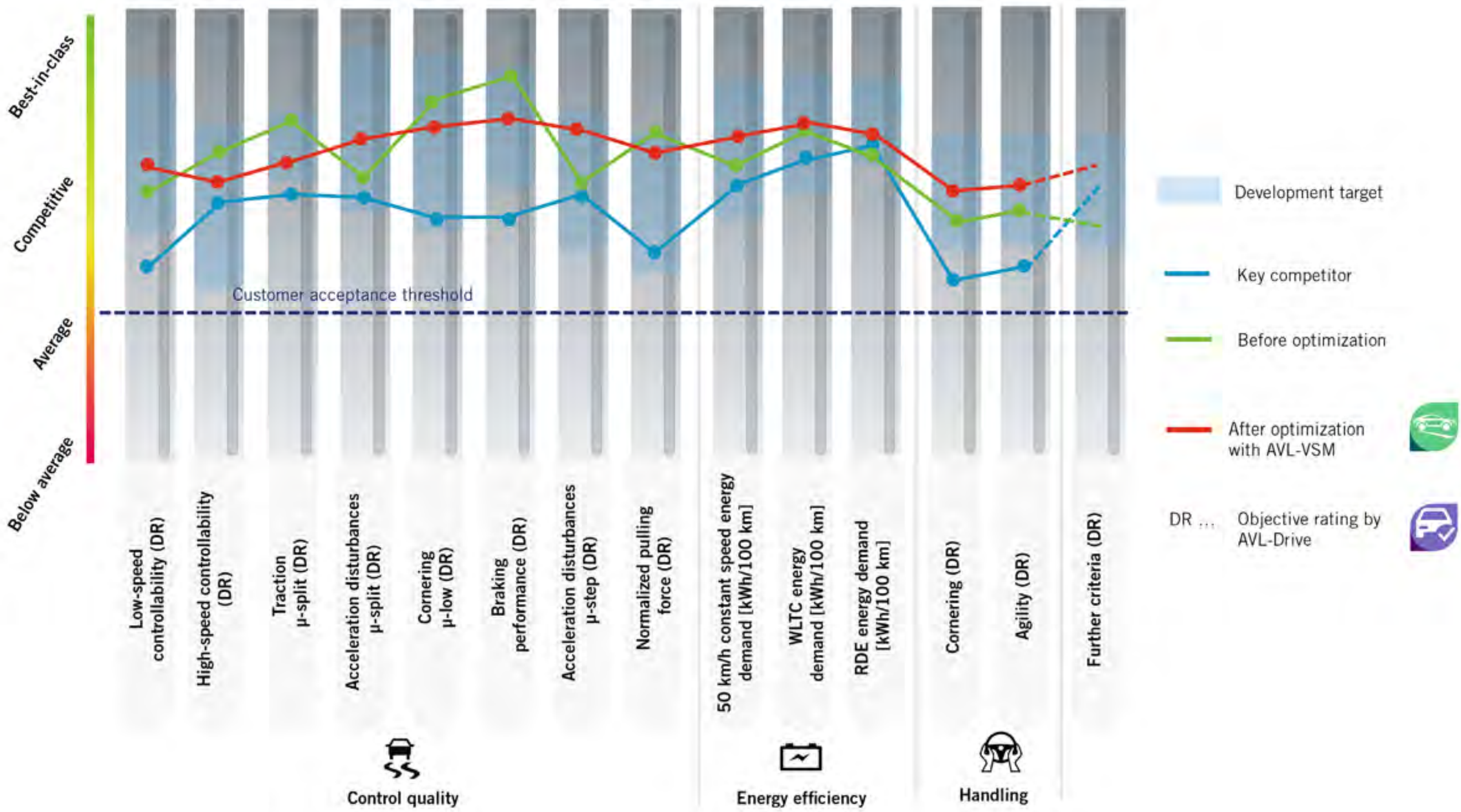

FIGURE 4 Selected criteria ratings assessed by AVL-Drive for the driving attributes control quality, energy efficiency and handling (© AVL)

ation of the results runs automatically, and the results are fed back to the optimization tool. **FIGURE 3** shows the process of the automated assessment and pre-calibration of powertrain control functions schematically.

The DoE software can learn how the complete system reacts to changes in calibration parameters and finally finds calibration parameter sets that lead to sweet spots in system behavior (for example, to reach the desired trade-off between very efficient and very performant driving behavior). The goal of the automated calibration is to automatically create a couple of solutions (at least two, typically less than ten) that all end up within the defined target range. **FIGURE 4** shows selected criteria ratings assessed by AVL-Drive for the driving attributes control quality, energy efficiency and handling. The green line shows the vehicle's initial condition before the red line indicates after the automated controller optimization, also compared to the targets range. It can be seen that the automated controller optimization leads to a clearly more balanced vehicle behavior within the target range defined and the product positioning.

SUMMARY

The integration of powertrain functions of electrified powertrains and their controllers in vehicle simulation models enables vehicle manufacturers and suppliers to develop their products even more time- and cost-efficiently. Increased use of virtual development environments and the associated ability to demonstrate the influence of the control strategy on the fulfillment of customer requirements (and the associated targets) allows automated pre-calibration of powertrain controllers to be performed in a simulative manner. A significant reduction in physical test time and associated effort can be achieved through the mature base calibration. The increased development effort in the virtual environment is more than compensated by the reduced test and calibration time and thus makes it possible to realize the requirements of the end customers more effectively, faster, more efficiently and thus at lower costs.

