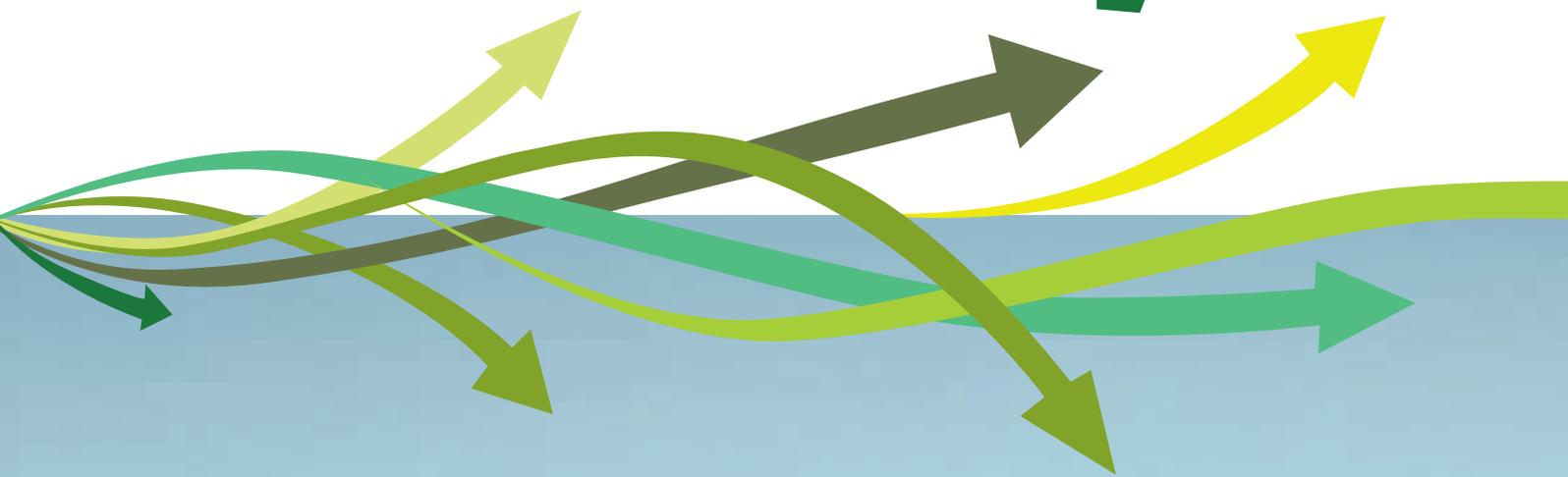


Researching:

Mobility



Researching:
Mobility





Message of Greeting



Message of Greeting

In recent years the processes of innovation have gained significant dynamic force. The “High-Tech Strategy for Germany” has been a major factor in this. Introduced in the last legislative period, it constituted the first national all-embracing concept for the research sector and has led to a new quality of cooperation between the scientific, business and political communities. In developing the High-Tech Strategy further, proven measures will be continued, but new points of emphasis are also being accentuated. The “High-Tech Strategy 2020” focuses on five major areas: climate and energy, health and nutrition, mobility, security, and communication. The aim is to make Germany a leader in the solution of urgent global problems by giving impetus to new technologies and innovations and by pooling the resources of science and industry.

The members of the Alliance of Scientific Organizations have a key role to play in the successful implementation of the High-Tech Strategy. So that science can perform its central task in research and development, in technology transfer and in the innovation process, the federal and state governments have agreed to continue with the Pact for

Research and Innovation, and to support the Excellence Initiative and the Higher Education Pact. Together, these initiatives represent the biggest investment in research, science, innovation and education ever seen in Germany.

The scientific organizations are successfully addressing issues of the future and are advancing into new areas of research. The current series of brochures shows how well German research is placed to deal with the major future challenges. Each brochure is devoted to one of the main subjects identified in the High-Tech Strategy and uses engaging examples to illustrate the work conducted in Germany’s research institutes. With their easy-to-understand descriptions of advanced research, these publications support the broad dialogue with the public on the pressing questions of our time.

A handwritten signature in blue ink, reading "Annette Schavan".

Prof. Dr. Annette Schavan, MdB
German Federal Minister of Education and Research



Preface



Dear readers,

“Life is movement. Without movement, there is no life,” said Leonardo da Vinci. In times of increasingly networked global markets and people’s growing need to keep mobile, his insight is more relevant than ever before. But, with its negative impacts on people and the environment – in terms of noise and emissions, pollutants and energy consumption – mobility comes at a high price. This is why the task of organizing the transition to economically, ecologically and societal sustainable transportation systems for people and freight takes on such major importance in the work of the scientific community, industry and government.

Long-distance mobility is inextricably linked to motorized vehicles, which are the only means of fast and comfortable transportation by road, rail, sea and air. In the past, the focus was mainly on engine performance or top speed. Today, by contrast, environmental aspects such as energy efficiency, CO₂ emissions or noise levels occupy center stage. Striking a balance between these more recent performance criteria and growing demands in respect of safety, security, reliability and comfort represents an important challenge for research and development.

Since expansion of the infrastructure in line with demand is neither economically nor ecologically viable, traffic management is becoming more and more important as a means of making the utilization of infrastructure more effective and efficient. Approaches exploiting multiple technologies are in demand not just for road, rail, sea and air transportation, but also at traffic hubs such as train stations, seaports and airports. The latest communication and IT technologies that link vehicles to the transportation infrastructure are of particular interest. They open up new opportunities for better traffic management, even transcending the boundaries that delineate individual modes of transportation.

Transportation system research deals with the complex interdependencies between transportation growth and the environment. The goal is to develop a comprehensive understanding of cause-and-effect relationships that allows us to map out paths toward a more environmentally compatible transportation system. Examples here include work on describing the traffic behavior and decision-making processes of people and companies as well as evaluating new technologies. This provides the groundwork that allows the impact on people and the environment to be quantified.

Protecting the climate, conserving resources and reducing our dependence on fossil fuels are all challenges being addressed by research into electromobility. A great deal of research will be required if the opportunities offered by electromobility are to be fully utilized and Germany is to occupy a leading position in this competitive field. While short-term considerations focus on vehicle technologies that are of practical day-to-day utility, it is just as important to devote efforts, for instance, to the needs of vehicle users, to multimodal mobility systems and to the integration of electric vehicles in energy grids. Convincing systemic solutions are a prerequisite to successfully capturing the markets.

Another major area of mobility research concerns freight transportations and logistics. For a major exporter like Germany, it is of crucial importance that the transportation sector is enabled to achieve its forecasted quantitative and qualitative growth. This calls for solutions that strike a sustainable balance between economic and ecological imperatives.

We have become used to almost limitless mobility, and we will have to work very hard in future to adequately meet our expectations in this regard. How will tomorrow’s vehicles be powered? How can we achieve a higher level of integration between different modes of transportation in cities? How can we ensure global mobility? What support do travelers require before and during their journeys? How can we balance the interests of economy, the environment and society in our transportation systems?

These are just some of the questions that researchers in Germany are endeavoring to resolve. The aim of this brochure is to showcase selected examples of their work in order to give you an impression of their expertise and diversity. The ultimate goal is to make local, national and global mobility sustainable – in the best possible sense of the word.

Sincerely,

A handwritten signature in blue ink, appearing to read 'Ul. Wagner', written over a light blue grid background.

