MATHEMATICS FOR VEHICLE ENGINEERING

DR. KLAUS DRESSLER
DIVISION DIRECTOR

DR.-ING. JOACHIM LINN
HEAD OF DEPARTMENT

COMPUTER AIDED DEVELOPMENT AND OPTIMIZED PRODUCTION IN THE AUTOMOBILE INDUSTRY

The department has experienced significant growth in recent years and, accordingly, has expanded the range of applications. For example, expanding from the simulation of cables and hoses, we also explore new fields of application in the area of the digital factory. Additionally, our VMC and USim tools, which were initially developed for load assumptions used in durability studies, are now widely used in the fields of energy efficiency, powertrains, and alternative drives as well as safety in Advanced Driver Assistance Systems and Autonomous Driving (ADAS/AD). Consequently, the department has re-organized these activities and created a new division: "Mathematics for Vehicle Engineering" (MF). The MF division consists of two departments: Dynamics, Loads and Environmental Data (DLU) and Mathematics for the Digital Factory (MDF); also, the Tire Simulation project group and a cross section unit called MF Technologies, which is responsible for testing and measuring systems.

The Dynamics, Loads, and Environment Data department continues to develop the simulation methods and tools for integrating environment data in variable use systems. This effort addresses the vehicle design attributes of durability, reliability, energy efficiency, and ADAS/AD. Subsequently, our system simulation activities center on vehicle-human-environment-interactions and the development of tire simulation models and methods for invariant system excitation. The development activities of the Mathematics for the Digital Factory department concentrate on software tools for the virtual genesis and development of products. Our software product IPS Cable Simulation, jointly created with FCC in Gothenburg, supports the virtual design, optimization, and safe assembly and operation of wiring, wiring harnesses, and hoses. Additionally, our IPS IMMA tool is a digital human model developed to facilitate virtual optimization of assembly installation processes.

Contact
klaus.dressler@itwm.fraunhofer.de
joachim.linn@itwm.fraunhofer.de
www.itwm.fraunhofer.de/en/mdf

MAIN TOPICS

- Dynamic, load assumptions, and variable use
- Durability and reliability
- Digital environment data
- HMI and driving simulators
- Non-linear structural mechanics / IPS cable simulation
- Tire simulation – CDTire

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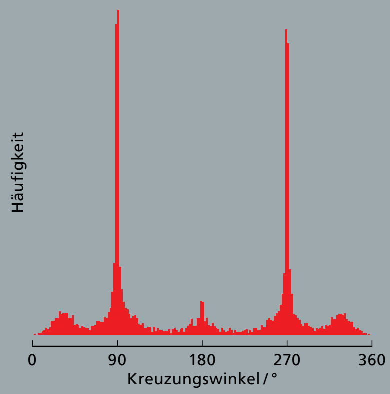

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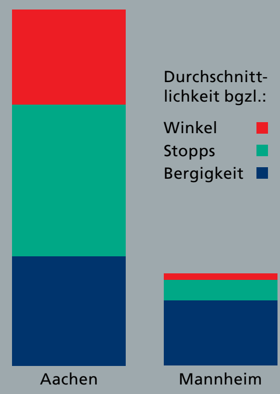

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VMC® – STATISTICS-BASED SELECTION OF REFERENCE ROUTES AND REGIONS

1 *Section of the road network in downtown Mannheim with its famous square pattern*

2 *Histogram of the crossing angles in Mannheim. The amount of 90° and 270° angles here are quite exceptional.*

3 *Comparison of averages between Aachen and Mannheim, referencing a pool of 190 cities in Germany The larger the bar for a characteristic, the closer it is to the average. The angular distribution in Mannheim is particularly far from the average.*

Global geo-referenced data can play a major role in statistical validation of the assessment base and the estimation of fuel consumption as used for vehicle development: In view of the great variability of use in the automotive sector, statistical analysis of these data can be a valuable supplement to the current methods.

The software package Virtual Measurement Campaign VMC® enables the simulation of vehicle loads. To this end, VMC® combines information from the global road network with algorithms developed in the MF division. A key function of VMC® is the regional analysis. It gives users the option to select an individual region, like a city or a municipal district. After selecting the region, users can analyze different consumption and load variables that are relevant to that area.

