



# Mathematics for Industry and Production

Our modern, industrialized world without mathematics? Inconceivable. Because mathematics is involved almost everywhere. Around 500 people work at our institute, putting applied mathematics into practice. It is an interdisciplinary field that uses mathematical methods and models to solve problems to increase efficiency, reduce costs or improve quality. This makes mathematics an important driving force for the economy.

Working in industry has changed dramatically in recent years. Production processes are being digitalized and the use of automated machines and robots has increased. Lower energy consumption is required everywhere in order to save costs, but also for reasons of sustainability. This also affects the demands placed on employees: In addition to manual skills, technical understanding and an experienced handling of new technologies are required.

At Fraunhofer ITWM, we develop customized solutions, often together with partners from the industry. These are intended to help companies move forward, but also to provide employees with concrete tools for better work.

## What Does Fraunhofer ITWM Offer for Industry and Production?

### ■ Data analysis and Machine Learning

With the advent of big data, data analysis plays a central role. Machine learning algorithms based on mathematical models help companies to recognize patterns in large data sets and carry out analyses.

### ■ Simulation

Simulation techniques help to model complex systems and predict their behavior under different conditions. This is particularly useful in manufacturing to identify bottlenecks, make production planning more efficient or avoid production errors.

### ■ Optimization

Mathematical optimization is used to make efficient use of resources. Companies use optimization algorithms to im-

prove production processes, minimize material costs and optimize supply chains. But optimization is also used in personnel deployment planning.

### ■ Statistics

Statistical methods are crucial for quality control and process improvement. Companies use statistical methods to analyze data, identify trends and make decisions based on facts.

### ■ Risk Analysis

Mathematical models are used to assess risks and to develop strategies to minimize them. This is particularly important in the financial and insurance sectors, but is also used in production planning.

# “Mathematics is the Language of Science and Technology”

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What does mathematics do for industry and production? We want to answer this question in this report. We spoke to Dr. Klaus Dreßler, who has been heading our “Mathematics for Vehicle Engineering” department for many years.

## For many people, mathematics is above all theory. How do you bring mathematics into industry?

This is a fundamental question that has been with us since our institute was founded. Mathematics is the language of science and technology. Mathematics is essential in all technical development processes – in product development, which today is predominantly virtual, in product validation, production planning and the associated quality assurance.

## What does this look like in practice, what topics is your department working on?

We enable the simulation-supported, virtual development of vehicles, systems and plants. The focus for vehicles is on tires, cable harnesses and the variability of vehicle use. One area of research, for example, is our digital human models: people’s body sizes vary, but a vehicle must be able to be used safely and easily by as many people as possible. We also support the development of quality assurance inspection solutions.

## Statistics is a field that many people can imagine. How are statistics used in the automotive industry, for example?

Statistics are particularly important at the beginning and end of the development and

validation processes. At the beginning, when a vehicle is being developed, it is necessary to model and quantify what a vehicle will have to endure in its lifetime – for example, what happens how often over the course of 300,000 kilometers? The type of use, i.e. a commuter or a parcel delivery driver, and the geography are variable. That’s statistics! And this is the basis for all the calculations for the vehicle. At the end of the development process, the vehicles and their components are validated. Test and validation scenarios are designed and run through to ensure that a vehicle meets the requirements. This is also statistics.

## Can mathematics prevent errors in production?

It can make a significant contribution to minimizing errors in production. For example, by simulating assembly processes using digital human models and then optimizing them. Mathematics can use condition monitoring processes to help detect and correct the slightest deviations in process control at an early stage before these process deviations lead to production errors. The mathematics involved in condition monitoring is now often referred to as Artificial Intelligence (AI). Image processing-supported inspection solutions, also with mathematical AI algorithms, are used to detect errors and prevent subsequent errors.

“Mathematics can prevent errors in production.”



### How important is mathematical education in engineering for industry?

Very important! As already mentioned, mathematics is the language of technology. Today, however, it is no longer enough to have mathematically well-trained engineers in industry, but it is important to have good interdisciplinary cooperation with people who have a mathematical or information science background.

### What do mathematicians need to bring with them when they come to our institute?

You must be very good at your subject. In our field, we also require an interest in physics and technology. And they must be open to interdisciplinary work. In particular, they must be prepared to work on problems from the "real world". Here we often see that work is done differently in the university sector. In the industry, problems are not always "methodically clean". With mathematics, we can formally represent structures. We have people with mathematical knowledge and skills on site with whom we can generate added value, particularly in terms of how a problem is understood. An engineering institute would not go as deeply into the analysis as we do here.

**Today, it is no longer enough to have well-trained engineers in mathematics; good interdisciplinary cooperation is essential.«**

**Dr. Klaus Dreßler,**  
Division Director "Mathematics for Vehicle Engineering"

### Are there any trends or developments in mathematical applications that you find exciting?

The rapidly increasing availability of data over a long period of time is creating more and more opportunities for data-based modeling – machine learning, AI, predictive maintenance – in all technical areas. However, in order to be able to predict and make decisions, you still need to understand physics. This constantly creates new opportunities, but also challenges for hybrid mathematical modeling. So it remains exciting for us.