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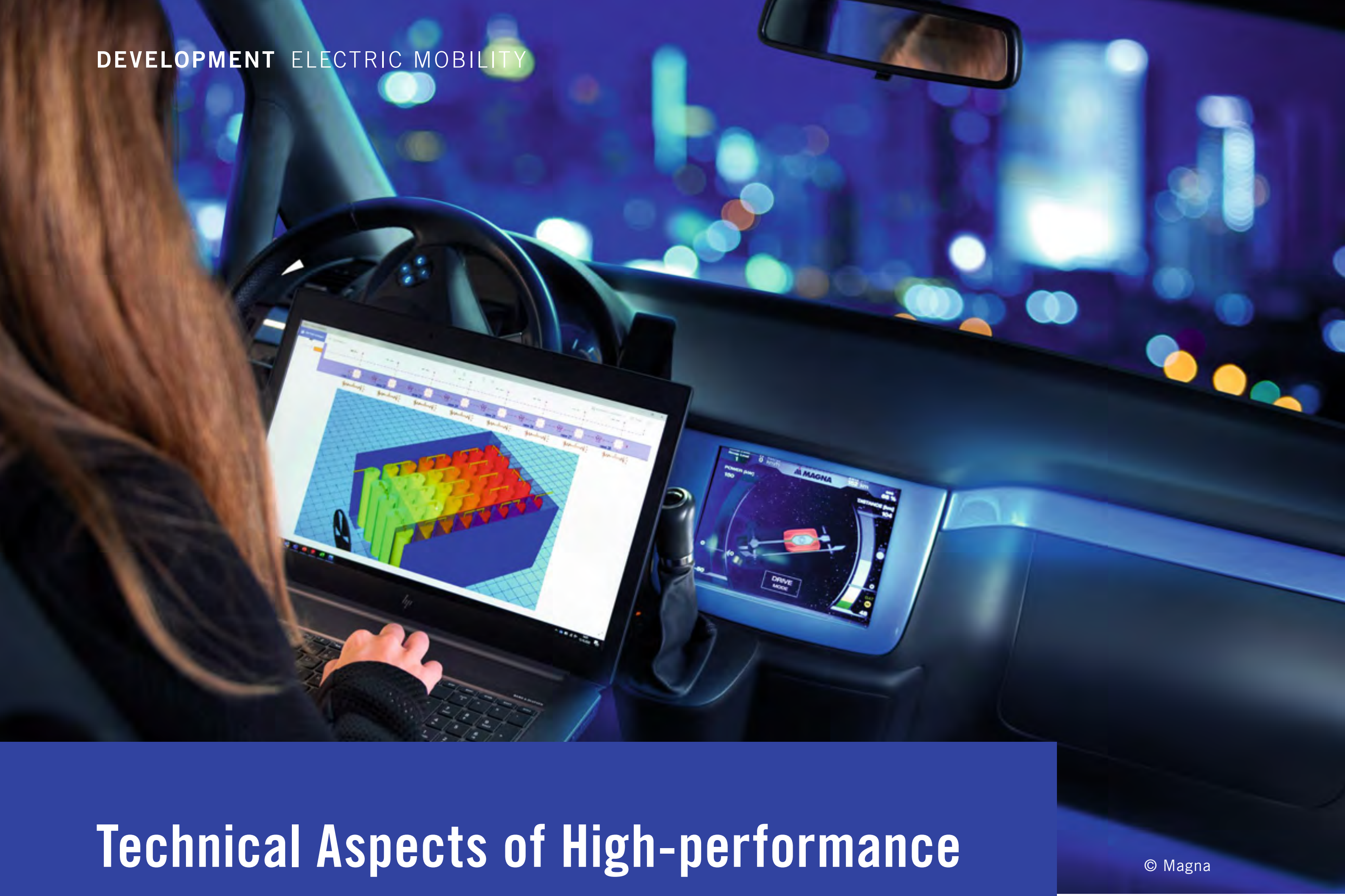

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Technical Aspects of High-performance Electric Vehicles

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An increased market penetration of battery electric vehicles could be achieved by extending their range. Magna is investigating a possible improvement in shortening the charging process by increasing the charging power, which can be realized, for example, by using rapid charging systems with up to 400 kW.

The present article focuses on different aspects of high-performance electric mobility to increase market acceptance of customers for BEVs. A possible strategy is to use a higher voltage to enable the vehicle for High-power Charging (HPC), improve the efficiency of the High-voltage (HV) system and reduce weight by reducing the HV wiring diameter. Increasing the battery voltage has an impact on all high-voltage components in the vehicle and on the thermal system. Especially after highly dynamic maneuvers, fast charging needs to be considered in the context of thermal strategy and requires comprehensive thermal testing.

IMPACT OF PERFORMANCE ON HV COMPONENTS

Higher performance which results in higher power requires increased voltage or current. This has an impact on the HV system and especially on the components which are the main vehicle performance providers: the electric drive units, the HV battery, the HV AC compressor and the

HV heaters. For example, increasing the voltage level also changes the isolation and creepage requirements according to for example IEC 60664-1 and ISO 6469-3.

POWER ELECTRONICS OF HV COMPONENTS

Due to the higher voltage level, wide-bandgap semiconductors, for example made of Silicon Carbide (SiC), are of interest for power electronics. SiC enables higher voltage and a higher switching frequency at lower switching losses, which results in smaller capacitances and inductances. An increase of the voltage level increases the voltage gradient (du(t))/dt. The higher voltage gradient and increased frequency need the Electromagnetic Emission (EME) and the insulation of the electric machines to be taken into account. The main advantages of SiC components are:

- reduction in size of descrete components (capacitances, inductances) due to higher switching frequency
- reduction of semiconductor volume up to 63 % [1] compared to conventional Insulated Gate Bipolar Transistors (IGBTs)
- wider temperature range which results in more flexibility of the cooling circuit design and thermal management of powertrain components [1]
- higher efficiency.

Possible drawbacks are:

- Total Harmonic Distortion (THD)
- EME
- technology readiness.

The simulations and experiments carried out by Bubert et al. [2] showed that two-level inverters at 800-V DC-link voltage have drawbacks if compared with 400-V inverters at the same power level. Therefore, a multi-level topology or SiC was preferred, instead of replacing, 650-V IGBTs with 1200-V IGBTs. Summarized if SiC is used as technology, the drawbacks and advantages need an application-tailored balancing, for example EMC filter design, volume/size and efficiency.