Virtual urban district and real cities

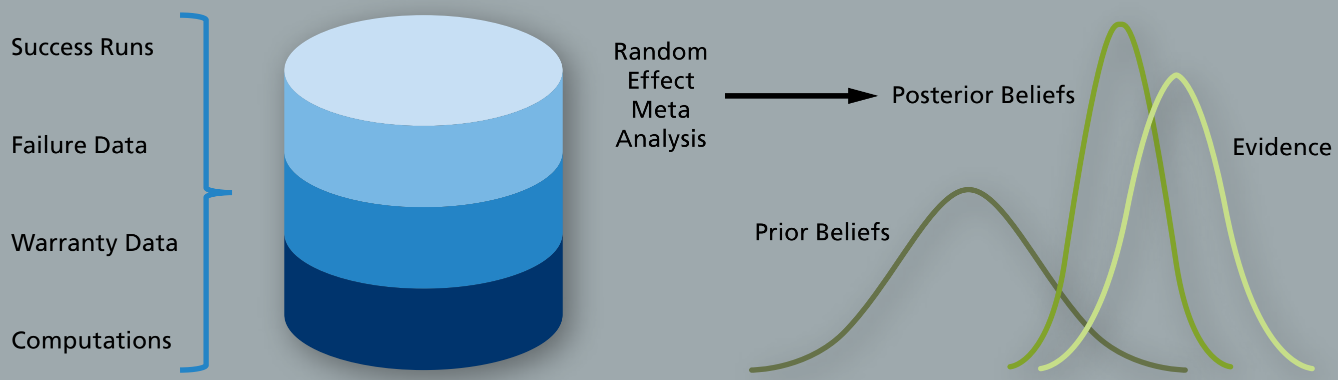
Last year, two of our research projects were tasked to expand the regional analysis. The core question to them was: What cities are particularly representative or above average for a specific area of application? Each project provided a different motivation for solving this problem: One involved the preparation of a representative virtual urban area for a vehicle simulator, while the other made a selection of suitable cities for an actual measurement campaign.

To compare two cities, we used various categories of characteristics. Which category a characteristic is assigned to is defined by how closely the characteristic relates to the expected load factor. For example, hilliness and curviness correlate quite directly with vehicle load and are assigned to the category of pseudo-load factors. Conversely, the appearance of the crossing angles in a city road network or the city's population density only indirectly affect the load, and so are placed in one of the other categories.

Appropriate criteria for each application

We developed pseudo-load factors using combinations of the various base measures established in VMC®. They can be simple measures, such as the stop event density, or more complex objects, such as the statistical hilliness distribution. To characterize the appearance of a road network, we used factors like the distribution of the crossing angles in the city. This process enables a statistically based selection of cities with a suitable formulation of criteria for the respective application.

VMC®



JUROJIN – PUTTING PRIOR KNOWLEDGE TO USE

Safety critical components must not fail even in very demanding customer usage. Statistical testing of several hundred components without failure is necessary for even 99 percent reliability. A joint project with ZF applies prior knowledge from historical data sets to improve the predictive accuracy.

1 *Schematic process for the use of various sources of prior knowledge*

Attempts to reduce the high costs through longer test duration or greater load placement on just 5 to 10 components, makes the certification test less selective and only components that are substantially better than the requirement will pass. At the same time, all manufacturers have accumulated experience: thousands of similar components have been successfully produced in series for many years. The systematic use of historical data for the certification test was difficult in the past. A human had to assess how well each individual data set transferred over to the current component generation. Automation was never an option.