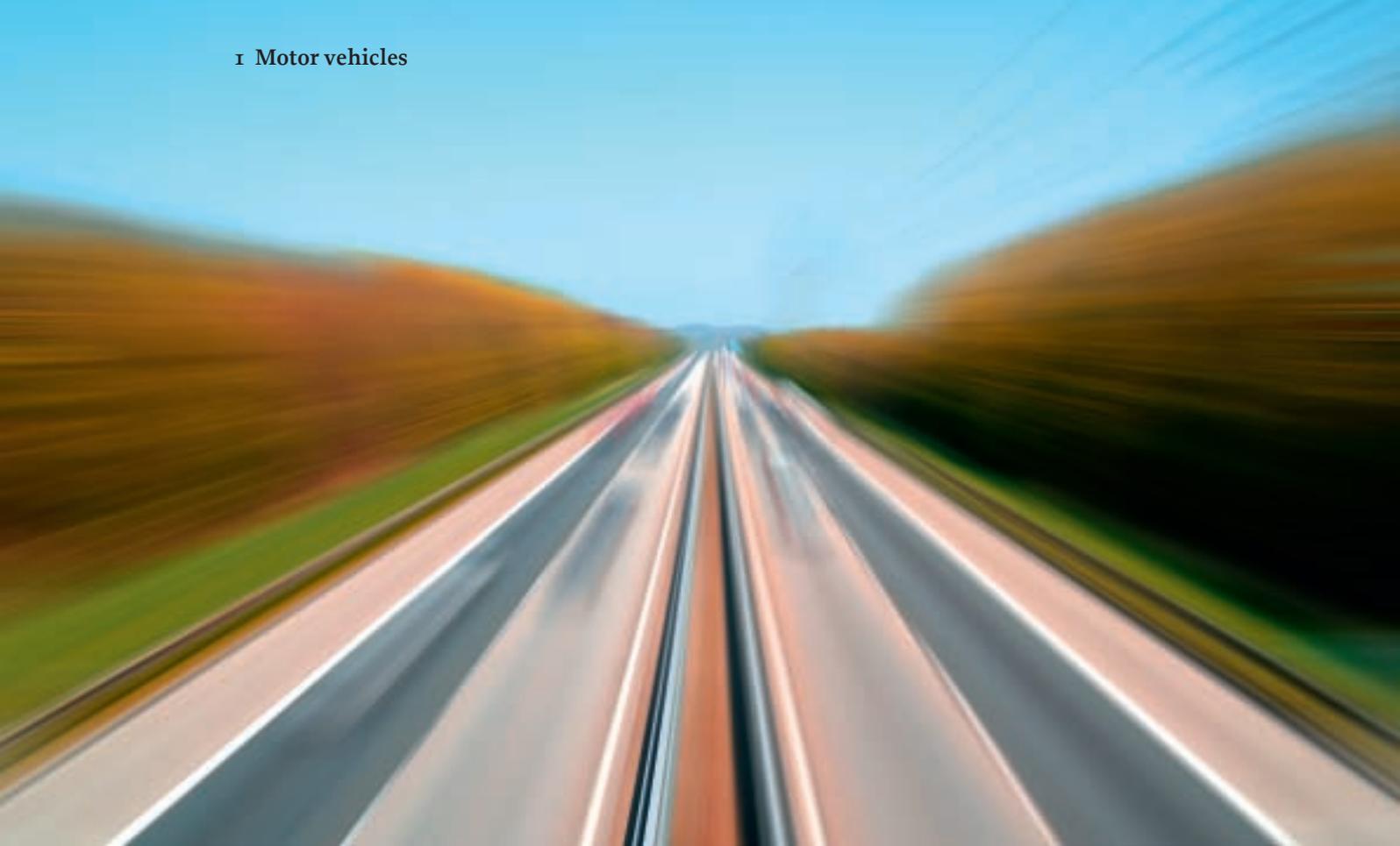
Ulrich Wagner

Member of the Executive Board for Energy and Transport of the German Aerospace Center (DLR)

Contents

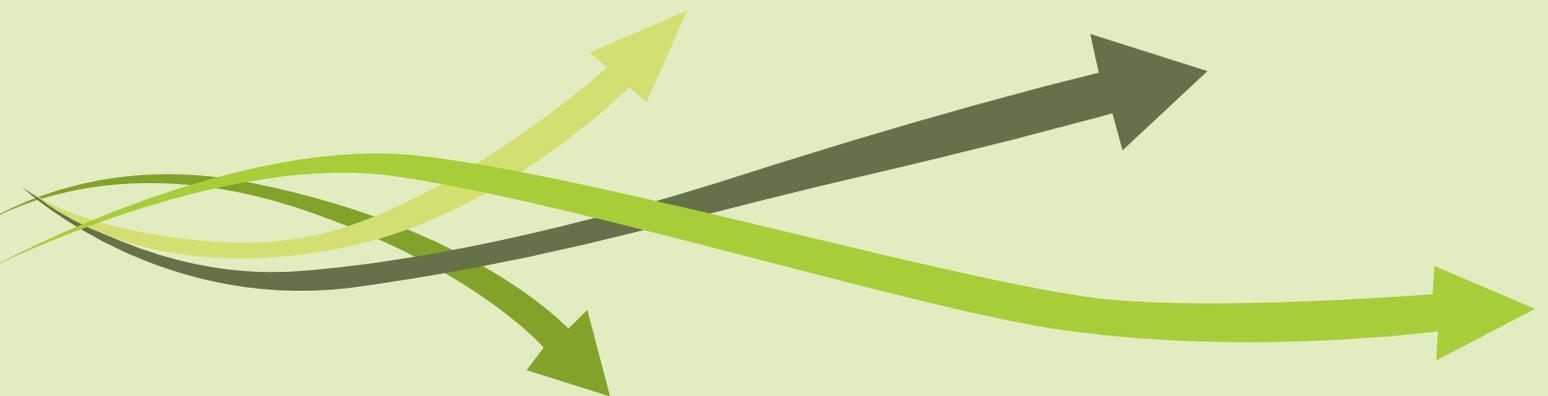
1	Motor vehicles	
	Following tried-and-tested paths, forging new ones	6
2	Traffic management	
	Effective planning, efficient control	15
3	Transportation development and environmental impacts	
	Comprehensive understanding sustainable approach	23
4	Electromobility	
	More than just cars	29
5	Freight transportation and logistics	
	Reaching customers the clever way	37
6	Future mobility	
	Imagining tomorrow today	41
	Contact	46
	Editorial notes	48





Following tried-and-tested paths, forging new ones

Everything is in flux, and that includes the transportation systems and vehicle concepts of the future. The finite nature of fossil fuels is driving research into alternative solutions. The development of new vehicle concepts must take into account the fact that already over half the world's population lives in cities. Behind demands for clean, environmentally friendly places to live lies the idea of zero-emissions transportation systems. Tomorrow's energy will be from renewable sources and vehicles will by that time be integrated in power supply and communication networks. The challenge of research into new vehicle types is simultaneously its mission – namely, to substantially improve the harnessing of potential energy and to achieve a breakthrough for CO₂-neutral vehicle and drive technologies.





Roads today are still dominated by diesel- and gasoline-powered motor vehicles. In future, they will be outnumbered by hybrid and all-electric vehicles.

Even assuming the most favorable political, economic and social conditions, an analysis of current scenarios reveals that all-electric cars will not achieve any notable market penetration for some 10 to 15 years. Until they do, a variety of different drive systems will be competing with each other: gasoline and diesel engines, hybrids, engines that burn natural gas or bio-gas as well as vehicles powered by batteries or fuel cells. What all hybrid variants have in common is the combination of combustion engine and electric drive. Intensive research combines the advantages of both

drive types, enabling fuel savings of up to 30 percent. Depending on how user profiles evolve, the degree of hybridization can be stepped up to the point where an all-electric vehicle is suitable for mass production. Technologies that extend the range vehicles can travel continuously are also driving forward electromobility.

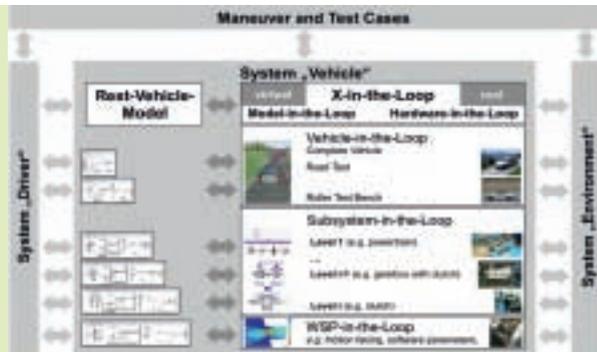
In the case of road and rail vehicles, the focus is not just on developing new drive technologies but, just as importantly, on improving the performance of conventional systems. The broad array of options here include



Lightweight materials
The lighter, the faster

Engineers rave about carbon-fiber-reinforced plastic (CFRP), as this material is virtually unparalleled in combining exceptional strength and lightness. But it is not easy to manufacture. In order to make progress, particularly with large components, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM and the German Aerospace Center (DLR) are working together at the new major research center CFK Nord at Stade in northern Germany. In cooperation with partners from research and industry, researchers at the center will develop processes for automated machining – i.e. drilling, milling and trimming – and for the automated adhesive bonding of XXL-sized CFRP structures.

Dr. Michael Wolf
Fraunhofer Institute for Manufacturing Technology
and Advanced Materials IFAM
www.ifam.fraunhofer.de
michael.wolf@ifam.fraunhofer.de



Holistic approach to development
Putting drive systems to the test

In its search for new drive concepts for motor vehicles, the Karlsruhe Institute of Technology (KIT) has developed an end-to-end method and process chain that can be used to examine how subsystems – from the mechanism of action through to the vehicle itself – function and interact with the system as a whole. The advantage of this methodology is that the hardware and software components/modules are interchangeable, thus creating a holistic development and validation environment. Through the integration of simulations and tests, this state-of-the-art technology can be used to recreate and examine real-life driving and traffic situations in a laboratory environment. If necessary, a virtual driver can be included in the experiments. Expansion of the KIT's eastern campus (Campus Ost) will bring another substantial increase in the available infrastructure in this field.