Considering the operating strategy of HV consumers – with cables and connectors included – is important during development and design phases to achieve an additional weight saving potential. Assuming an All-wheel Drive (AWD)-powered vehicle, the power is usually distributed between the front and rear axle. Therefore, considering the AWD distribution strategy and operating strategy to identify the power flow between the battery and the HV components helps to optimize the wiring diameters and power requirements for the used cases only. If the operating strategy of the HV auxiliaries such as HV compressor and HV heaters are considered together with the HV architecture, optimization using power-distribution algorithms to minimize the weight of the HV system is a smart approach. However, this requires also an early definition of the operating strategy including the derating behavior and failure handling in the development phase to maximize the optimization potential of the HV system. Furthermore, additional algorithms which monitor the HV-system power are recommended to ensure a derating behavior which has no impact on the customer.

CABLES AND WIRING

Considering charging and focusing on the vehicle only, one expected bottleneck is the path from the charging inlet to the battery connector. HPC with a charging power of more than 200 kW usually requires a liquid-cooled charging-station cable. The wiring harness in the vehicle is commonly not actively cooled. The charging inlet might overcome the Joule losses due to an implicit cooling effect (heat conduction) between the pins of the connector and the inlet. Furthermore, it is possible, for a short period of time, to electrically overload the wiring harness in the vehicle. A design of the cable cross section and pins based on the current profiles and ambient temperatures is necessary. Furthermore, it is necessary to consider the position of the charging inlet in the vehicle and surrounding ambient temperature and component temperatures, the current curve and the thermal boundary conditions (for example contact to the body).

BATTERY

The price of a BEV is currently mostly driven by the battery costs. Due to the high C-rates, high-performance electric powertrains have an impact on the lifetime and on the battery pack thermal management. The chemistry of the cells and the cell design needs to be adapted. This might lead to an additional cost increase. High C-rates could influence the battery degradation. Especially during HPC, the cell temperature of the battery tends to increase, which speeds up the capacity loss of the battery [3]. From a practical point of view, if only the C-rate is considered, there is no difference between the 800-V and 400-V systems. If two battery packs with the same energy content are compared, one could present an 800-V configuration and a 400-V configuration: except for the clearance and creepage topics, there is no difference in the cells if the C-rate is kept constant for comparison.

FIGURE 1 shows a brief overview of the current limiting factors for charging. There are several limiting factors during charging, and the battery itself is limited in power/current due to the cell technology used; furthermore, the battery connector is also limited depending on the connector used. Typically, and depending on the cell technology, the C-rate needs to be reduced when SoC reaches 40 to 80 %. **FIGURE 1** summarizes these typical limitations using a 21700 cell.

CHALLENGES OF THERMAL DESIGN

Besides the electrical challenges of high-performance vehicles, also the thermal design requires attention to ensure thermal stability and a safe vehicle state even during critical maneuvers and fast charging processes.

CRITICAL MANEUVERS

A critical topic in the complete vehicle development process for BEVs is the definition of load ranges to derive appropriate requirements for the electric powertrain components, such as the electric drive units, the HV heaters and the cooling system components. To emphasize the basic approach, a battery pack with a weight of 560 kg based on a 21700 cell was considered. The cell capacity was defined with 4.75 Ah at a thermal capacity of 0.95 kJ/kgK. The battery pack with 189 cells in series and 31 branches in parallel reaches approximately 100 kWh energy. A voltage range of minimum 567 V and maximum 794 V was computed for the battery pack. Based on benchmark data the convective exchange area was defined at 4 m². The thermal simulations are performed at 25 °C ambient temperature with the battery preconditioned at the same temperature. Also,

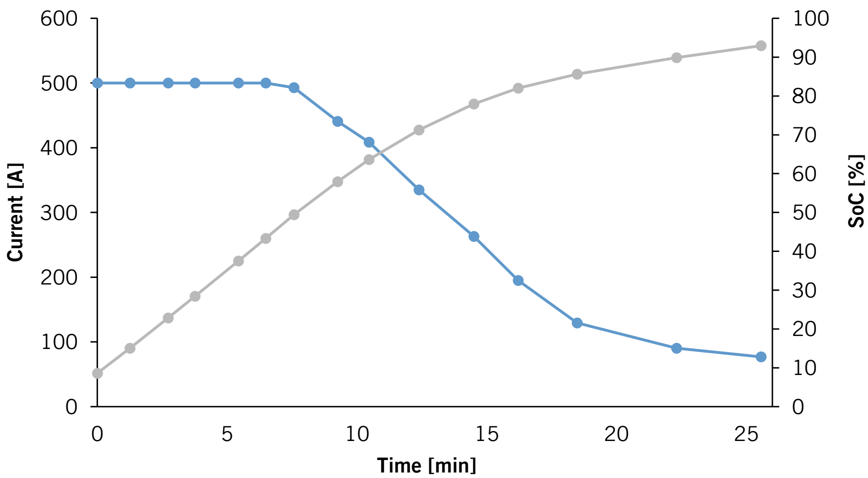

FIGURE 1 Generic charging curve showing typical cell limitations (© Magna)

the initial cooling fluid temperature was set to 25 °C at a constant coolant flow rate of 15 l/min. Summarized three simulation scenarios are discussed in the following section to emphasize the connection between the cooling system power, maneuvers and charging. For the simulations a charging current profile with 500 A maximum current, **FIGURE 1**, was defined and applied in the simulation model. This charging current heats up the battery.

Considering the current availability for HV compressors in the mass market and the vehicle segment, the cooling capacity range was defined up to 8 kW for all scenarios. The first scenario is a constant speed drive (130 km/h) and the others are cycles with dynamic maneuvers. It can be seen, with the maximum cooling capacity, the battery does not reach the target temperature in all cases as the heat-up is conditioned by the cycle characteristics.

In the computations the target for the battery pack temperature was 32 °C, which is a realistic value for liquid-cooled batteries where cell temperatures could easily reach 60 °C, especially after high-speed driving or dynamic city cycles. To study the performance of the thermal system, in scenario 3, a generic approach for the assessment of the transient behavior is to vary the speed between 80 to 200 km/h for a defined time (highway dynamic cycle) with HPC as stress test, **FIGURE 2**.

A strategy for thermal conditioning before starting the fast charge process should be considered as the capability of HPC depends on the driving cycle which previously occurred. In the case shown in **FIGURE 2**, the cool down of the battery occurs after starting the charging phase. The appropriate approach is to focus on a controlled heat-up of the battery pack during the HPC procedure (for example staying below a peak temperature of 50 °C). Considering the operating strategy, the cells may be cooled down to a lower temperature during driving, before the HPC charging station is reached, using, for instance, a predictive operating strategy in combination with the navigation system.