Prior knowledge from historical data sets

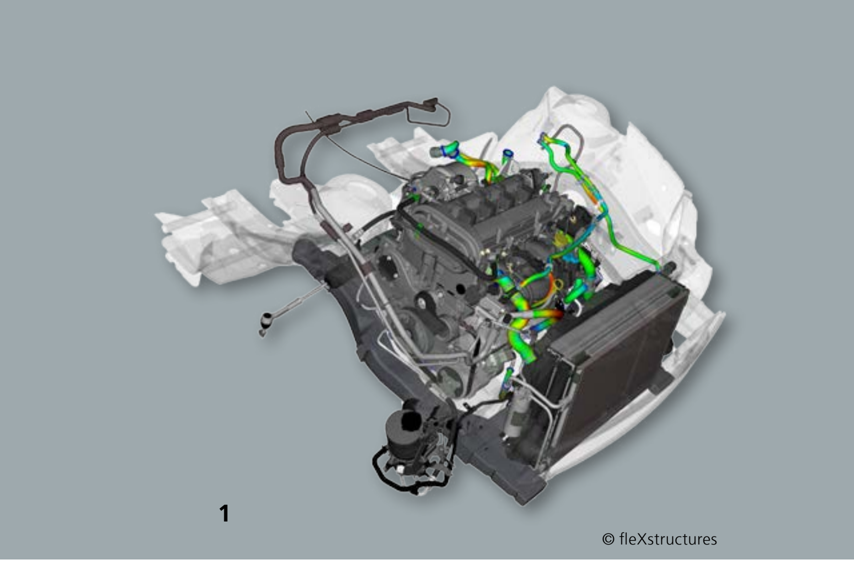
The joint project with ZF resulted in a process that we have implemented in Jurojin. It automatically generates a single individual knowledge model from any number of historical data sets. Bringing this prior knowledge into a smaller sample using Bayesian statistics, produces a level of quality that traditionally would have needed a much larger sample size. The design and planning of certification testing is significantly more efficient now. Our near term goal is to achieve a savings of 10 percent or more in the sample size.

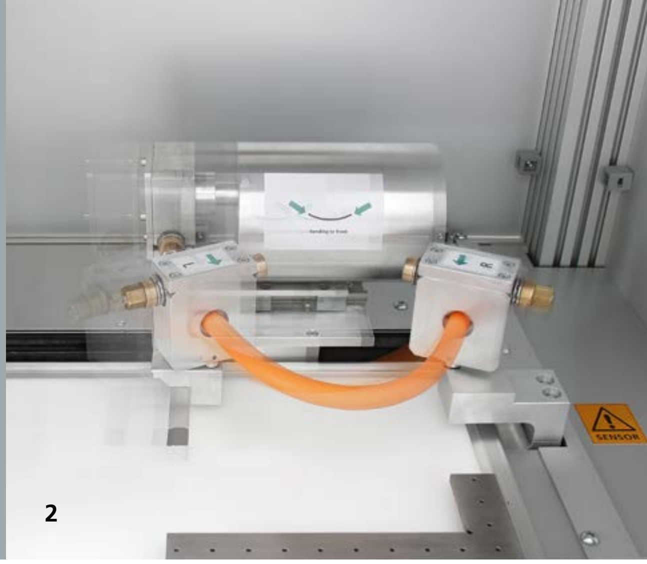
Random Effect Meta-Analysis

The new process can accommodate many types of historical data sets: whether the sample size is large or small, and no matter if there are just suspended items or all of the components have been tested until failure. The Random Effect Meta-Analysis we use automatically assigns the correct weighting to each data set (depending on sample size, consistency of the sample, and compatibility with other samples).

As the new, smaller size samples are also suitable for this format, the effect will be even greater in the coming years. Jurojin supports the entire process:

- ·Evaluates historical data and stores it in a database
- Combines many prior sources of knowledge in a Beta-distribution
- Uses the Beta-distribution for cost savings in the test plan





IPS CABLE SIMULATION AND MESOMICS® – SOFTWARE AND PARAMETERS FROM ONE PROVIDER

1 *Vehicle engine with cables and hoses*

2 *MeSOMICS bending test*

Cables are omnipresent. Looking into vehicles or other modern technical products, all contain moving cables and hoses which must not get damaged. Computer simulation helps to optimize the cable design and assembly, even before hardware prototypes are available.

However, to achieve realistic results, two essential requirements have to be fulfilled:

- The kinematical formulation and the computation of the mechanical equilibrium states, i.e. the cable deformation, must be physically correct.
- The simulation model has to include the mechanical properties of cables and hoses in a convenient way.

IPS Cable Simulation is developed by Fraunhofer ITWM and Fraunhofer Chalmers-Centre and fulfills both of the above criteria. Moreover, the computation is real-time capable and enables interactive simulation of cables and hoses.