Prof. Dr.-Ing. Dr. h. c. Albert Albers
Karlsruhe Institute of Technology (KIT)
IPEK – Institute of Product Engineering
www.ipek.kit.edu
albert.albers@kit.edu



For many decades, a combustion engine was the standard in drive systems for motor vehicles.

reducing the drag resistance generated by outside forces acting on the moving vehicle, making more intensive use of lost or residual heat, through to the use of low-emission fuels. Where they are not depleting the farmland used to grow crops and foodstuffs, second- and third-generation biofuels have an important role to play for all vehicle engine types, especially aircraft engines.

Without exception, the goal of the research in progress is to increase the overall efficiency of the future vehicles, and to reduce their emissions or eliminate them altogether.

The internal combustion engine still offers abundant scope for optimization, and this is one of the strongest levers for cutting both fuel consumption and emissions. R&D work in this area is focusing on more advanced direct-injection and cylinder cutoff systems, on turbocharging and downsizing as well as on the



Thermoelectrics
Electricity from waste heat

Thermoelectrical materials can directly transform a heat flow into electrical power, thus enabling part of the waste heat given off by cars, computers and heaters to be harnessed as electrical energy. Both, the Institute of Materials Research at the German Aerospace Center (DLR) and the Fraunhofer Institute for Physical Measurement Techniques IPM are carrying out research into the type of materials that can be used for this process, while optimizing the manufacturing processes in cooperation with partners from industry. One of their short-term goals is to increase the efficiency of the thermoelectric generators used with exhaust systems to such an extent that they can fully power a vehicle's electronic system.

Dr. rer. nat. Wolf Eckhard Müller
German Aerospace Center (DLR), member of the Helmholtz Association, Institute of Materials Research
www.dlr.de/wf; eckhard.mueller@dlr.de

Dr. Harald Böttner
Fraunhofer Institute for Physical Measurement Techniques IPM
www.ipm.fraunhofer.de; harald.boettner@ipm.fraunhofer.de



A better ride
Tires made of new elastomers enhance driving safety

Tires play a key role in driving safety and influence many aspects of the vehicle's performance, especially fuel consumption. Scientists at the Leibniz Institute of Polymer Research Dresden are examining the mechanisms acting on wet grip performance and rolling resistance, and are searching for ways to optimize these contradictory properties. Starting from 2012, new tires sold in the EU have to bear a label indicating their wet grip and rolling resistance. The targeted use of nano-scale fillers in combination with high-performance rubber mixes can help make the contact surfaces of car tires even safer without impairing their rolling resistance – and thus their energy efficiency.

Prof. Dr. Gert Heinrich
Leibniz Institute of Polymer Research Dresden
www.ipfdd.de
gheinrich@ipfdd.de



Odorless, safe, quiet:
An electric car is charged up.

reduction of friction losses. New engine concepts permit even greater efficiency, especially for units that generally work at their operational optimum and, for instance, extend the range of electric vehicles: rotary engines, free piston linear alternators, microgas turbines. Research into such concepts is proceeding apace.

Reducing drag resistance is another important approach to lowering fuel consumption, and applies equally to land vehicles and aircraft. Aerodynamic drag

can be lessened by optimizing the shape of the vehicle body, while low-resistance tires can help to reduce wheel drag. The driving characteristics of future tires will be determined by improved design of the tire casing and new high-performance rubber types that have been optimized at the nanoscale level.

Acceleration resistance can be lowered mainly by reducing the vehicle mass, and literally every ounce of weight counts. Lowering the weight of an automobile by 100 kg, cuts its fuel consumption by 0.3 l/100 km.



Galileo helps reduce accidents
Driver assistance system utilizes European navigation satellites

Researchers at RWTH Aachen University are developing a driver assistance system for collision avoidance that is based on Galileo, the European satellite navigation system. Unlike today's systems, the one being developed in Aachen offers an alternative to just an emergency braking by automatically changing the vehicle's course. That requires precise recognition of the vehicle's surroundings and is achieved through highly accurate positioning in the University's Galileo test center. This recognition can be enhanced even further when combined with other sensor signals and vehicle-to-vehicle communication. Based on the tests being carried out at the center, also requirements for the positional accuracy of tomorrow's safety-critical driver assistance systems can be analyzed.

Prof. Dr. Lutz Eckstein; RWTH Aachen University, Institute of Automotive Engineering
www.ika.rwth-aachen.de; eckstein@ika.rwth-aachen.de
Prof. Dr. Dirk Abel; RWTH Aachen University, Institute of Automatic Control; www.irt.rwth-aachen.de; d.abel@irt.rwth-aachen.de



Assistance and automation
Support at the touch of a button makes driving safer

The German Aerospace Center (DLR) collaborated successfully with partners from across Europe in the EU-sponsored HAVEit project (Highly Automated Vehicles for Intelligent Transport). In highly automated driving, the vehicle basically drives itself; the driver can, however, always take charge as the situation demands and intuitively control the vehicle at any time. So, although drivers benefit from a high degree of assistance, they are still responsible for the vehicle. The key question to be answered by researchers is how people and automated functions can sensibly interact to ensure a safe and relaxing driving experience. On completion of the project in June 2011, the research vehicles developed by the project partners demonstrated what highly automated driving could be like.

PD Dr. Frank Köster
German Aerospace Center (DLR), member of the Helmholtz Association, Institute of Transportation Systems
www.dlr.de/ts; frank.koester@dlr.de

1 Motor vehicles



Carbon-fiber-reinforced plastic will make tomorrow's cars particularly light and economical.

That is why researchers in this field have taken up the challenge of reducing vehicle weight by up to 50 percent. The biggest steps forward are being made with new designs and types of material. Multi-material design, for instance, involves developing and combining innovative materials that not only reduce weight, but also enhance safety-relevant properties of the vehicle's structure. Although often still too expensive for mass production, advanced high-performance steels, magnesium, aluminum and carbon-fiber-reinforced plastic (CFRP) are the materials from which the cars

of tomorrow will be made. Unless efficient production processes can be developed for CFRP-intensive components, it will not be possible to lower the manufacturing costs of large, integral components for road and rail vehicles via the economies of scale that mass production promises.

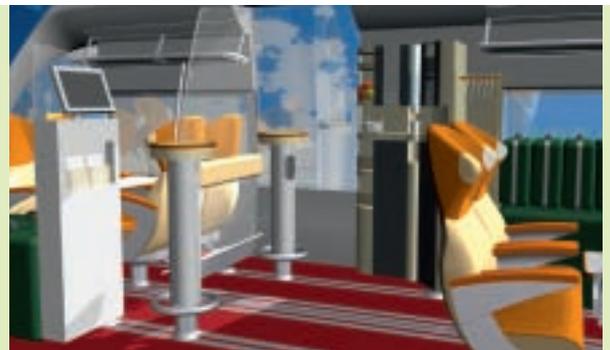


Tomorrow's trains

Next-generation high-speed rail

In a research project entitled "Next Generation Train" (NGT), nine institutes of the German Aerospace Center (DLR) are cooperating to create the high-speed train of the future. With a cruising speed of 400 km/h, the NGT will be faster and more comfortable than today's trains, but will require only half as much power per seat as Germany's current high-speed ICE trains. While this would make the NGT a viable competitor for short-haul aircraft, it does pose huge challenges for the researchers. The train needs to be light, yet display stable handling and sophisticated aerodynamics. It requires an efficient drive system and brakes that deliver extremely high performance. And all of this must be accomplished without compromising on an adequate degree of comfort for passengers. The findings of the project are to be applied to future high-speed regional and freight trains as well.

Dr.-Ing. Joachim Winter
German Aerospace Center (DLR), member of the Helmholtz Association, Institute of Vehicle Concepts
www.dlr.de/flk; joachim.winter@dlr.de



RailCab

New technology on old tracks

RailCab is new technology on old tracks. The research initiative behind this modular rail system intends to deploy state-of-the-art chassis technologies featuring wear-free linear motor technology on the existing rail infrastructure – and thus overcome one of the main obstacles to the spread of innovative rail transportation systems. At the heart of RailCab are small, driverless vehicles which serve a demand-driven transportation system for passengers or freight. Intelligent chassis technology makes for a very comfortable ride. In scientific terms, this utterly new transportation system is based on the systematic deployment of mechatronics. RailCab is the main demonstrator in "Collaborative Research Centre 614 – Self-optimizing systems in mechanical engineering," which is sponsored by the German Research Foundation (DFG).