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# Industry Insight: What We Offer the Automotive Industry

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## Digital Environmental Data

How must a vehicle be constructed so that it can be used in a wide variety of ways at different locations? How are certain vehicle parts stressed? How do environmental conditions affect assistance systems? Today, tests that provide answers to questions like these are mainly carried out virtually. Simulation makes it possible to repeat a test as often as required with different parameters. Digital environmental data, which provides

information about the conditions under which a vehicle is used, plays a major role in simulations: mountainous or rather flat landscapes, city traffic or extensive routes – they all have to be taken into account when planning and statistically evaluating tests. At Fraunhofer ITWM, we can access different digital environmental data and thus test the operational stability of construction machinery, commercial vehicles or trucks.



[www.itwm.fraunhofer.de/umgebungsdaten-en](http://www.itwm.fraunhofer.de/umgebungsdaten-en)

## Load Data and Fatigue Strength

The properties of the systems and components as well as the load data are required for questions relating to reliability and operational stability. In order to enable a customer-specific design, our researchers determine the stresses occurring in the field and their variance. This is done using a suitable mixture of direct load measurement and simulation in selected conditions,

general observation of customer behavior and statistical extrapolation of partial data.

### This is what we offer:

- Collecting, simulating and evaluating data
- Determining operational stability using statistical methods
- Data simulation and load tests



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## Dynamics and System Simulation

In system and vehicle development, it is crucial to simulate the physical system properties at an early stage and in various phases of the development process in order to evaluate, improve and validate design statuses.

The possibility of hybrid and interactive simulation is becoming increasingly important in order to realistically include electronic control units and the driver in the calculation.

### We are working on this:

- Further development and application of methods in the system simulation of mechatronic systems
- Traffic simulation
- Regulation and optimal control of technical systems
- Data-based mathematics, in particular data analysis and machine learning

- Simulation of coupled physical systems (co-simulation)

We are particularly concerned with real-time capable methods, but also with methods that simulate vehicle behavior in any region or market in the world as part of a virtual measurement campaign (VMC<sup>®</sup> Simulation).



[www.itwm.fraunhofer.de/dynamics-system-simulation](http://www.itwm.fraunhofer.de/dynamics-system-simulation)

## Human Models and Human-Machine Interaction

Numerous high-end products are still – and will continue to be in the near future – manufactured by people. Wherever skill, intelligence and experience are essential for high product quality, people are involved. The digitalization of the product creation process requires simulation tools. These should map human work

activities so well that the influence of the “human factor” on product quality can be mapped and product quality ensured. The ergonomic design of workstations is equally important, supports workers in maintaining their health and ultimately also benefits high product quality.



[www.itwm.fraunhofer.de/Menschmodelle-en](http://www.itwm.fraunhofer.de/Menschmodelle-en)

## Cables, Hoses and Flexible Structures

Virtual assembly planning requires a fast and physically correct description of the behavior of cables and hoses, such as those laid in the engine compartment of a vehicle or mounted as dress packs on industrial robots. We have developed special non-linear structural models for assembly simulation with IPS Cable Simulation. We use them to calculate the

deformation of cables and hoses realistically and interactively.

For the practical use of the IPS software, it is important that the simulation models are well-dimensioned. The MeSOMICS<sup>®</sup> measuring machine developed by us offers the optimum solution for this.



[www.itwm.fraunhofer.de/ips-cable](http://www.itwm.fraunhofer.de/ips-cable)

## Tire Models CDTire

Simulating tires is challenging because their behaviour is complex and non-linear. As a component of modern MBS programs, CDTire supports development engineers in almost all analysis scenarios. Special attention to belt dynamics and interaction with 3D road surfaces allows good prediction accuracy – both of

transient amplitudes and in the frequency domain. CDTire as a software tool offers a family of tire models with different modeling of belt, sidewall and tread to provide an optimal mix of accuracy and computational effort for different applications.



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# Test Facilities for the Automotive Industry

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Fraunhofer ITWM's Technikum is home to test facilities designed to support and generate input data for our simulation. Our researchers also develop measurement and simulation techniques that are used in the automotive industry.

- In the Technikum, three laboratories are available for interactive driving simulation: The largest facility is the robot-based driving simulator RODOS<sup>®</sup>, in which off-the-shelf vehicle cabins are moved by a robotic arm to combine realistic motion feedback with the haptics of the real vehicle. There is also a static driving simulator for the interactive simulation of passenger cars. Vulnerable road users such as pedestrians can be integrated into the simulation in the specially equipped virtual reality laboratory. Interlinking the three laboratories enables the investigation of human interactions in highly complex traffic situations.
- The MeSOMICS<sup>®</sup> measuring machine is manufactured and further developed in the Technikum. MeSOMICS<sup>®</sup> is an automated system designed to determine parameter sets for cables and hoses that can be used directly in the IPS Cable Simulation software. The measurement of effective cable stiffness is extremely robust thanks to optical monitoring and automation, and delivers results within a few minutes.
- With our 3D measurement vehicle REDAR, we can capture environmental data using cameras and laser scanners. The highly accurate, realistic virtual environments generated via sensor fusion based on the acquired data are used in industry for the virtual validation of driver assistance systems or interactive driving simulation.
- The Technikum is currently being expanded to include a tire laboratory to study tire emissions. The test benches located there will allow to acquire data and validate simulation models for tire emissions with regard to abrasion, noise and air pollution – and thus create the ideal conditions for a promising research topic in the future.