Fast computation of cable deformations

The kinematical model is based on discrete Cosserat curves, where curvatures and strains describe the local deformation. To compute the overall cable deformation, we use the fact that static equilibrium states correspond to local minima of the potential energy of the cable.

For industrial applications with IPS Cable Simulation, a linear constitutive model with effective stiffness values integrated over the cross section is particularly useful. It turns out to be very robust and allows efficient numerical computations. Furthermore, these effective stiffness can be determined directly from measurements.

Determine mechanical properties automatically

MeSOMICS is developed especially for this purpose. The highly automated measurement system comprises an innovative bending experiment under practically relevant curvatures, a torsion experiment and a computational determination of the tension stiffness. After inserting the specimen, the measurement and the evaluation of measurement results runs automatically. In addition, an optical monitoring ensures a reliable parameter identification. Finally, a full parameter set for IPS Cable Simulation is provided. Thus, customers are enabled to measure the mechanical properties of important cables within a few hours on their own.

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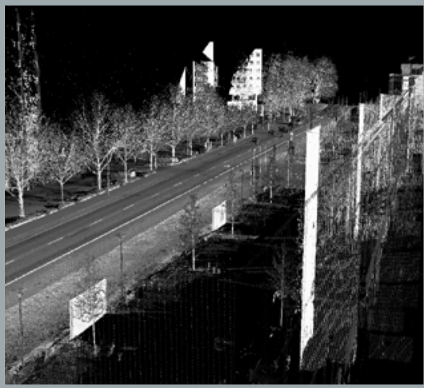

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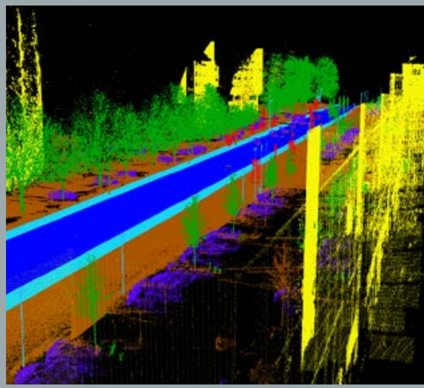

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VMC® ROAD-AND-SCENE GENERATOR: DIGITAL ENVIRONMENTAL DATA FOR VEHICLE ENGINEERING

The development, evaluation, and validation of modern assistance and automation systems for passenger cars and commercial vehicles is more complex than ever before. The VMC® Software-Suite enables vehicle engineers to connect the real world to its digital twin.

1 *Picture of the real scene (Trippstadter Straße, Kaiserslautern)*

2 *Georeferenced 3D-laser scan of the environment*

3 *Automatic semantic segmentation and classification of the scanner data*

Since many years, we deal with the statistical analysis of geo-referenced data in order to support and improve the virtual evaluation of vehicles. While assistance and automation systems getting more and more complex, traditional testing and proving procedures are reaching their limits.

Current approaches such as the description of the logic of road networks often fail when capturing complex edge cases. However, these are omnipresent in reality, e. g., incomplete lane markings or damaged road surfaces. Even in the absence of lane markings, assistance systems have to ensure safe driving conditions. This must already be taken into account in the development process.