Prof. Dr.-Ing. Ansgar Trächtler
University of Paderborn
NBP – New Rail Technology Paderborn
www.railcab.de
railcab@nbp.upb.de



Train travel, too, will be faster, more comfortable and more efficient in future.

The vehicles of tomorrow will not only be more efficient, but also more communicative. Integrated in networks, they will constantly exchange information with other vehicles and the surrounding infrastructure via wireless or the Internet, helping to enhance the flow of traffic and thus lower emissions. What is more, Car-2-X technology should make accident-free driving a reality: GPS and ESP data can be combined in a single network, for example, to generate warnings – of approaching vehicles at intersections, of accidents, traffic jams or adverse weather conditions

ahead – giving drivers the possibility to react and avoid the danger in time. So, tomorrow's vehicles will not only be cleaner, safer and more comfortable, but also intelligent. The goals of R&D specialists even extend as far as autonomous or automatic driving.

Similar challenges await researchers in the realms of rail travel, shipping and air traffic. Intensive research is being carried out into the train of tomorrow, which will not only be more comfortable and faster, but also quieter, cheaper and more efficient than today's passenger



Reducing rail noise emissions
A quiet revolution in rail safety

In future, trains will roll through Germany much more quietly. Deutsche Bahn – the German national rail corporation – and numerous other companies and universities collaborated in the "LZarG" project to develop noise protection measures for existing rail cars and tracks, such as rail dampers, silencers for train wheels and vibration-dampening pads for railroad sleepers. Retrofittable elements like these could help German Rail achieve its goal to halve rail traffic noise between 2000 and 2020. Using a new lab method in combination with track tests, researchers at the Technische Universität München have proven that, despite what some had feared, the padded sleepers are just as stable as unpadded ones, and do not shift sideways when summer heat causes the tracks to buckle.

Dr.-Ing. Walter Stahl
Technische Universität München
Lehrstuhl und Prüfamnt für Verkehrswegebau
www.vwb.bv.tum.de
walter.stahl@vwb.bv.tum.de



Train inspections
Drive-by testing

Compared with other means of transportation, rail enjoys a good reputation in terms of safety. And yet, a number of serious accidents in tunnels in Europe have prompted rail operators to invest more in tunnel safety. An international consortium is currently working on monitoring stations that can detect defects in passing trains. To this end, researchers at the Fraunhofer Institute for Physical Measurement Techniques IPM have developed a laser scanner that quickly and safely captures and evaluates any deviations from the standard geometry of the train cars, such as loads that may have shifted. This means any dangerous changes to the train and its load can be detected before it enters the tunnel, even if they only arose en route.

Dr. Heinrich Höfler
Fraunhofer Institute for Physical Measurement Techniques IPM
www.ipm.fraunhofer.de
heinrich.hoeffler@ipm.fraunhofer.de



I Motor vehicles



As the volume of freight traffic rises, traffic planners will need to distribute goods flows expediently between road and rail.

trains, thus making it a serious competitor for aircraft. One ambitious target of researchers is to halve the specific energy consumption per passenger-kilometer compared with the current high-speed ICE3 train in Germany. At the same time, they aim to raise the cruising speed to at least 400 km/h. They will achieve this only by developing innovative technologies for use in lightweight construction and in the train chassis, new solutions for highly efficient drive and braking systems that recuperate energy, innovative options for energy transmission, and sophisticated aerodynamics.

What is right for passenger traffic, cannot be wrong for freight transportation. Goods traffic is on the increase worldwide, and, in Germany, rail traffic accounts for the second biggest share of the transportation market, growing by more than 10 percent over the previous year. That is why researchers are working intensively on a high-speed freight train.



Aircraft of the future

New designs for next-generation airplanes

With the Airbus A380, the limits of conventional aircraft design have been reached. That is why scientists at the German Aerospace Center (DLR) are now focusing their attention on the design of tomorrow's planes. One possible variant is a so-called blended wing body, i.e. an aircraft whose fuselage flows seamlessly into its wings. Such aircraft are to be larger, lighter and more energy-efficient, and also offer more passenger comfort. For the first time, the cabin and fuselage designs have been integrated in a computer simulation, offering a theoretical basis for a more detailed integrated aircraft design. The blended wing body design could help reduce fuel consumption by around 20 percent and operating costs by as much as 30 percent.

Prof. Dr.-Ing. Volker Gollnick
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Air Transportation Systems
www.dlr.de/ly; volker.gollnick@dlr.de



Shape-adaptive wings

More flexible flying

A wing's aerodynamic properties are determined by its angular shape and airflow profile. In order to improve how these features respond to different flight situations such as maneuvering or cruising, a project team sponsored by the German Research Foundation (DFG) is doing research into a configuration that is comparable with a bird wing. It comprises jointed spars to actively alter the wing shape and a membrane that can be adapted to suit the prevailing airflow. Designing the wing required a fundamental conceptual understanding of how birds fly. The project team's findings furnish the basis for innovative wing designs for the unmanned aircraft that will play a key role in future air transportation scenarios.

Prof. Dr.-Ing. Nikolaus Adams
PD Dr.-Ing. Christian Breitsamter
Technische Universität München
Institute of Aerodynamics and Fluid Mechanics
www.aer.mw.tum.de
nikolaus.adams@tum.de



Shipping plays a key role in the intercontinental traffic of goods. That is why it is so important to tap the potential for greater efficiency and safety in this sector.

Innovative technologies are also set to make a significant contribution to lowering the emissions of the world's shipping fleet. There are many possibilities for achieving this. The deployment of more efficient engines and alternative fuels, optimized propeller and rudder profiles, and the utilization of contra-rotating propellers can all help save fuel. In particular, adjustments to the shape of a ship's hull and innovative coatings on its surface can substantially reduce fuel consumption. Researchers talk of a total reduction potential of up to 30 percent. Another key area of re-

search is looking into a comeback for wind power, with sails or kites being used to support forward motion, in combination with an automatic system for altering the route sailed depending on the weather conditions.

The overriding goal of current trends in air traffic is to counteract climate change and achieve a substantial reduction in the gases and aerosols that affect the climate. The target is to achieve a 50 percent reduction in CO₂ emissions and 80 percent in NO_x emissions per passenger-kilometer relative to the emissions level of



High-lift technology

The aircraft for people who live close to airports

To make air traffic more tolerable for people on the ground, future commercial jets will get by with much shorter runways for take-off and landing. That will reduce the space required by airports and lower noise emissions for the people living near them. Achieving this aim calls for technologies that – in terms of aeroustics, aerodynamics and flight dynamics – go far beyond the current state of the art. The Collaborative Research Centre "Fundamentals of High Lift for Future Civil Aircraft" is examining different concepts for the active high-lift system needed to reach this goal. Research is focusing on noise reduction and the enhanced scalability of aircraft performance during take-off and landing.

Prof. Dr.-Ing. Rolf Radespiel
 Technische Universität Braunschweig
 Institute of Fluid Mechanics
www.tu-braunschweig.de/sfb880
r.radespiel@tu-braunschweig.de



Greater safety for helicopters

Active flow control for main rotor blades

The use of transonic blade profiles on the main rotor has increased the flight performance of the latest helicopters while reducing their fuel consumption. In certain flight conditions, however, these improvements can also aggravate the dynamic stall on the retreating rotor blade. Extreme variations of the aerodynamic loads on the rotor blade then cause significant structural loads, vibrations and wear and tear. SIMCOS, a Franco-German project of the German Aerospace Center (DLR) and French aerospace research institute ONERA, is focusing on this problem, and developing active techniques for controlling the flow on the rotor blade. Thus far, the researchers have achieved an 85 percent reduction in the peak loads that can be so detrimental to the rotor.

Dr.-Ing. Kai Richter
 German Aerospace Center (DLR),
 member of the Helmholtz Association,
 Institute of Aerodynamics and Flow Technology
www.dlr.de/as
kai.richter@dlr.de



Air traffic has been on the rise for many decades, and no end to this growth is in sight.

2000. New aircraft types, outstanding technological breakthroughs and the use of low-emission fuels will all be needed to reach this target. In addition to the deployment of innovative lightweight materials that are designed to reduce aircraft mass, a key goal will be to optimize the aerodynamic properties of future aircraft. For example, researchers are currently developing wing structures that adapt their shape to suit the prevailing flight conditions and airflow patterns.