# A Non-Destructive Look Inside – Terahertz tests Semiconductors

Semiconductors are at the heart of modern technologies – whether in smartphones, cars, solar panels or high-performance computers. To ensure they function reliably, they need to be inspected precisely during production – ideally quickly and without touching them. In the “THz-SEMICON” (Terahertz Semiconductor Inspection) project, we are working with our partners to develop a non-destructive testing system for the semiconductor industry.

“With the help of our terahertz time-domain spectroscopy (THz-TDS), we can measure thin layers of semiconductor materials with high precision and in the shortest possible time,” explains Joshua Hennig from the “Materials Characterization and Testing” department. The technology sends ultra-short pulses through the thin layers. The reflected signals provide detailed information about the inner structure – without any contact.

## Larger Wafers, Ever Thinner Layers, New Material

This means that even wafer-thin layers of modern materials such as silicon carbide or gallium nitride can be reliably tested for layer thickness, electrical resistance or charge carrier density. This is a great advantage for the semiconductor industry, which is under high cost pressure and at the same time developing ever more powerful and complex components.

While conventional measuring methods require direct contact with the sample – with the risk of damage or contamination – terahertz technology works completely contact-free and also increases the measuring speed: even large semiconductor wafers with diameters of up to 450 millimeters can be fully tested within a few minutes.



*The “THz-SEMICON” project is funded by the “Central Innovation Program for SMEs” (ZIM) of the Federal Ministry for Economic Affairs and Climate Protection.*

## Keeping Production on Track

The project goal: a fully integrated testing system that detects the smallest deviations and defects without slowing down the production line. In this way, “THz-SEMICON” will help to make our smartphones, solar modules and computer chips even more reliable, efficient and, in the best case, sustainable in the future.

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# Getting the Most Out of It

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Mathematical optimization is a branch of applied mathematics. We have named an entire department after it. Its expertise: solving optimization problems as they arise in industry, especially in production. Whether in the chemical industry, mechanical engineering, the energy sector, healthcare, production planning, machine learning or supply chain management – there is a need for optimization everywhere. We give a look at some current projects.

## Production Networks Across Departmental and Company Boundaries

The “Optimization – Operations Research” department develops solutions for complex planning tasks in production, logistics and for service-providing companies. These ensure that resources are used efficiently and processes are improved. Production processes often extend across different departments and locations or even include other companies. To ensure that everything runs smoothly in such cases, the researchers develop software solutions that coordinate complex production networks.

One example of the use of production networks is the pharmaceutical industry: drug manufacturers outsource parts of their production to specialized companies (Contract Management Organizations, CMO). Through thorough planning, production volumes, product variations, and the time management of collaborating companies are coordinated. “When it comes to the reliable supply of vital medicines, nothing should be left to chance,” says Dr. Heiner Ackermann. “Our software solutions are optimally tailored to the needs of the respective client.”

## Using Mathematics for Fairer Personnel Planning

Those responsible for duty scheduling in a hospital ensure that sick patients are cared for by specialist medical staff at all times – even at weekends and on public holidays. “These shifts are often less popular than others, but they have to be staffed,” says Ackermann. A team is therefore developing a tailor-made software solution based on mathematical models and optimization algorithms for scheduling medical staff at the Department of Anaesthesiology at the Heidelberg University Hospital.

“The aim is to take employees’ individual wishes into account when planning shifts, and to create a platform that automates the previously manual planning process and ensures rolling fairness,” explains Ackermann. Until now, this process has taken up a lot of time of highly qualified personnel. The aim is to significantly reduce the manual planning effort. “This is an exciting use of mathematics, which can ensure greater fairness here because the planning is data-based. However, it is also important that it does not replace the dialog between people who work together and ultimately have to agree.”

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*The expertise of our researchers is in demand in numerous projects in the chemical and pharmaceutical industries.*

## Mathematical Method Applied to Chemistry for the First Time

Whether it is the design of a technical system or the question of an optimal control strategy for a specific work step, such questions can almost never be answered in isolation. They must be considered in the context of many interlinked processes and procedures. In process engineering, the focus at our institute in the "Optimization – Technical Processes" department is particularly on the chemical, pharmaceutical and biotechnology industries and fields of application.

A current cooperation project with BASF SE is dedicated to the optimization of overall processes including uncertainties in the chemical industry. "A central question that keeps us busy: How do you take uncertainties into account in process design and operations management?" says Prof. Dr. Michael Bortz. "The methods for such an assessment are well known in mathematics: A distinction is made between 'here-and-now' and 'wait-and-see' variables, which describe decisions on process design or even actual operation." In addition, there are typically competing objectives in almost every process – such as profitability, sustainability or quality. This leads to multi-criteria, two-stage optimization problems.

Our researchers are applying these mathematical concepts to chemical production processes for the first time: Together with BASF SE, the methods were made available for their flowsheet simulator Chemasim in order to be able to react better to uncertainties in the operating process.

## Optimization of Overall Processes in the Chemical Industry

In another project, the focus is not on the actual operational management; our researchers start earlier and provide support in the decision-making process: What equipment and systems are needed to separate mixtures of substances? The starting point for the considerations here are certain properties of a mixture of substances that are to be used. The mathematics lies in the description of the material properties: "This is at least as much physics and mathematics as chemistry," says Bortz. In order to extract certain substances from a mixture, different boiling points must be taken into account. "We are creating software that supports engineers in the design of complex separation processes. To do this, the topology of the phase diagram is calculated beforehand and a flowsheet of unit operations is suggested based on this."