FAST CHARGING

The thermal simulation for the HPC, also after the critical maneuvers, **FIGURE 2**, gives an estimation of the cooling power required to manage HPC for a 100 kWh battery pack. Based on the simulation, the auxiliary power (including cooling power) was estimated for the total efficiency computation in **FIGURE 3**. The HV wiring harness and the battery busbars including relays are estimated at approximately 7 mΩ. The internal resistance of the cells varies with temperature and SoC. For the HV auxiliaries (HV compressor, HV/LV, DC/DC converter, water pump, fan, ECU), 550 W are defined for the 50-kW charging case, 6.4 kW for the 150-kW and 11 kW for the 350-kW charging case.

FIGURE 3 represents the worst-case operating point for each charging scenario. In practice the losses fluctuate with SoC and temperature. This figure gives an indica-

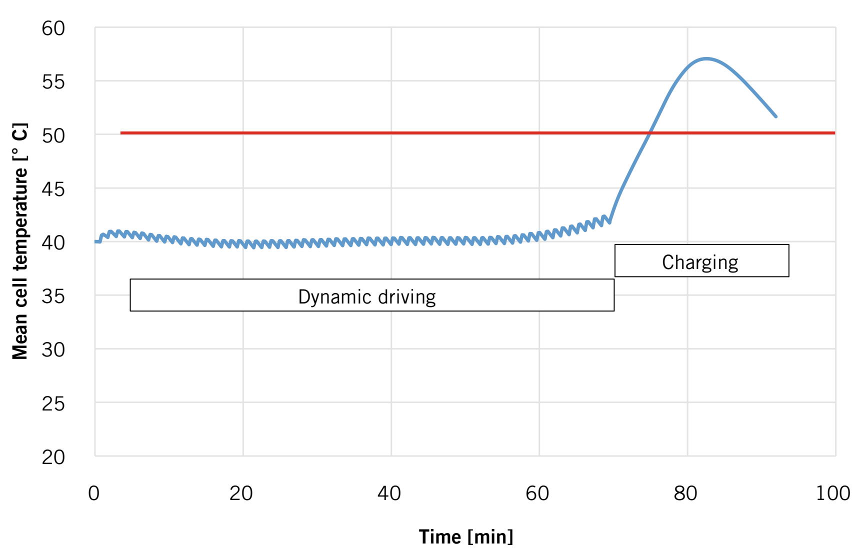

FIGURE 2 Scenario 3: 80 to 200 km/h with higher-performance charging immediately after the driving maneuver (© Magna)

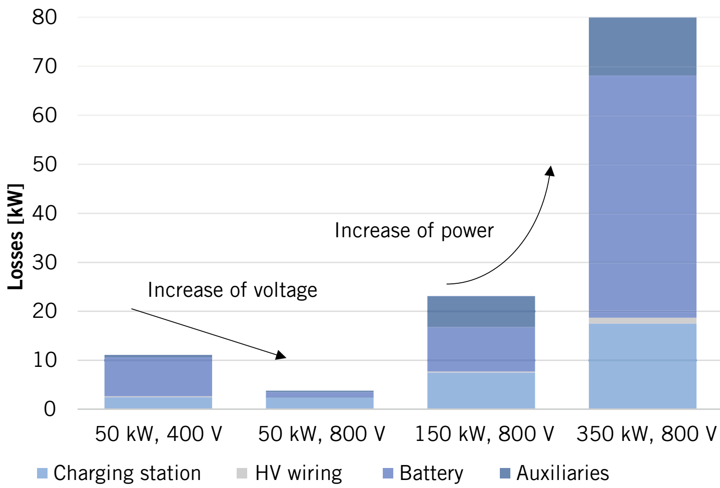

FIGURE 3 Charging losses: A higher voltage decreases the ohmic losses if the power level is kept constant; the auxiliary losses increase due to the higher cooling demand of the high-voltage battery (© Magna)

tion of the total efficiency: The total losses increase with increasing power; therefore at 350 kW the losses are approximately 77 kW (initial peak) in the worst case. At 50 kW/400 V and 350 kW/800 V, the total efficiency was computed to be about 82 %. At 150 kW/800 V, the efficiency is higher, by 87 %. Compared with [4] (30 % losses at 350 kW), this computation shows a better efficiency. However, the efficiency depends on the technology used also on the infrastructure side (for example consideration of additional cooling in the infrastructure, feed lines from the transformer station). Therefore, a comparison needs detailed consideration of the estimated boundary conditions. To sum up, HPC also has a higher share of energy losses despite increasing system voltage.

IMPACT ON THERMAL MANAGEMENT

Tackling the thermal conditioning of the HV battery requires an extra effort not only because of the battery constraints themselves but also because of their impact on other systems of the vehicle such as the cooling and air conditioning systems. On the one hand, thermal systems must cope with the charging and driving energy losses and, on the other hand, also have to be capable of overcoming low temperatures (up to -20 °C) to keep the HV battery and power electronics at the optimum operating point.

These requirements increase the complexity of the systems and their synergies, which need a holistic approach. To validate the control functions, once the virtual development is finished, a test bench is built up. The setup of the test bench includes the mechanical and elec-

FIGURE 4 Thermal system testbench (example configuration) (© Magna)

FIGURE 5 Thermal dummy battery (© Magna)

trical integration of each component in the original vehicle position, **FIGURE 4**.

In order to test hardware involving the HV battery, **FIGURE 5**, the use of a thermal dummy battery enables safe physical tests to be carried out in the early stages. This dummy simulates the thermal mass of the real battery by controlling the flow through the cooling channels and the housing.

The available energy for propulsion in the HV battery is reduced by the air conditioning system, whose main goal is to ensure the passengers' thermal comfort. The test bench, together with the dummy, supports the assessment of relevant cases for the system definition and control strategies. For example, different thermal functions can be tested during a classic heat up, where the cabin is heated from negative temperatures until reaching a target temperature.