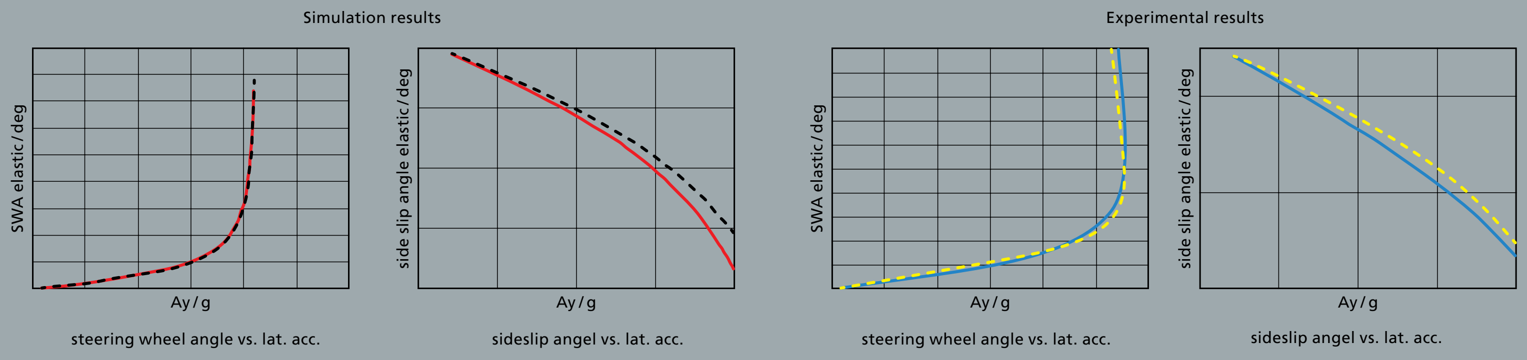
Real environment data as a basis

The "VMC Road-and-Scene Generator" is a software package that is currently developed at ITWM and enables the virtual development and evaluation of automation systems based on real environment data. Therefore, the process is as follows: Built on traditional statistical methods, we select a representative city, and then capture it using the institute's measuring car REDAR and save it as a 3D point cloud. We apply methods of machine learning and deep learning neuronal networks to analyze and classify the data; relevant objects such as vehicles, lanes, lane markings, buildings, etc. are automatically identified.

Automated data analysis and classification

This information provide a key component for a highly accurate sensor simulation since additional attributes can be made available for each object and each point, e.g., material properties, reflection and absorption characteristics depending on various electromagnetic wavelengths, etc. The data analysis and classification is highly automated leading to a highly efficient overall process.

VMC®



CDTIRE/3D: MODELLING TIRE VARIATIONS

1 *Qualitative comparison of tire size variation: 235/60 R 18 both axles (red/ blue straight lines) vs. 235/55 R 19 front and 255/50 R 19 rear axle (black/ yellow dotted lines).*

Simulation tools can shorten the time it takes for a product to reach series production with no loss in quality. Above all, they speed up the concept phase. Our department works together with various car manufacturers to improve the accuracy of simulation results in the early stages of development. Currently, a very promising new technology known as “morphing” is providing automotive manufacturers with access to data on many possible tire and wheel sizes in the earliest stages of planning – including, especially, some that do not yet physically exist.

The handling and performance of a passenger car is very dependent on the selection of tires. A new method uses the CDTire/3D model to predict the characteristics of a tire without having a physical prototype. Among the questions that arise in the early stages of development are the choice of tire and rim size, the optimal tire pressure, how much does changing tire specifications help in achieving the stated goals and how important is the vehicle itself.

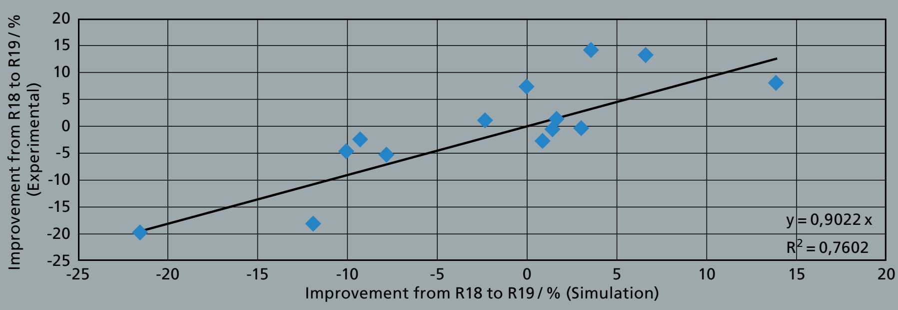
Geometric description of the tire

Fraunhofer ITWM develops the tire model CDTire/3D, which is used by the automotive industry in comfort, durability, and vehicle dynamics studies. A shell based discretization method combines the functional layers of a tire (like the cap plies, steel belts, and carcasses – each having defined material parameters), with their respective geometries. Modeling the elastic component for each fiber reinforced layer includes a nonlinear part that results from different tensile and compressive behaviors. The geometric description permits large deformations.

Separating material and geometric characteristics

The design assistant uses pressurized cross sectional geometry to parameterize the tire based on the construction properties of the functional layers. In effect, because the model strictly separates material and geometric properties, our method is able to modify an existing tire based on nominal specifications.