Implementation of the “wing-only” design could help reduce the fuel consumption of future aircraft by 20 percent.

Today’s research serves as a bridge to the transportation of tomorrow. The motto of the scientists working on mobility innovation in Germany is to continue honing tried-and-tested technologies, while daring to create entirely new ones.



Development software for ship-building
Computerized ship design

Although German ship-builders have secured themselves a decisive advantage in a globally competitive market by carving out a niche in the highly specialized construction of one-of-a-kind vessels, they still need to keep an eye on costs and recognize risks in good time. That is why software is so important to them in the early phases of design. Based on the computation methods used by the FSG shipyard in Flensburg, the German Aerospace Center (DLR), the Fraunhofer-Gesellschaft, the Hamburg University of Technology and partners from industry have teamed up to develop the SESIS design system. Incorporating state-of-the-art software technology, SESIS offers a high-performance user interface and enables designers to collaborate with suppliers at different locations. The component-based architecture facilitates maintenance of the software and its ability to be expanded.

Rolf Hempel
German Aerospace Center (DLR), member of the Helmholtz Association, Institute of Simulation and Software Technology
www.dlr.de/sc; rolf.hempel@dlr.de



Reducing fuel consumption
Sharkskin saves energy

Micro structured surfaces reduce flow resistance in the same way as sharkskin, and that is of particular interest when it comes to aircraft and ships. Scientists at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM developed a coating system that technically optimizes the advantages of micro structured surfaces can offer. The system consists of a lacquer – which is reinforced with nanoparticles and can be hardened with UV light – and a roller device that applies, structures and hardens the lacquer. If the system were to be deployed on a large scale, the estimated reduction in the fleet consumption of aircraft and ships would be around two percent.

Yvonne Wilke
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM
www.ifam.fraunhofer.de
yvonne.wilke@ifam.fraunhofer.de



Effective planning, efficient control

The ever rising demand for mobility goes hand in hand with growing volumes of freight and passenger traffic – and all the negative impacts they have in terms of congestion, noise and emissions. Road traffic is a particular problem, with networks increasingly overloaded and the environment under threat. Mobility cannot function properly unless this trend is reversed, which is why traffic researchers are looking into ways to manage the growing volume of traffic on all routes. Their focus is not only on road, rail, sea and air traffic, but also on the hubs that act as interchanges between different modes of transportation. Their work is supported by large-scale systems such as the “Application Platform for Intelligent Mobility”, and by simulations.



2 Traffic management



The need for effective road traffic management is particularly evident in big cities.

The goal of research into road traffic management is to optimize traffic flow. Before traffic can be steered in any meaningful way, it is necessary to analyze the current traffic situation in a comprehensive manner. New technologies and procedures for recording and processing data on the current traffic situation can help improve our overview and aid the development of cost-effective processes.

An approach for urban regions is floating car data (FCD), a technology that allows the position of whole car fleets to be determined at any point in time, thus making it possible to draw conclusions about the effects of speeds traveled in the traffic network. Even in small and mid-sized towns, new technologies such as GSM, WLAN, Bluetooth or camera surveillance offer cost-effective options for gaging the traffic situation.



Capturing traffic data **Taxi fleets as traffic sensors**

Efficient traffic management hinges on having an exact picture of the traffic situation. That is why the German Aerospace Center (DLR) is looking into ways of making the capture of traffic data cheaper and more efficient. One focus is on Floating Car Data (FCD) technology, which allows conclusions to be drawn about the traffic situation using the position data of motor vehicles equipped with satellite navigation systems. Unlike conventional localized technologies, FCD directly measures travel times, and this provides excellent input for real-time traffic information systems, dynamic navigation and route planning for fleets. FCD can also be deployed for traffic planning and its assessment – in order to optimize traffic light phases, for instance.

Dr. Peter Wagner
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Transportation Systems
www.dlr.de/ts
peter.wagner@dlr.de



Self-organizing green waves **Keeping urban traffic flowing**

Green waves at traffic lights help to keep traffic moving through urban areas. In addition to enhancing the flow of traffic, they are especially good at reducing the number of stops drivers have to make and thus lowering vehicle emissions. Up till now, green waves were planned centrally in a static manner. In a cooperative project between Leibniz University Hannover and Karlsruhe University, and with funding from the German Research Foundation (DFG), scientists are developing intelligent, cooperative and self-learning traffic light control units that automatically adapt to the current traffic situation to generate green waves when and where they are needed. The methods used to construct such systems have been developed within the new research field of Organic Computing. In simulations it was possible to reduce harmful emissions by as much as 25 percent.

Prof. Dr. Christian Müller-Schloer
Leibniz Universität Hannover – SRA
www.sra.uni-hannover.de/index.php?id=585&L=0
cms@sra.uni-hannover.de



New guidance and safety systems are being developed to enhance the efficiency of rail transportation.

This situation can be significantly improved by influencing traffic flow in a targeted way to prevent traffic jams and ensure traffic is spread to the most favorable effect across the available infrastructure. For this reason, the thrust of research is directed at road traffic control and management strategies, which are evaluated using simulations. Scientists are taking a systematic approach to the deployment of all-electric vehicles and the effects they will have on traffic flows and emissions. They are also working on support tools for emergency services, the goal being to organize

traffic flows efficiently under the extreme conditions caused by disasters or large-scale events so that those called out on an emergency can reach their destinations quickly.

A transportation system cannot function unless more traffic is shifted from roads to rail lines. Rail travel needs to be made more attractive and competitive, and that means pressing ahead with optimization in operational, technical and economic terms. Signaling and safety technology is a key concern here as it makes



InSignls

A more effective traffic flow at intersections

Traffic lights at intersections have built-in intergreen times when switching from green to red and vice versa. These are designed to enhance traffic safety. As part of the "InSignls" project funded by the German Research Foundation (DFG), scientists measured traffic flows in heavy traffic conditions. They discovered that, in contrast to the approach taken in Germany to date, a substantial part of the intergreen times actually serves to keep traffic flowing. The InSignls project group used these findings to develop a model that takes the effective green time into account, unearthing considerable potential for the situation-dependent, dynamic measurement of intergreen times. The scientists will also be carrying out research into the stochastic nature of traffic processes during the shift between traffic light phases and into more in-depth evaluation of aspects directly related to safety.

Prof. Dr.-Ing. Manfred Boltze
Technische Universität Darmstadt
Chair of Transport Planning and Traffic Engineering
www.verkehr.tu-darmstadt.de/vv; boltze@verkehr.tu-darmstadt.de

Safe intersections

Cooperative systems for preventing accidents

Intersections could become safer in future. As part of SAFESPOT, a European research project, scientists at the Technische Universität München collaborated with MAT.TRAFFIC, a private company, to develop software that avoids the consequences of inattention and traffic violations at intersections, which harbor a high potential for accidents. The software analyzes the position, speed and acceleration of vehicles and their intended direction as indicated by their blinkers, combining this data with information provided by traffic lights and the laser scanners used to monitor the movements of cyclists and pedestrians at the intersection. If, for instance, a road user ignores a red light or a driver overlooks a cyclist when making a turn, the cooperative system warns all those involved of the incident and potential collision.

Prof. Dr. Fritz Busch
Technische Universität München
Chair of Traffic Engineering and Control
www.vt.bv.tum.de
fritz.busch@tum.de

2 Traffic management



Alongside safety and punctuality, the main aim of air traffic management is to minimize the environmental burden caused by exhaust emissions and noise.

rail traffic safer. This technology must function reliably at all times. Maintaining rail infrastructure is a costly business, and any technical failures inevitably lead to delays. What is more, high acquisition costs, stringent approval processes, and the complexity of the system as a whole, all act as a brake on modernization. In this difficult environment, solutions are being sought to help lower the cost of signaling and safety equipment over its entire useful life, for instance through predictive maintenance. The introduction of the European Train Control System (ETCS) harmonizes specifications

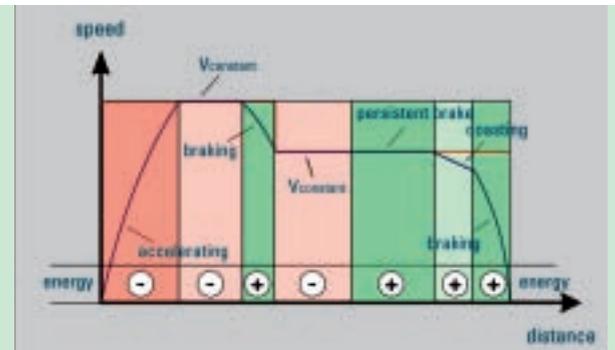
across Europe, serving to open up the market and increase competitive pressure. The challenge consists in achieving true interoperability and easing the approval process for new components with the aid of tests. In an effort to improve safety, researchers are examining the influence of the human factor and developing assistance systems for safer, more energy-efficient travel.