 [www.itwm.fraunhofer.de/verfahrenstechnik-chemie-en](http://www.itwm.fraunhofer.de/verfahrenstechnik-chemie-en)

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# For Better Quality Control – Surface Inspection for Wooden Panels



*A user-defined tool enables the detailed display of anomalies.*

The quality of surfaces plays a decisive role in most industrial products: new methods are being developed in the “Image Processing” department to automate the detection of defects on surfaces in production.

One application example from research practice is the inline inspection system for shelf panels. It is intended to replace manual inspection in the production of wooden panels in the future. Our researchers use various image acquisition and image processing techniques. This ensures a high detection rate of defects and at the same time meets the increased production requirements and demands for traceability of quality decisions. “Our technology makes it possible to analyze surfaces in real time and provide immediate

feedback to production,” explains contact person Dr. Henrike Stephani. “This not only reduces rejects, but also saves time and costs for manufacturers. This also increases competitiveness.”

## Machine Learning is Used

The researchers use hybrid methods that combine traditional image processing with Artificial Intelligence (AI) and this combination enables the stable industrial use of current AI methods. This means that even the smallest irregularities that are barely visible to the human eye can be reliably detected. “We rely on AI-supported analysis that is constantly evolving and adapting to the specific requirements of our customers,” continues Stephani. This ensures that the wooden panels are not only aesthetically pleasing, but also functionally flawless.

## Insight Into the Extensive Error Catalog

In the case of the shelf panels, the product variants consist of single-colored panels and wood decor. The panels come in different sizes. The catalog of defects includes numerous typical defects, including scratches, holes, discoloration, excess glue or lines. A deep learning algorithm is particularly suitable for wood-like decors with irregular surface patterns. The system developed at Fraunhofer ITWM achieves high precision values for various defect categories.

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# Cut Costs With Predictive Maintenance

Unplanned repairs are roughly three times more costly and time-consuming than scheduled maintenance. Equipment failures create avoidable opportunity costs and unnecessary scrap. Predictive maintenance helps prevent these issues.

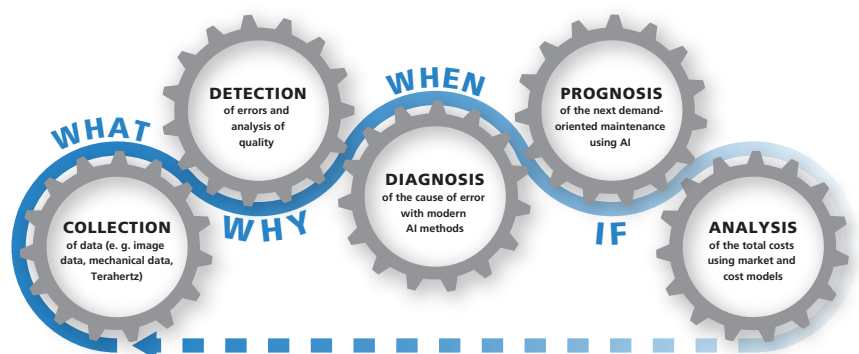
Fraunhofer ITWM brings deep, proven expertise from numerous deployments to make production lines more efficient and cost-effective in maintenance and quality monitoring. Machine-specific solutions help companies unlock the potential of digitalization and put it to work on the shop floor.

## What Predictive Maintenance Delivers

- Prevent production losses and scrap caused by unplanned downtime
- Schedule necessary downtime in advance during non-production windows
- Ensure that spare parts, tools, and experts are available for quick repairs
- Reduce manual effort through digitized inspections
- Improve system effectiveness and reliability

As Benjamin Adrian notes, predictive maintenance helps prevent unnecessary repairs, secondary damage, and the associated stress. Continuous machine monitoring not only extends service life; but also safeguards product quality. When machines run smoothly, product quality improves – and so does the working environment for employees.

For example, condition monitoring digitally tracks machine status. Intelligent algorithms



*The modules include rentable measuring systems, the collection and analysis of data, the creation of condition monitors, RUL forecasts, target/actual comparisons and the commercial creation of market and cost models, as well as a combined automated quality analysis.*

analyze the data and deliver precise predictions of maintenance needs, enabling condition-based maintenance rather than fixed intervals.

## Start Small with Modular Solutions

Researchers at Fraunhofer ITWM help companies boost the effectiveness of their systems. They build on proven modules and tailor them to each customer's requirements.

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# More Efficiency, Quality and Sustainability for Battery Production

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The demand for high-performance energy storage systems is growing, as is the desire for independence from international markets. That is why we at Fraunhofer ITWM are working on using our digital methods to optimize the quality and efficiency of battery cell production – especially with regard to electromobility.

At our institute, we develop software tools with which we can also improve the production processes for lithium-ion cells and battery packs and drive forward the development of new battery technologies. Our researchers are contributing their expertise across departments in the “DiBaZ” project. One goal is to develop a digital twin for all process steps in battery production. We can offer comprehensive models that simulate battery production processes, enable non-destructive quality control and include energy management with predictive control.