SUMMARY

High performance electric mobility needs to take into account the complete vehicle level. An increased HV-system voltage level impacts the component requirements such as clearance and creepage, withstand voltage and, in fact, material requirements. Using the example of HPC after driving, all performance-providing components and functions should be incorporated in an optimization approach of the vehicle operating strategy to achieve thermal comfort and performance targets. All required technical fields are covered by Magna in a one-stop shop to achieve the optimum performance of battery electric vehicles.

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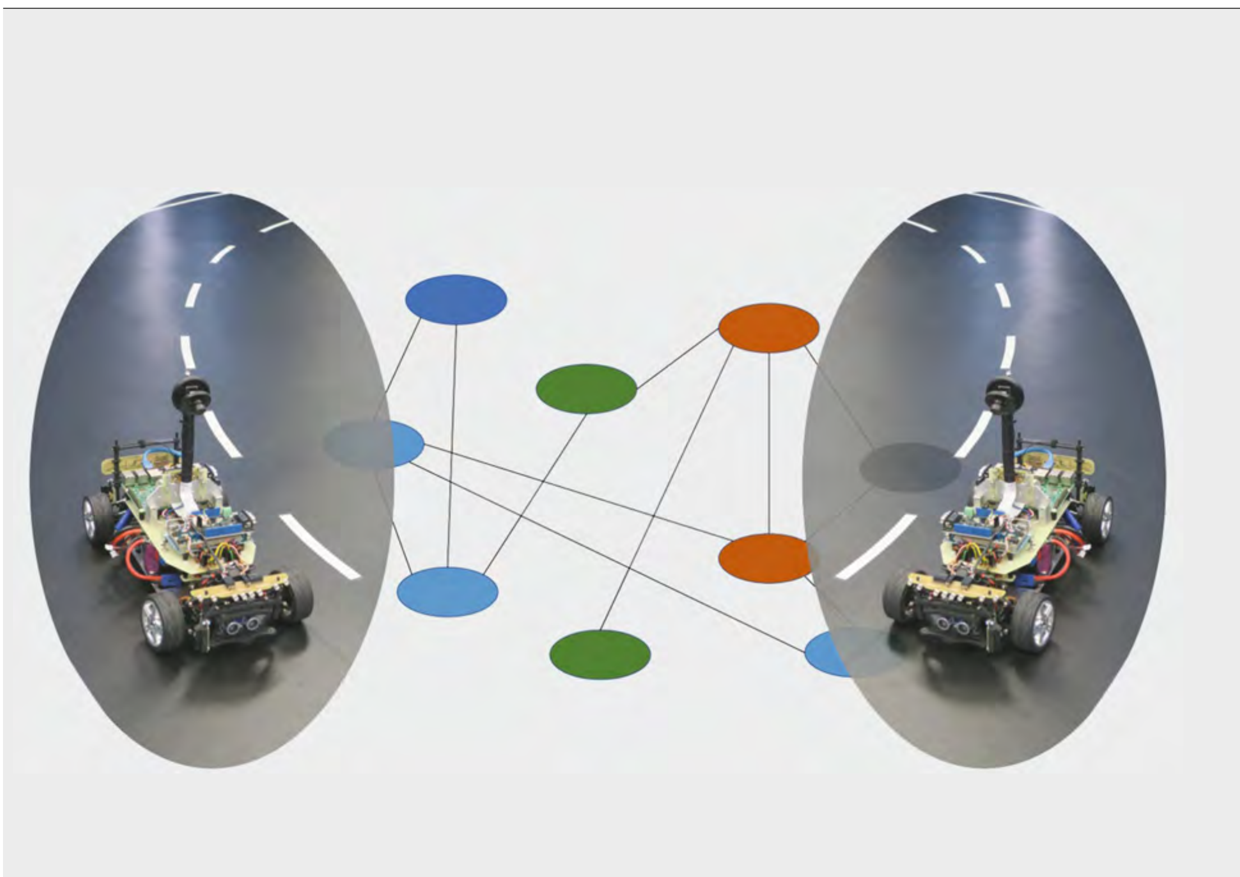
Safety in Autonomous Driving – Evaluation by Maximum Entropy

Autonomous driving is considered one of the key technologies of future mobility. High demands are placed on driving safety in particular, and proof of safety is therefore a central task. In a research project of the Fernuniversität in Hagen and the University of Applied Sciences Esslingen, new concepts for safety analysis and evaluation on a simulation basis are being developed.



1 MOTIVATION

Proof of driving safety is of central importance for autonomous vehicles, which play a key role in future mobility [1]. Since the early 1970s, the Traffic Conflict Technique (TCT) [2] has established an approach to safety assessment, whose metrics often do not meet all the requirements of a comprehensive risk analysis. For this reason, a concept was developed within the framework of the research project as a further development of this method, which enables a complete model of safe driving.

2 INTRODUCTION

TCT has established an approach to safety assessment that analyzes traffic conflicts instead of collisions, that means, critical traffic situations without contact between the vehicles involved [2]. This allows for an early proof of safety without the presence of accident data. The indicators (metrics) for traffic conflicts can be divided, according to [3], into reactions for collision avoidance [4] and time- and distance-based variables [5].

The evaluation by individual metrics, such as Time-to-Collision (TTC), often provides only a partial picture of the criticality of driving situations. Based on vehicle-following scenarios, this publication presents a concept that increases the quality of criticality evaluation by the following features:

– quantitative connection of different metrics
– integral criticality measure for conflict risk and collision severity
– dealing with vague and missing knowledge.

The core element – besides stochastic modeling – is the principle of maximum entropy [6], which allows to generate a complete model of safe driving that allows to infer the criticality of driving situations from vehicle motion data. With this concept a contribution to the further development of TCT shall be made.

3 LEARNING PROCESS

A learning process according to **FIGURE 1** provides the complete stochastic model of the relationships between metrics. An evaluation process based on this model is used for safety assessment. The stochastic model results from a set of rules, which are derived from data of a traffic simulation as well as from other knowledge about relations between metrics. Gaps in knowledge about further correlations are supplemented by the principle of maximum entropy. A complete probability distribution as a result of the learning process represents the model of all relationships between metrics.