Our morphing algorithm adapts the geometric description and weight distribution of the reference tire to the specifications (tire width, tire cross section, rim diameter and width), without changing the material properties. For example, a 225/45 R17 (x7.5) tire size can be transformed into a 235/40 R18 (x8).



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Internal pressure variation

The importance of tire inflation pressure as a factor influencing tire performance characteristics must also be mentioned. The compressed air acts as a force on the innerlinerof the tire and puts a strain on the structure, in particular, the load bearing elements of the spiral layers (steel belts, carcass and cap plies). The CDTire/3D tire model can apply gas pressure to the entire inside of the tire (using various gas models such as the ideal gas equation or the compressible Euler equation), to accurately describe and predict how is effected not only by size changes to an existing tire and rim, but also by variations in the internal pressure.

This method is used in the early stages of tire development – from a base tire – to study different tire and rim sizes. The prerequisite for this approach is that the materials, construction, and profile all remain the same.

Comparison of simulation and result

Our evaluation compared the predictions about varying tire size with the experimental results for the typical criteria of driving dynamics. The results showed only small differences between measured and predicted vehicle behavior (see Figure 1). The method is also useful in cases where not many measurements are available. Figure 2 shows the measured and simulated percentage improvement for each criteria used by a luxury vehicle manufacturer to assess vehicle handling. As is clearly shown, the predictions always reflect the same tendencies.

Morphing engineering in tire development has proven successful and its continued use in the future is assured. Planning for future projects includes a study of minor changes to the materials and construction.

2 *Comparison between simulated and measured improvement of key performance indicators when switching from 18'' to 19'' wheels*

NEWS

5^{TH} INTERNATIONAL COMMERCIAL VEHICLE TECHNOLOGY SYMPOSIUM

The 5^{th} International Commercial Vehicle Technology Symposium was held on the campus of TU Kaiserslautern on March 13– 15, 2018. Attended by nearly 200 national and international experts and managers from scientific and business communities and supported by approximately 50 expert lectures and 15 poster presentations, the symposium provided a discussion forum for trends and technological developments in the commercial vehicle industry. Specifically, the topics ranged from energy and resource efficiency to safety, reliability and service life, automation, driver assistance, and autonomous driving.

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EMMA-CC SYMPOSIUM

In April 2018, the results of the Fraunhofer project EMMA-CC (www.emma-cc.com) were presented by each of the research institutes involved. This symposium was complemented by highly respected speakers from industry and research who accepted our invitation and presented expert lectures which examined different areas of application and the industrial needs of digital human models from different perspectives. Speakers included Prof. Lars Hanson (SCANIA AB; University of Skövde), Dr. Sascha Wischniewski, Federal Institute of Occupational Safety and Health, Dr. Thomas Bär (Daimler AG), and Prof. Sigrid Leyendecker (University of Erlangen-Nürnberg).

4^{TH} SYMPOSIUM ON DRIVING SIMULATION

4^{th} Symposium on Driving Simulation was held at Fraunhofer ITWM on November 14, 2018. More than 50 participants actively discussed current challenges in the area of virtual development, testing, and verification of systems for autonomous vehicles. The practical relevance of the symposium was underscored by diverse live demonstrations of the simulation methods available at ITWM (static driving simulators, VR Lab, RODOS®, etc.).

Front, left to right: Tim Rothmann, Christine Biedinger, Björn Wagner, Canhui Wu, Dr.-Ing. Lilli Burger, Vanessa Dörlich, Dr. Jochen Fiedler, Dr. Michael Speckert, Dr.-Ing. Michael Roller, Dr. Klaus Dreßler, Thorsten Dahlheimer, Hannes Christiansen, Dr.-Ing. Michael Kleer, Thomas Stephan, Thomas Halfmann, Christine Rauch, Dr.-Ing. Joachim Linn, Steffen Polanski, Thorsten Weyh, Axel Gallrein, Dr. Fabio Schneider, Dr. Sascha Feth, Christoph Mühlbach, Jonathan Jahnke, Dr. Michael Burger, Simon Gottschalk, Benjamin Bauer, Marius Obentheuer, Thomas Jung, Tobias Ruhwedel, Dr. Stefan Steidel