## Simulation of Individual Process Steps in Battery Production

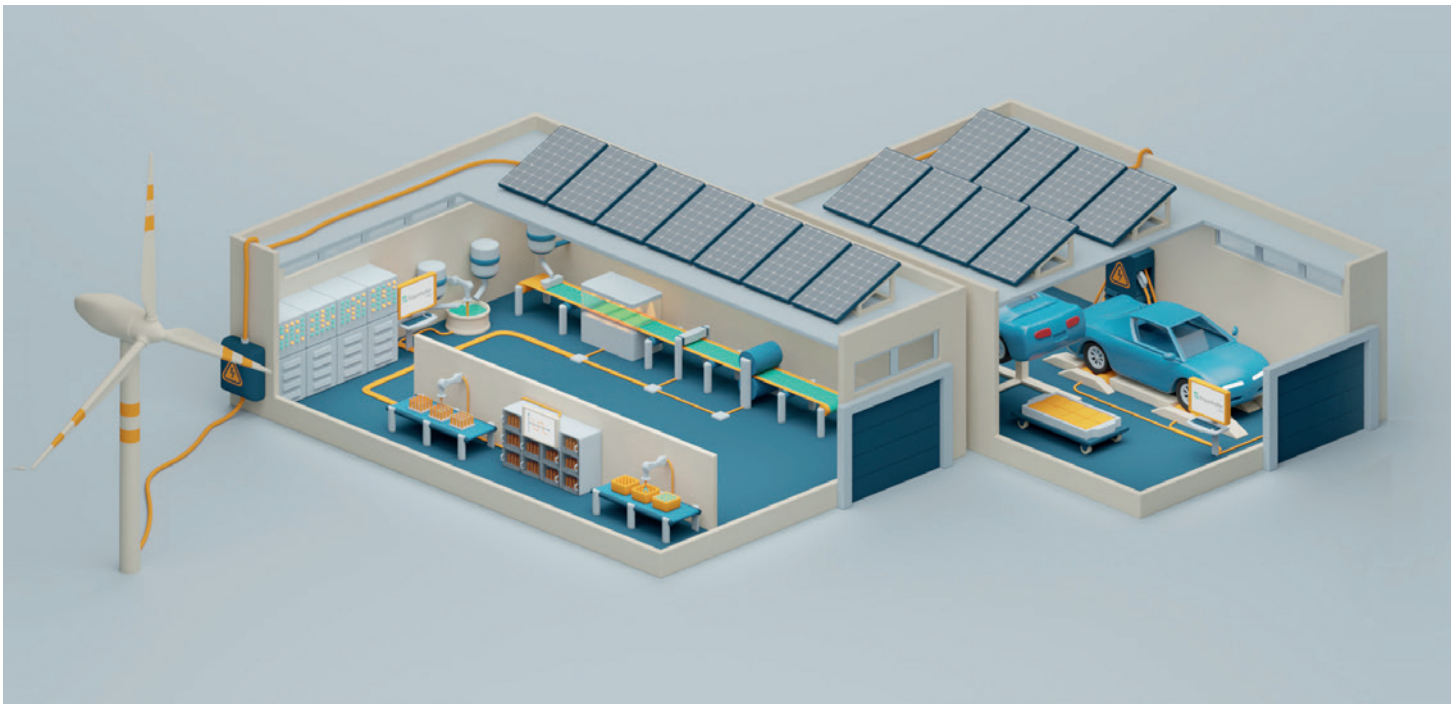
The production of batteries consists of a series of complex processes, ranging from electrode production and cell assembly to module and pack assembly. In order to optimize these production processes, we have further developed our simulation techniques and can use them for the essential processes of cell production. This includes the mixing of electrode slurries, drying and calendaring of the electrode sheets, and electrolyte filling of the assembled cells. Our software simulations also lead to greater efficiency when foaming battery modules.

## Electrochemical Simulation for Cell Design, Analysis and Performance Prediction

We use our BEST software to carry out the physics-based, three-dimensional simulation of lithium-ion batteries. “Our BEST simulation tool can be used in a variety of ways: for example, we can use it to predict cell performance and virtually design the cell at both microscopic electrode level and macroscopic cell level. We can optimize charging strategies or investigate ageing and degradation phenomena,” explains Jochen Zausch, Team Leader “Electrochemistry and Batteries”.

## Quality Control Through Non-Destructive Testing

For optimum battery performance, the coating of the electrode foil must meet high requirements in terms of thickness and homogeneity. Continuous monitoring of these material parameters is crucial for product quality. In order to monitor them inline during production, our researchers have advanced our terahertz measurement technology.



*In the "DiBaZ" project (digital methods for the production and application of battery cells), we are developing a cross-departmental digital twin for all process steps in battery production – from electrode production and quality control to energy management in production.*

The measurements are carried out inline on single and multi-layer coatings at various points in the wet or dry process. "Terahertz is always non-contact and non-destructive, is suitable for anode and cathode coating and is non-hazardous – so there is no need for complex radiation protection," says Dr Joachim Jonuscheit, Deputy Head of the "Materials Characterization and Testing" department, explaining the advantages of measuring the thickness of coatings using terahertz technology.

### Energy Management and Predictive Control

We have also developed digital twins for various stages of battery production in order to predictively control the energy consumption." These models simulate the behavior of the machines and enable precise predictions of energy requirements. In the formation process in particular, our predictive control optimally coordinates the charging and discharging cycles – in line

with the desired consumption curve. This allows load peaks to be specifically avoided or shifted to times with a high proportion of renewable energy. We can also flexibly integrate photovoltaic systems and energy storage systems.