4 TRAFFIC MODELING AND SIMULATION

Some of the statistical relationships between metrics of the considered vehicle following scenarios were taken from empirical data of a traffic simulation in PTV Vissim [7]. A section of the A9 highway south of Ingolstadt (Germany) was used for the modeling and data from three stationary measuring points were applied. All three measuring points are equipped with side radar and Bluetooth detectors, one of them additionally with an induction double loop and sensors to collect environmental data. Only the direction of travel north–south, with a route length of 5.6 km, two exits and one access road, were considered. The model was calibrated and verified with macroscopic traffic data, such as traffic intensity or average speed, as well as the distributions of speeds and time headways. In this article the time headway is interpreted as the time gap ("bumper distance") between two vehicles. Since

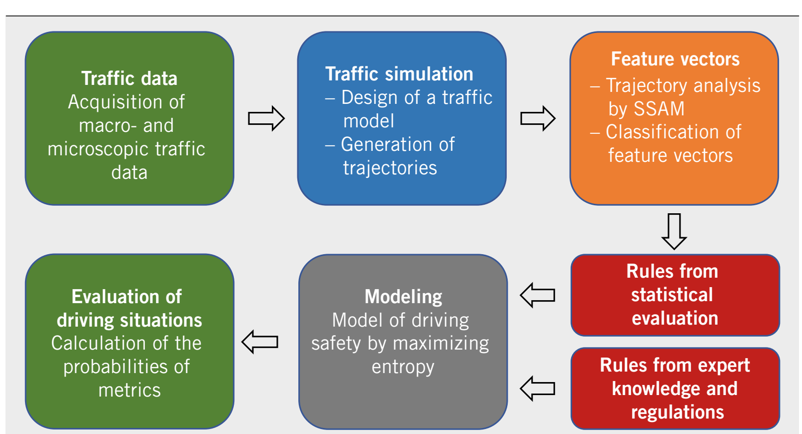


FIGURE 1 Illustration of the learning process for evaluating driving situations (© Fernuniversität in Hagen)

Metric	Description	Metric	Description
DR	Initial deceleration rate	*DeltaS*	Differential speed of a pair of vehicles
MaxD	Maximum deceleration	*MaxS*	Speed of the faster vehicle
TTC	Time-to-Collision	*Severity*	Severity of a possible collision
THW	Time headway	*Kriti*	Combined metrics of *SiFa* and *Severity*
Sifa	Probability of conflict		

FIGURE 2 Metrics of the domain for the evaluation of vehicle tracking scenarios (© Fernuniversität in Hagen)

Rule type	Example
Statistical analysis	*DR = dr_gt-2.50..inf | DeltaS = deltas_0..8.00 = 0.866*
Expert knowledge	*¬SiFa | TTC = ttc_gt0.7..1.1 = 0.9*
Regulations and recommendations	*¬SiFa | THW = thw_gt0.9..1.8 = 0.4*

TABLE 1 Examples of probabilistic rules from the three categories used (© Fernuniversität in Hagen)

the measuring points only record vehicles on the A9 highway, the vehicle flows at the intermediate entrances and exits are initially unknown. In order to determine the route choices, a procedure based on Bluetooth data was developed as part of the research work. The vehicle trajectory data generated by PTV Vissim in a standardized format was automatically evaluated in the software tool Surrogate Safety Assessment Model (SSAM) [8] with respect to *TTC*, Post Encroachment Time (PET) and other metrics, and the results were made available in a conflict list. In the trajectory file of a 10-min simulation run, for example, SSAM identified a total of 199 conflicts at threshold values of 3.0 s for PET and 1.5 s for *TTC*, 134 of which were rear end conflicts.

5 MODEL FOR SAFETY ASSESSMENT

The model for evaluating the safety of driving situations consists of a domain, in which all metrics are defined as discrete random variables including their categories (value intervals), and probabilistic rules (conditionals) which describe relationships between these variables as conditional probabilities. The domain of the model for the evaluation of vehicle following scenarios consists of nine metrics, including the three criticality measures *SiFa*, *Severity* and *Kriti*, **FIGURE 2**. The state space comprises $3^4 \cdot 4^2 \cdot 5 \cdot 2^2 =$ 25,920 states, each of which is assigned a probability.

The knowledge about relations between random variables, such as motion quantities of vehicles, can be described by probabilistic rules. A rule R_j is a conditional that connects junctions A_j or B_j of random variables as conditional probabilities. Formally, the set of rules R of a limited knowledge domain is described as follows, where J represents the number of rules and x_j the probability of the j^{th} rule, Eq. 1:

Eq. 1 $$R = \{B_j | A_j = x_j, j = 1, \ldots, J\}$$

Reasoning with such rules is called probabilistic conditional logic according to [9]. The set of rules of the model consists of $j = 32$ conditionals, which were obtained by statistical analysis from the SSAM conflict list, from expert knowledge and by evaluation of legal regulations and recommendations. The rules listed in **TABLE 1** show one example from each category.

The probability distribution of all states, which is incompletely defined by 32 rules, is completed by the principle of maximum entropy. In information theory the term entropy is based on the definition of the information content I of a message, which was introduced by Shannon [10]. If x is a character of an alphabet X (that means, X is the character set of an information source) and $p(x)$ is its probability of occurrence, then its information content $I(x)$ is given by Eq. 2:

Eq. 2 $$I(x) = log_2 \frac{1}{p(x)} = -log_2 p(x)\ [Bits]$$

The entropy $H(X)$ of the whole alphabet X is then its mean information content, Eq. 3:

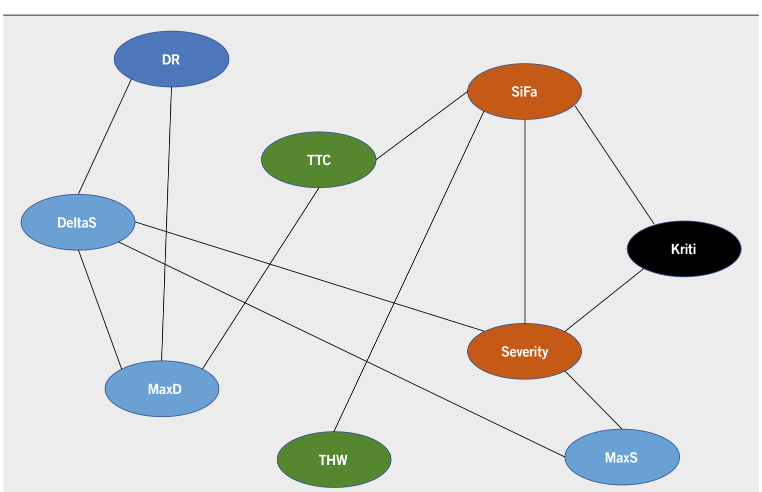


FIGURE 3 Markov mesh of the model for evaluating the safety of driving situations, whose modeled rules are represented by one or more edges each (© Fernuniversität in Hagen)

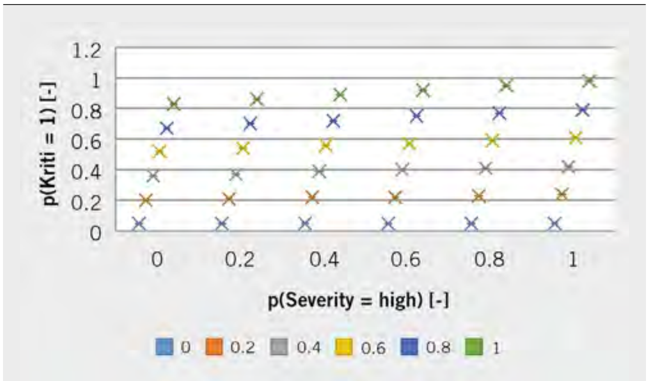


FIGURE 4 Exemplary model behavior of the metric *p(Kriti = 1) = f(p(Severity = high)* with *p(SiFa = 0)* as a parameter (© Fernuniversität in Hagen)

Eq. 3 $H(X) = \sum_x p(x) \cdot I(x)\ [Bits]$

If the alphabet *X* is interpreted as a discrete random variable with its possible states x_i, then *H(X)* is a measure for the uncertainty of the distribution *P(X)*. E. T. Jaynes developed a principle [6] to generate missing knowledge about the probability distribution of a probabilistic model. From all permissible probability distributions *P(X)*, this principle selects the one whose distribution *P*(X)* has the maximum entropy H_{max}. Thus, a maximum of uncertain knowledge is added to the model, that means, as little (non-available) certain knowledge as possible is assumed, Eq. 4:

Eq. 4 $H_{max} = H(P^*(X)) = \arg max(-\sum_x (p(x) \cdot log_2 p(x)))$

The calculation of the maximum entropy *MaxEnt* represents an optimization problem with constraints, which usually has to be solved numerically. *MaxEnt* is used in this publication as a collective term for the maximum entropy and the minimum relative entropy, which represents the distance between two distributions. Also the models for evaluating the safety of driving situations, **FIGURE 3**, consist of complete probability distributions, which were obtained from the given 32 rules as constraints by maximizing the entropy. The cover picture of this paper schematically shows a Markov mesh and two autonomous model vehicles of the University of Applied Sciences Esslingen for the connection and evaluation of motion states.

6 EVALUATION OF LONGITUDINAL CONFLICTS

To investigate the model, all possible state configurations were made plausible in their effect on the classification result *p(Kriti)*. **FIGURE 4** shows exemplarily the model behavior of the metric *p(Kriti = 1)* as a function of *p(Severity = high)* with *p(SiFa = 0)* as parameter. Some of the results are presented in the following:

- The model combines the probabilities of conflict frequency *SiFa* and collision severity *Severity* to an integrated criticality measure *p(Kriti)*.
- The model prevents the mutual healing of *TTC* and *THW*, where an uncritical value of one metric would “override” the critical value of the other metric.
- At low probabilities of a conflict *p(SiFa = 0) << 1*, the severity *p(Severity)* has only a slightly increasing effect on the criticality rating *p(Kriti)*.
- Low values of *p(Severity = high)*, left vertical traces in **FIGURE 4**, lower the criticality *p(Kriti = 1)* compared to an evaluation of only the conflict probability *p(SiFa = 0)*.
- If *p(SiFa = 0)* >> 0, the criticality *p(Kriti = 1)* increases along with severity *p(Severity = high)*. The increasing slope of the vertical tracks from left to right in **FIGURE 4** describes the growing influence of greater *p(Severity = high)* on criticality.

FIGURE 5 exemplarily shows the model behavior on the basis of a conflict situation. The value intervals of *TTC, THW, p(SiFa = 0)*, *p(Severity = high)* and *p(Kriti = 1)* were scaled to 1, where 1 stands for the most critical value.