Neutral testing of components ETCS – the integration of Europe

The new European Train Control System (ETCS) – which aims at harmonizing cross-border rail travel – is beginning to be introduced on sections of the European rail network. ETCS enables data such as the track warrant to be transferred to the train and monitored on board. To ensure that new components can be deployed, it is necessary to comply with the ETCS specifications and provide proof of compliance. Corresponding tests can be carried out in a neutral test laboratory such as DLR-RailSiTe®. The German Aerospace Center (DLR) is supporting the launch of ETCS by testing new components and carrying out further analyses, for example in respect of planning, migration or operating rules.

Dr. Michael Meyer zu Hörste
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Transportation Systems
www.dlr.de/ts
michael.meyerzuhause@dlr.de



DYNAMIS Driving for better fuel economy

Even on rail lines, a lot can be done to achieve better fuel economy and reduce the burden on the environment. For instance, the Institute of Transport, Railway Construction and Operation (IVE) of the Technische Universität Braunschweig has developed DYNAMIS, an interactive software system that analyzes the driving dynamics of trains – including suburban trains, subway trains and trams – and measures signal locations, engine performance, braking distances and critical loads. DYNAMIS enables scientists, railroad operators and train manufacturers to develop timetables that take into account a train's technical components. It thus supports strategies for energy-saving train-driving, the goal being to improve the environmental friendliness and economy of rail travel and to enhance its acceptance by the public.

Prof. Dr.-Ing. Thomas Siefer
Technische Universität Braunschweig
Institute of Transport, Railway Construction and Operation (IVE)
www.tu-braunschweig.de/ive/wus
th.siefer@tu-bs.de



Major airports are complex systems that require comprehensive control and monitoring.

The goals of air traffic management include substantially reducing the environmental impact of carbon dioxide, nitrogen oxide and noise emissions, achieving a punctuality rating of 99 percent, shortening passenger processing times and implementing high safety standards. Research is focused on end-to-end airport management that integrates all activities on the ground and in the air. This is accompanied by new process structures that aim to help steer passengers through the terminals in a more targeted manner. Research is also being carried out into new

technologies that will speed up security checks of passengers, luggage and freight as well as improve the efficiency of handling processes. As transportation hubs, airports play a central role in the overall traffic network, and they need to be integrated with other modes of transportation to create an intermodal traffic network.



Optimal control of rail systems
Driver assistance systems help save fuel

ENAFlex, a driver assistance system, supports locomotive drivers to get from point A to point B in a punctual and energy-efficient manner. Via a display unit such as a smartphone, the driver is shown exactly when to switch from acceleration to coasting to braking. That helps to prevent unnecessary braking and acceleration phases. The potential fuel savings have already been analyzed in test runs, with savings of 10 – 15 percent being recorded with electric trains, and 8 percent with diesel locomotives. Several partners will collaborate to drive forward the further development of ENAFlex and test it in the field.

Prof. Dr.-Ing. Jürgen Krimmling
 Technische Universität Dresden
 Institute of Traffic Telematics
www.tu-dresden.de/die_tu_dresden/fakultaeten/vkw/vis
juergen.krimmling@tu-dresden.de

From game theory to train route allocation
The greatest gain does not generate the greatest benefit

Today, different rail companies are competing for the limited capacity available on the European rail network. As part of a research training group entitled “Algorithmic synthesis of reactive and discrete-continuous systems,” which is sponsored by the German Research Foundation (DFG), a game-theory abstraction of the rail route allocation process took place at RWTH Aachen University. In the abstraction, rail transportation companies were modeled as players wanting to maximize their economic target function. The results revealed the economic optimum in capacity utilization cannot be achieved without cooperative, integrated planning.

Dr. rer. nat. Jürgen Jacobs
 RWTH Aachen University
 Chair of Railway Engineering and Transport Economics
www.via.rwth-aachen.de
jacobs@via.rwth-aachen.de

2 Traffic management



Inland shipping plays an important role in the transportation of bulk goods; here, too, there is potential for improving efficiency and safety.

Research into sea transportation management serves to strengthen both ocean-going and inland-waterway shipping, which together account for 80 percent of international trade. An overriding goal in this area is to enhance safety by preventing ships from colliding or running aground. But the focus is also on improving efficiency by ensuring that transportation processes relating to ships are executed expediently while consuming as little fuel as possible.

The availability and distribution of equipment, as well as the performance of existing technology, including satellite-based localization, radar and the Automatic Identification System (AIS), do not yet allow us to determine the traffic situation in a comprehensive and reliable way. That is why researchers are working on integrating different sensors and measurement systems to gain feedback on data quality and ensure traffic movements are reliably captured. Critical locations – such as bridges, locks and harbor entry points – and docking procedures place extreme demands on a



Virtual reality at airports

Four-dimensional decision-making tools

When flight paths are changed or airports enlarged, the distribution of the noise emissions and pollutants generated by aviation is altered too. Now, five institutes of RWTH Aachen University have come together in the “Virtual air traffic simulation” project to make these and other effects tangible. On the basis of simulations, they are developing a time-dependent model that contains data on aircraft noise, weather conditions, wake vortices and harmful emissions. The results are then visualized and rendered audible in the CAVE, a projection space for a four-dimensional world. The goal is to create decision-making tools, in particular for airport planning, approval processes, communication with neighboring communities and research.

Univ.-Prof. Dr. rer. nat. Johannes Reichmuth
RWTH Aachen University
Chair of Air Transport and Airport Research
www.via.rwth-aachen.de
reichmuth@airport.rwth-aachen.de



Automated landing procedures

Environmentally friendly approaches

The goal of the flexiGuide project organized by the German Aerospace Center (DLR) is to the lower fuel consumption and reduce the pollutants and noise emissions of aircraft on their landing approaches. Automated approach procedures could help achieve this goal in the foreseeable future. But air traffic controllers will need targeted support if these automated approach procedures are to be used at airports. The controllers see the aircraft on these new approach paths in the form of projections, so that they appear to be following conventional approach paths. This enables them to better estimate the location of the aircraft. As part of the flexiGuide project, researchers and air traffic controllers are collaborating to test different approach conditions on simulators with the aim of creating an optimum environment for the controllers.

Dr. Marco-Michael Temme
German Aerospace Center (DLR), member of the Helmholtz
Association, Institute of Flight Guidance
www.dlr.de/fl
marco.temme@dlr.de



Passengers expect the change between transportation systems to function smoothly.

ship's commander. This is where assistance functions can help assess the traffic situation and conditions en route, and optimize the maneuver strategies presented.

State-of-the-art communication technologies open up further opportunities for traffic management and for linking up individual traffic participants. Networked motor vehicles, trains, aircraft and ships can not only furnish data on their current position and speed, but also about the condition of the transpor-

tation route they are using. Traffic infrastructure can provide information, for example, on the length of traffic light phases at any given time, on speed limits, or on where the end of a traffic jam is. Such information can be utilized to improve assistance systems and enhance safety in the vehicles themselves. But researchers are also leveraging the potential of networked communication in order to capture traffic data and manage traffic.



Airport management

Making ground procedures more efficient

Airports are increasingly regarded as bottlenecks in the air traffic system. In projects at the Technische Universität Dresden sponsored by the German Research Foundation and SESAR (the Single European Sky ATM Research program), scientists used stochastic to estimate the length and target times of ground procedures to significantly improve the accuracy of forecast values. The researchers are now focusing on control algorithms for automated process managers, which are deployed when practice deviates from plan. The projects are supplied with data from Stuttgart, Dresden, Munich and Leipzig/Halle airports, and the work is being carried out in cooperation with George Mason University. Siemens is providing input as regard requirements. The first prototype will be tested in early 2012 using live data.

Prof. Dr.-Ing. Hartmut Fricke
Technische Universität Dresden
Chair of Aviation Technology and Logistics
www.ifl.tu-dresden.de
fricke@ifl.tu-dresden.de



Automated taxiing

Conflict management and optimization of taxiing procedures

One component of future strategies for controlling air traffic is greater automation of taxiing procedures at airports. Nowadays, air traffic controllers bear almost the entire responsibility for ensuring that aircraft taxi in a safe and efficient manner. In order to handle the rising volume of air traffic, current research projects are focusing, among other things, on the deployment of assistance systems for air traffic controllers and pilots. This includes the automatic prediction and detection of conflicts along with strategies for preventing or resolving them. Traffic simulations can serve to validate newly developed systems and procedures, and reduce the risk and costs of potential mistakes in development.