### Fraunhofer Battery Alliance: Solutions Along the Entire Value Chain

In the Fraunhofer Battery Alliance, we pool our expertise in the field of battery technology with experts from 25 other Fraunhofer Institutes. The aim is to quickly transfer scientific findings to industry and thus to the market. To this end, the member institutes of the Fraunhofer Battery Alliance work together with industry on technical and conceptual solutions along the entire energy storage value chain – from material development to system integration of mobile and stationary electrochemical storage systems – either directly on behalf of customers or in funded projects.

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# Textile Industry: Simulation of the Spinning Process

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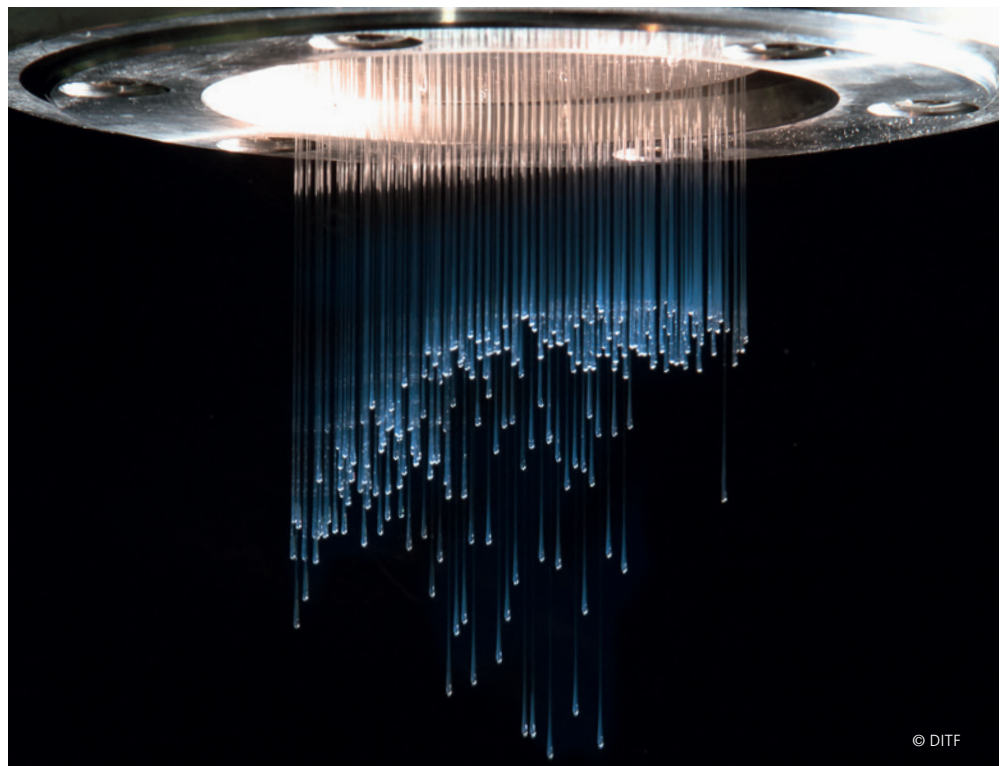
Mechanical engineering is a cornerstone of the German economy and plays a crucial role in promoting innovation and technological development in many sectors. The textile industry in particular faces the challenge of continuously adapting to the demands of globalization, sustainability and the rapid progress of digitalization. Digital simulations are indispensable tools for optimizing production processes, testing design alternatives and increasing efficiency.

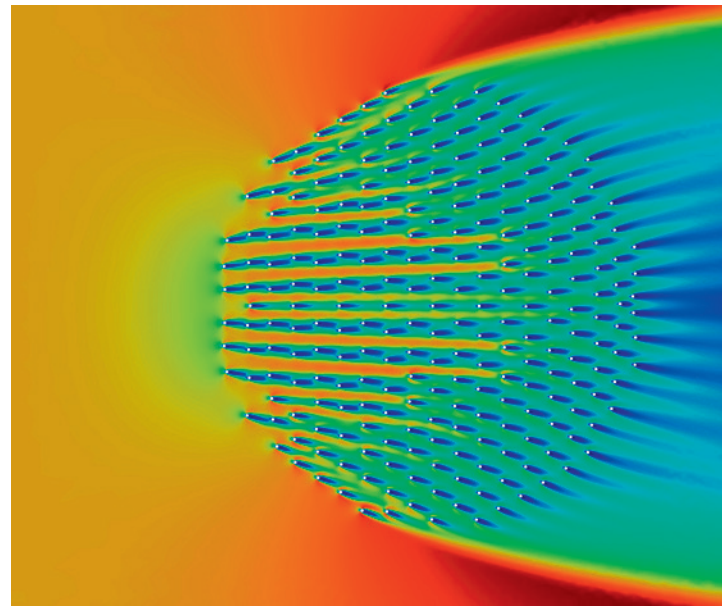
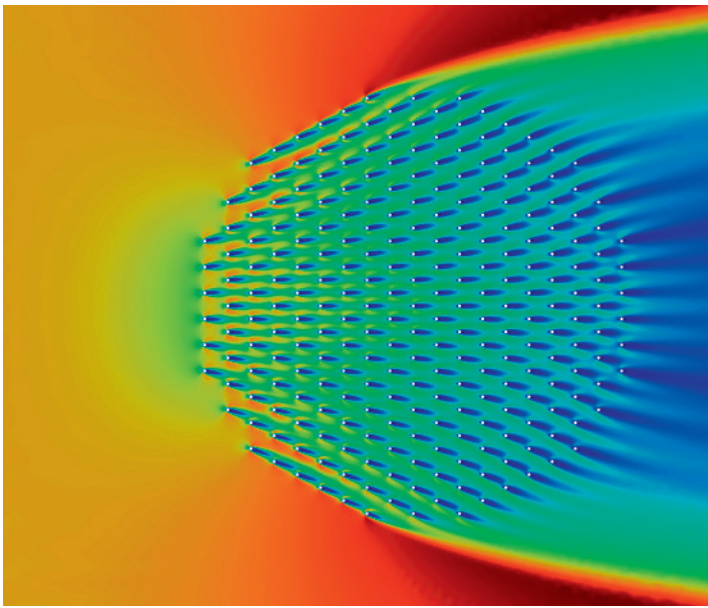
A central aim of VISPI (virtual spinning) is to increase the flexibility of textile production. The ability to react quickly to market changes is also crucial for this industry. Virtual spinning enables companies to test the impact of different process settings without having to create physical prototypes. "We want to help manufacturers speed up their product development and reduce costs at the same time," explains Dr. Walter Arne, who is co-developing the software.