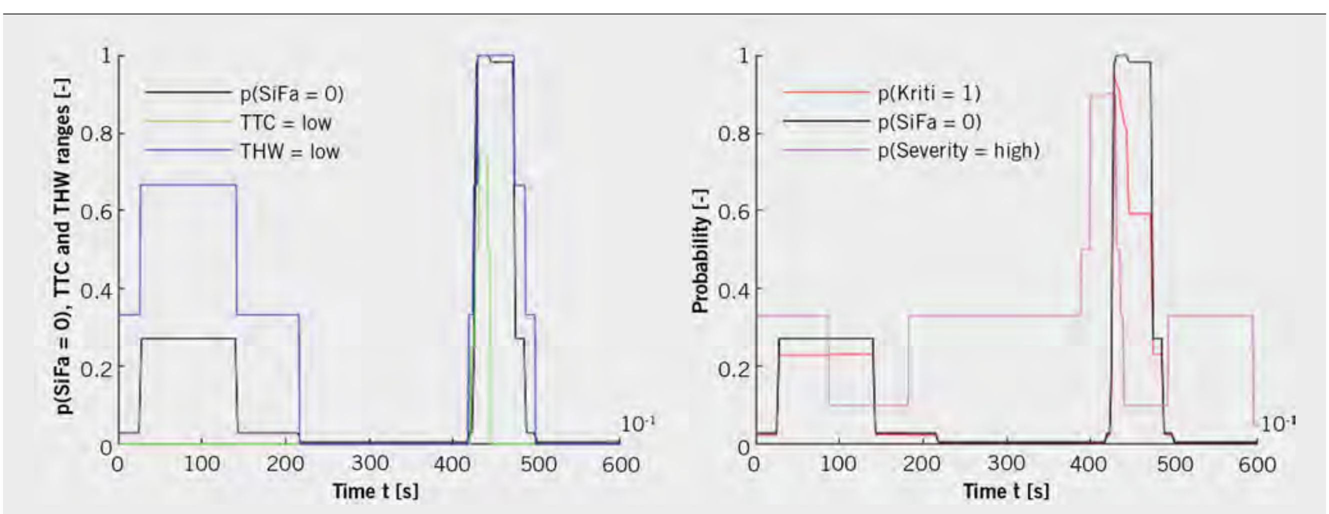


FIGURE 5 Probability *p(SiFa = 0)* of a critical situation as a function of *TTC* and *THW* (left); criticality *p(Kriti = 1)* as a function of *p(SiFa)* and *p(Severity)* (right) (© Fernuniversität in Hagen)

7 SUMMARY

With the methodology presented in this paper, plausible connections between different metrics for evaluating the safety of driving situations could be created, uncertain knowledge could be modeled, missing knowledge could be generated and an integral criticality measure for longitudinal conflicts could be defined. This supports an early and comprehensive safety assessment of new driving assistance systems and autonomous vehicles based on simulation.

The criticality model showed plausible behavior in all configurations to calculate the probability of a critical situation by combining the probability of conflict with the severity of a possible collision. The presented methodology, which was developed on the basis of longitudinal conflicts, can be applied to any type of conflict.

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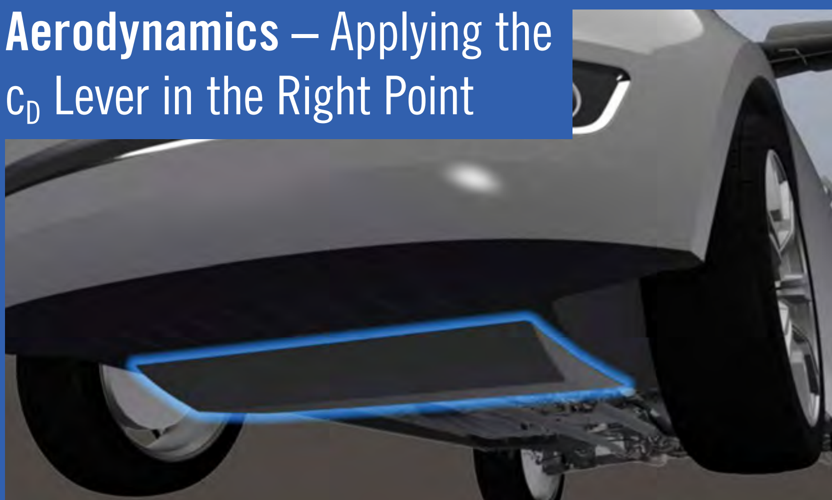
COVER STORY

Aerodynamics – Applying the c_D Lever in the Right Point



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To achieve low fuel consumption and CO_2 emissions, aerodynamics is an important variable for cars and trucks from 50 km/h upward. Aerodynamic quality is often expressed in terms of the drag coefficient c_D and improved with spoilers and flaps. The new Caddy 5 from Volkswagen Commercial Vehicles achieves a c_D value of less than 0.30, making it the best in its class. This value, which represents a 9-% improvement over its predecessor, was reached primarily by consisently using numerical flow simulation. Taking advantage of aerodynamically optimized semitrailers for trucks will enable the European CO_2 emission reduction targets to be met more easily. Wing-shaped flap elements from ZF help to specifically influence rear and skirt airflow and provide faster payback times for freight forwarders. In the ATZ interview, Braendon Lindberg from Magna Exteriors explains how active radiator grilles and air deflectors can make SUVs, sedans, and trucks even better, and why the aerodynamics of an electric car need to be different from those of a car with an internal combustion engine.

DEVELOPMENT

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RESEARCH

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Dipl.-Bw. Marco Philippi, MBA
Senior Director
Procurement Strategy
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The Opportunity of Chemical Recycling

Audi is present in more than 100 markets and produces automobiles at 13 locations. Our supplier network comprises 14,000 direct suppliers from more than 60 countries. Changes that we initiate have a major impact on all those who are part of our network. We can achieve a great deal together. With its suppliers, Audi is placing an emphasis on the efficient and economical use of the resources we need for manufacturing our products. Our ambition is to be a pioneer with regard to handling these recyclable materials. Our goal is to establish closed-loop systems and obtain new recyclable materials from waste. I firmly believe that our industry must put sustainability at the core of its philosophy in order to be successful in the future.

The pilot project for chemical recycling is a prime example of this goal. It is designed to demonstrate that technology and innovation can lead to greater sustainability in Germany as a business location. In the "Industrial Resource Strategies" think tank at the Karlsruhe Institute of Technology (KIT), university science and entrepreneurship are working together with assistance from policymakers. The objectives of chemical recycling are ambitious: We want to transfer mixed plastic fractions from the automotive sector back into a resource-conserving loop and, in contrast to mechanical reprocessing, we want to do so at the high quality level of new goods. The procedure opens up additional potential for the resource-conserving purchase and handling of recyclable materials in the automobile. Initial pyrolysis tests are to determine the conditions under which chemical recycling of used plastics is possible. The focus of these tests will be on the effect of paint, contamination, or unwanted plastics in particular. At the same time, we will analyze the efficiency and possible environmental effects in the event of scaling.

If we succeed in demonstrating technical feasibility while taking into account ecological and economic premises, we will establish the process for suitable plastic fractions in cooperation with partners from the chemical industry. This gives us the opportunity to keep as large a percentage of our own plastics in the loop as possible and thereby save primary resources in the future. Audi has already had good experiences with these kinds of developments. For example, we closed the loop for aluminum together with our suppliers. This enabled us to avoid around 150,000 metric tons of CO_2 on balance and save valuable resources in 2019 alone.

We are convinced that similar success can also be achieved with plastics. These are crucial steps on the path toward the future viability of sustainable mobility – and therefore a common interest of business, politics, and society.


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