Prof. Dr.-Ing. Peter Hecker
Technische Universität Braunschweig
Institute of Flight Guidance and Control
www.tu-braunschweig.de
p.hecker@tu-braunschweig.de

2 Traffic management



When planning transportation structures, it is necessary to take people's growing need for mobility into account.

Smartphones are helping to increase the spread of communication technology and serve to integrate pedestrians, cyclists and public transportation in a single traffic network. This trend opens up a new dimension in intermodal and multimodal traffic, where travel involves several means of transportation. More effective use can be made of the benefits specific to different modes of transportation to make travel faster, more comfortable and less of a burden on the environment. Topics addressed here extend from the need to guar-

antee connections with public transportation, the automated search for parking spots, through to car-sharing systems that incorporate electric vehicles.

The approaches being taken by researchers in the field of traffic management are many and varied, and constantly being enhanced through the possibilities of new technologies. They all contribute toward helping us remain mobile despite the ever rising volume of traffic.



Assistance systems in shipping **From road to ship**

In order to achieve a deflection of cargo transportation from roads to inland waterways high-performance driver assistance systems are required, which need the reliable, demand-driven provision of position, navigation and time data. The continuous evaluation of these data in relation to traffic situation and traffic way conditions conduces the efficient planning and realisation of ships' manoeuvres. Both tasks are the focus of the Pi-LoNav project sponsored by the German Federal Ministry of Economics and Technology and realized together with partners from science and industry. Objective of the project is to enable vessels a safe and resource efficient passing of locks and bridges even when traffic volume is high.

Dr. Evelin Engler
German Aerospace Center (DLR), member of the Helmholtz Association, Institute of Communications and Navigation
www.dlr.de/kn
evelin.engler@dlr.de



Safe navigation of inland waterways **An autopilot for ships**

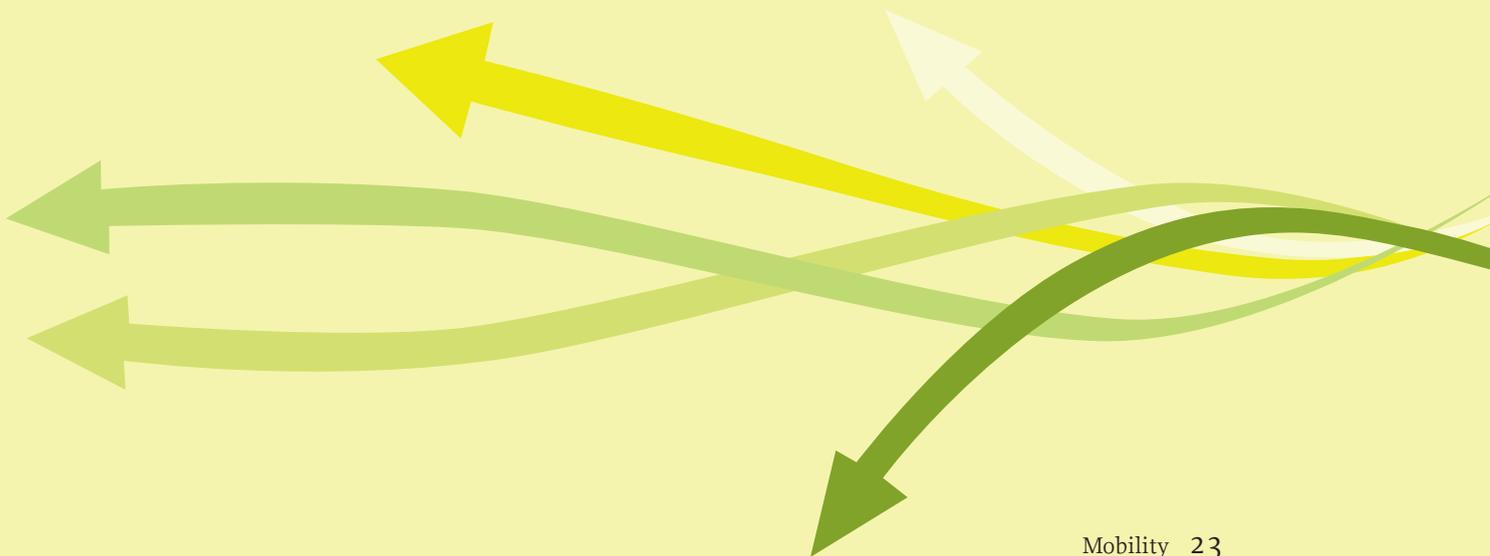
Before too long, it will be easier to navigate ships along rivers at night and in foggy conditions. Researchers at the Max Planck Institute for Dynamics of Complex Technical Systems have developed a navigation aid for inland water vessels that allows the person steering the vessel to retain a clear overview even in difficult situations such as when maneuvering at night through a narrow waterway. The combination of Automatic Identification System, GPS, radar, rate of turn indicator, water level data and digital maps not only makes it easier for the skipper to steer the vessel, it is also provides the requisite data for a control computer to execute the same function automatically – even in tight curves and during overtaking maneuvers.

Prof. Dr. Ernst Dieter Gilles
Max Planck Institute for Dynamics of Complex Technical Systems
www.mpi-magdeburg.mpg.de
gilles@mpi-magdeburg.mpg.de



Comprehensive understanding sustainable approach

Traffic and transportation are essential to the ongoing globalization of the economy. Only a powerful and efficient transportation system can guarantee individual mobility and enable the growing trade of goods. The price of this increasing mobility of people and movement of freight is an ever greater environmental burden in the shape of noise emissions and pollutants. Science is playing an important part in reducing these negative effects on our environment and climate, for instance through the evaluation of transportation policy measures.



3 Transportation development and environmental impacts



The growing volume of freight traffic poses a particular challenge to the road transportation system.

In Germany alone, the volume of freight traffic rose from just under 400 billion ton-kilometers in 1998 to 630 billion ton-kilometers in 2008. Over the same ten-year period, passenger traffic volume increased from 895 passenger-kilometers to 1,100 passenger-kilometers. It is not only the increase in traffic itself, but the longer distances traveled that are responsible for this growth. It has resulted in huge investments in the construction and upkeep of traffic infrastructure as well as rising costs to society as a result of

accidents and environmental pollution. What is more, traffic accounts for around 20 percent of the CO₂ emissions that have such a disastrous effect on our climate.

The answer to these challenges involves taking a holistic view of how traffic arises and develops and of the effects it has, especially on the environment and climate. The goal is to gain a thorough understanding of the cause-and-effect mechanisms at work in



The German Mobility Panel Measuring mobility behavior patterns

Since 1994, the Institute for Transport Studies of the Karlsruhe Institute of Technology has been surveying the mobility behavior patterns of private households once a year on behalf of the German Federal Ministry of Transport, Building and Urban Development. The survey not only provides a snapshot of the status quo of collective and individual mobility behavior, it also offers insights into cause-and-effect mechanisms and – because the interviewees are surveyed repeatedly – into long-term trends. Every year, some 1,500 people are surveyed, involving some 37,000 journeys in the last round. In addition, some households are asked about their driving habits and fuel consumption. One finding of the latest Mobility Panel is that there has been a measurable decline in the use of motor vehicles by people under 30.

Prof. Dr.-Ing. Peter Vortisch
Karlsruhe Institute of Technology (KIT)
Institute for Transport Studies
www.ifv.kit.de
peter.vortisch@kit.edu



Budget carriers Market with unlimited growth potential or just a passing fad?

With a share of currently 30 percent, low-cost carriers (or budget airlines) are already a force to be reckoned with in the German aviation market, and their market share has been growing steadily since 2002. But the growth is not limitless, and 2011 witnessed a decline in the number of low-cost offerings in Germany. It has become more difficult to find new airports that have the capacity for this air traffic and only very few new routes can be added to the existing networks. That is why the low-cost carriers are increasingly trying to move beyond Europe. In the long run, however, only very few major low-cost carriers who succeed in adapting their business model to the new situation will be able to carve out a niche for themselves alongside the traditional airlines.

Dr. Peter Berster
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Air Transport and Air Research
www.dlr.de/fw; peter.berster@dlr.de



The recent rise of budget airlines is impacting the parameters of competition between different modes of transportation.

the demand for transportation. In this way, recommendations can be made to policymakers with the aim of achieving a more environmentally compatible transportation system. A central task in this process is to analyze the factors influencing the demand for transportation, such as demographic change, economic growth and even trends in commodity prices. But the main focus is on the people and companies who decide what form their transportation will take. With the aid of targeted surveys, traffic research-

ers can gain important insights into how users reach their decisions and what forms of transportation they prefer. Large-scale surveys enable researchers to analyze the mobility behavior patterns of people and households, as well as the commercial use of motor vehicles.