## Tests Without Physical Prototypes

VISPI uses state-of-the-art digital technologies to virtually simulate the spinning process. This allows the properties of fibers to be digitally modeled and analyzed as early as the planning phase. The simulation of the spinning process also makes it possible to investigate the influence of various process parameters on the quality of the fibers. "Virtual simulation allows us to optimize the spinning process even

VISPI optimizes spinning processes before the actual production





*An optimized arrangement of the hole positions improves the flow and therefore the cooling of the filaments considerably.*

before actual production begins,” says Arne. This approach can significantly shorten the time to market for new textile products and at the same time significantly improve the quality of existing spinning processes.

### Software Tool “Cashocs” Enables Optimization of Spinnerets

In the manufacturing process of synthetic fibers, the polymer melt is pressed through fine nozzles, spun into fibers and then solidified by cold air flow. VISPI simulates from the spinneret to the first godet and also takes into account the supply of airflow to cool the fibers. “At Fraunhofer ITWM, we do not only simulate various spinning processes, but were also recently able to integrate a new tool for optimizing the design of nozzles into our investigations,” reports Arne. This refers to the software cashocs, which was developed as part of his colleague Dr. Sebastian Blauth’s

doctoral thesis. With cashocs, the nozzle itself, from which the fibers emerge, is optimized. To do this, the air flow around the fibers is simulated in detail and their arrangement is improved using mathematical optimization methods. “Uniform cooling of the fibers is important for product quality so that all filaments have the most uniform properties possible,” explains Blauth.

Optimization with cashocs creates lanes in the fiber arrangement, for example, through which the cooling air can also reach the rear filaments, which are often poorly cooled. The optimization changes the arrangement of the filaments so that they all receive the most effective cooling in the right place – the nozzles just have to be drilled in other positions for this. “Optimization with cashocs provides clear recommendations for action that are very easy to implement and have a major impact on the quality of the spinning process.”

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# Grid-free Calculation Software – Time-Saving Modeling of Complex Processes

Whether in the automotive sector or in production: simulations and digital twins are indispensable for many companies. Because highly dynamic processes often cannot be modeled satisfactorily with conventional software, researchers at our institute have developed the MESHFREE tool, a solution that works without a rigid computational grid and is able to simulate complex processes with great time savings and therefore cost-effectively. They were awarded the Joseph von Fraunhofer Prize 2024 for their work.

Rigid specifications rarely fit agile processes – what applies to organizations also applies to simulation methods. If complex processes such as aquaplaning or the machining of metal are to be modeled virtually, it is not possible to predict all the movements of the components in advance and create them in a suitable calculation grid, as is usually used for simulations.

free jet turbines. In some cases, this makes it possible for the first time to show particularly complex and dynamic situations in the simulation. All of the research results achieved since then have been incorporated into the MESHFREE software tool. The result is a simulation tool with a truly unique selling point: no other simulation tool in the world makes the Generalized Finite Difference Method (GFDM) available for industrial use.

## MESHFREE Replaces the Real Test

This was the challenge faced by a research group at Fraunhofer ITWM over 20 years ago. “Our very first task in the project team was to simulate the deployment of an airbag during a vehicle crash,” reports Dr. Jörg Kuhnert, who was already part of the group at the time. “Apart from cost-intensive crash tests carried out in real life, there was no way of quickly testing the safety of new developments in this area at the time.” This is because the more objects that move and interact with each other in a situation, the more difficult it is to reliably reproduce them using conventional simulation methods at a reasonable cost.

Based on Jörg Kuhnert’s dissertation, the team therefore developed the innovative grid-free approach – since 2012 also with the collaboration of Dr. Isabel Michel in the area of

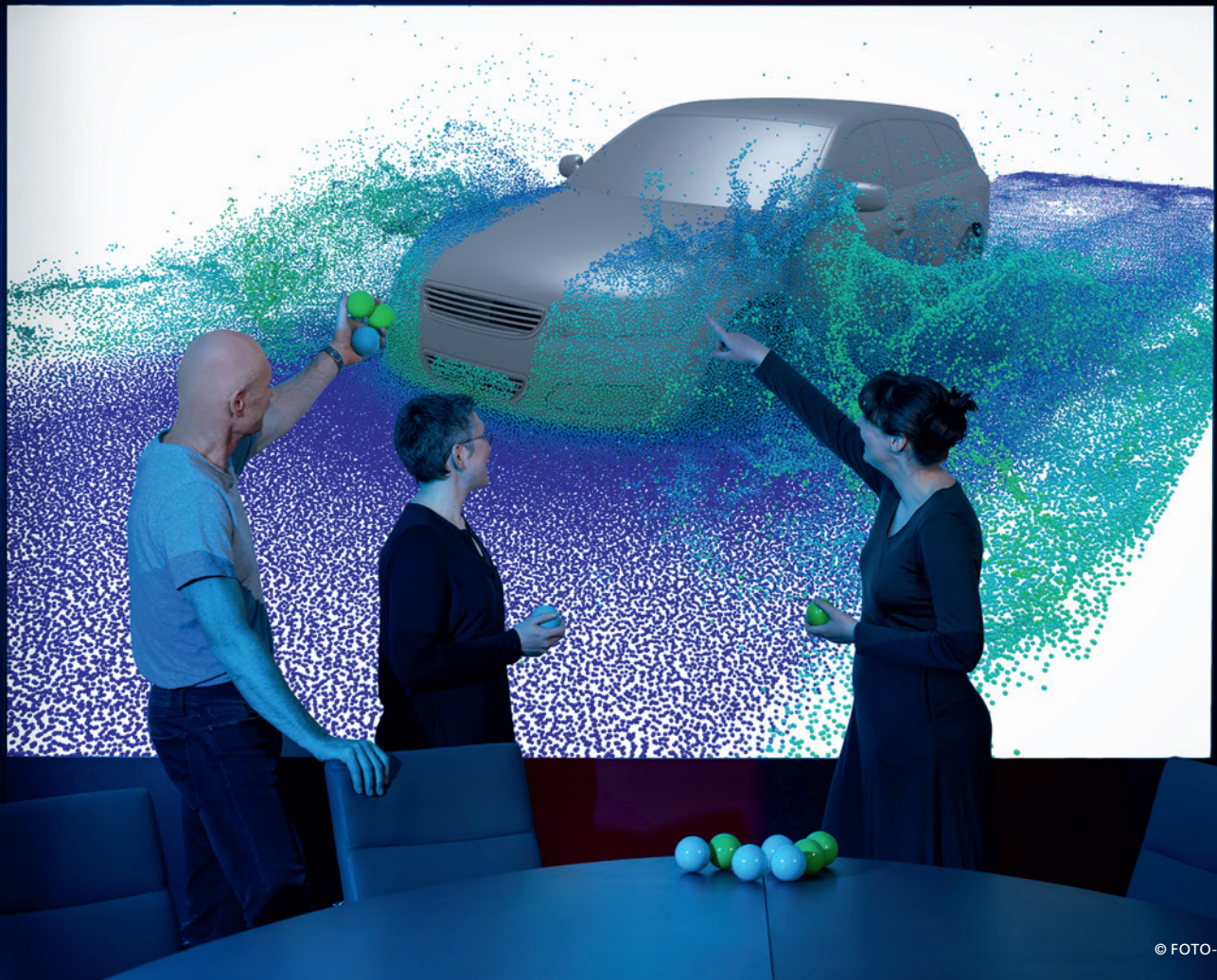
## Flexible Method for Dynamic Processes

Traditionally, the finite element method is used for simulations: engineers construct a grid suitable for the respective geometry and calculate the changes in each individual element based on this. Even setting up the grid structure is very time-consuming; it also has to be repeatedly adapted during the simulation. In contrast, the MESHFREE software combines the GFDM for solving the conservation equations for mass, momentum and energy with efficient algorithms for solving linear systems of equations, which were co-developed by the Fraunhofer Institute for Algorithms and Scientific Computing SCAI – a huge advantage, as the numerical point cloud used is able to adapt flexibly to moving geometries. There is no need for time-consuming corrections in the computational grid.

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## From Automotive to Process Engineering – And Beyond

The excellent methodology can be used for a wide range of applications. One focus is currently on the automotive sector: in addition to airbag simulation, the researchers have so far been able to support their industrial partners with modeling water crossings or the behavior of vehicles on sand or gravel, among other things. In process engineering, MESHFREE has helped companies to optimize parameters in the processing of molten glass and the production of plastic parts.

In principle, the method can be used wherever measurements or tests need to be replaced or only work poorly or not at all. Isabel Michel summarizes: “We are not limited to the classic applications of numerical fluid mechanics.

MESHFREE can do much more: the tool is deliberately kept generic.” The software therefore has great potential to save costs, time and materials in many other fields of application in the future.

## Joseph-von-Fraunhofer-Award

Dr. Jörg Kuhnert and Dr. Isabel Michel received the Joseph von Fraunhofer Prize 2024 for their development, which can replace real experiments.

Since 1978, the Fraunhofer-Gesellschaft has awarded annual prizes for outstanding scientific achievements by its employees who solve application-oriented problems. In 2024, three prizes of 50,000 euros each were awarded to groups of researchers from different institutes.

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