Of particular interest are those types of transportation that exhibit high growth rates: budget airlines are a case in point. With their aggressive pricing they



Freight transportation in 2030
More CO₂ emissions despite technological progress

On behalf of Shell AG, the German Aerospace Center (DLR) has carried out a freight vehicle study for Germany. Based on two scenarios for different improvement levels of vehicle technology, it was figured out that CO₂ emissions in the further growing road freight transportation sector would be higher in 2030 than they are today. Diesel technology remains dominant in road freight transport. Although hydrogen-, hybrid- and electric-powered vehicles are only in the early stages of development, they represent the basis for the propulsion concepts of tomorrow. Apart from examining different propulsion concepts and fuels, the freight vehicle study assessed the potential for reducing CO₂ emissions by other technical improvements, such as better aerodynamics, low-resistance tires and light-weight construction.

Andreas Lischke
 German Aerospace Center (DLR),
 member of the Helmholtz Association,
 Institute of Transport Research
www.dlr.de/vf; andreas.lischke@dlr.de

Material flow analysis
**Sustainable mobility by 2030 –
 the role of renewables**

In the “Renewability” project sponsored by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, researchers examined how the mobility of people and goods can be guaranteed in future while still lowering emissions. To this end, they developed an analytical tool that examines the potential for, and hurdles on the path to, sustainable mobility. The investigations also reveal how subsidies the use of renewable energy. The effects of transportation policy measures were analyzed using model-based scenarios and the resulting greenhouse gas emissions quantified. It is remarkable that, although the researchers predicted a drop in emissions for passenger traffic, forecasts indicate that the growing volume of freight traffic would cancel out any potential for reducing overall emissions.

Markus Mehlin
 German Aerospace Center (DLR), member of the Helmholtz
 Association, Institute of Transport Research
www.dlr.de/vf; markus.mehlin@dlr.de

3 Transportation development and environmental impacts



As the volume of traffic grows, we must not lose sight of the toll it takes on people and the environment.

have become an alternative to established carriers and sometimes even compete with rail on long-distance connections. Electric-drive vehicles are currently attracting a lot of attention because they promise to help reduce the negative environmental impacts of motor traffic. We must not forget, however, that the future growth in traffic – driven especially by the increase in commercial transportation – will cancel out the energy savings and reduction in emissions these vehicles can achieve. As a consequence, only new,

creative solutions from policymakers can help reduce the negative effects of transportation. Science plays a key supporting role here in evaluating transportation policy measures in terms of their effectiveness and efficiency, for example by assessing the potential benefits and consequences of the EU-wide aviation emissions trading system.



Influencing the climate **More than just CO₂**

In addition to greenhouse gases like CO₂ and NO_x, the direct emissions traffic produces also affect the climate in a number of other ways. They alter, for instance, the ozone and methane concentrations in the atmosphere, produce aerosols and promote the formation of clouds. Aviation and shipping are particularly influential in generating these effects. The German Aerospace Center (DLR) is involved in determining the individual contributions of different modes of transportation to climate change. This not only opens up new opportunities for taking non-CO₂-related effects into account in international treaties to combat climate change, it also makes it possible to reduce the effect on the climate of the same volume of freight or passengers by optimizing the route taken.

Prof. Dr. Robert Sausen
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Atmospheric Physics
www.dlr.de/ipa
robert.sausen@dlr.de



Forecasting traffic-related environmental impacts **Particulate matters**

Traffic is a burden on the environment, and being able to forecast the impact this has on human health is important. Researchers at the Fraunhofer Institute for Transportation and Infrastructure Systems IVI succeeded in deriving statistically relevant interdependencies from large sets of measurement data. They demonstrated that meteorological and location-specific conditions had an overriding influence on the absorption of emissions. Long periods of low precipitation or atmospheric inversions are much more relevant to the amount of particulate matter in the air than are changes in traffic flows. On the basis of these findings the researchers developed a predictive model. The actual data processing is carried out in a neuronal network that has been fed with local data and thus “trained” for each specific location.

Dr.-Ing. Matthias Klingner
Fraunhofer Institute for Transportation and
Infrastructure Systems IVI
www.ivi.fraunhofer.de
matthias.klingner@ivi.fraunhofer.de



As motorized private transportation is both costly and stressful, mobility behavior patterns are changing: bicycles and running shoes are experiencing a renaissance.

We must strive to view the transportation system as a whole, and that means taking the interactions between different modes of transportation into account. Only a system-centric approach will enable a holistic analysis of transportation in terms of climate protection, air quality and health. An evaluation of the entire process chain – from the origins of traffic through to the distances covered and passengers/goods carried by each mode of transportation – will allow us, for example, to assess transportation’s contribution to climate change.

An analysis of the transportation system can provide answers to questions such as how changes in mobility behavior patterns affect the utilization of different means of transportation or what potential new drive technologies have to offer in reducing local and global emissions. At the same time, we are moving toward more networked mobility, which should facilitate the transfer of passengers between trains, buses, cars and bicycles. Scientists and researchers can add value here by asking what contribution new concepts and technologies actually make and how



The burden of traffic noise
Sleeping for science

In several studies into traffic noise, the German Aerospace Center (DLR) invited 72 men and women of all age groups into a sleep lab, exposing each of them to different types of traffic noise over eleven separate nights. The researchers were investigating the effect of traffic noise on sleep continuity, waking responses and heart rate. They also observed whether the test persons were annoyed by the nocturnal aircraft noise and whether the sleep disruptions impaired their performance the following day. It was revealed that noise from road and rail traffic had a measurably greater detrimental impact on sleep than aircraft noise. One of the reasons for this is that sleepers tend to react to noise that occurs suddenly, quickly reaches the maximum sound pressure level and contains high frequencies. In purely subjective terms, however, the test persons considered air traffic noise to be more annoying.

Dr. med. Eva-Maria Elmenhorst
German Aerospace Center (DLR), member of the Helmholtz Association, Institute of Aerospace Medicine
www.dlr.de/me; eva-maria.elmenhorst@dlr.de



The carbon footprint of logistics
Climate protection and efficiency

Mobility consumes resources. That is why responsible companies are interested in finding out how to distribute their products in a way that is both economical and climate-friendly. A carbon footprint analysis can provide information, for instance, on the CO₂ emissions of a company’s own distribution structures or of the services of the logistics companies it uses. The Fraunhofer Institute for Material Flow and Logistics IML aligns such analyses closely with economic efficiency analyses in order to derive eco-efficient measures that have a positive impact on the climate and a company’s bottom line. By improving their distribution structures in this way, companies can also enhance their corporate image.

Prof. Dr.-Ing. Uwe Clausen
Fraunhofer Institute for Material Flow and Logistics IML
www.iml.fraunhofer.de
uwe.clausen@iml.fraunhofer.de

3 Transportation development and environmental impacts



New mobility concepts take into account people's need for travel, security and a healthy environment.

they would have to be designed for users to accept and utilize them.

In an age of growing diversity in drive technologies and fuels, of new means of transportation, and of the increasing integration of different modes of transportation, taking a systemic approach is becoming an ever more complex task. But such an approach offers an opportunity to make a thorough assessment of changes in overall conditions – especially as regards various

complex policy scenarios – from a variety of different perspectives (e.g. emissions, climate, health). As far as transportation's contribution toward reducing environmental and climate impacts is concerned, expectations are sure to rise, and that will make the development and testing of new mobility concepts, technologies and behavior-oriented measures in passenger and goods traffic even more important.



How important is the ticket price?

Use of public transportation depends more on the price of gasoline than on the price of the ticket

In a study carried out by the Rheinisch-Westfälische Institut für Wirtschaftsforschung (RWI), researchers examined the factors that determine whether, and to what extent, people use public transportation. The analysis focused on the influence that gasoline prices, ticket prices, person-specific characteristics and features of the public transportation system itself have on the frequency with which public transportation is used on workdays. The authors of the study used data provided by the German Mobility Panel and concentrated on the adult members of German households. The results show gasoline prices have a substantial influence on the use of public transportation by adults, whereas ticket prices do not have any statistically significant effect.

Prof. Dr. Manuel Frondel
Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI),
member of the Leibniz Association
www.rwi-essen.de
manuel.fronde@rwi-essen.de

Cooperating to cut emissions

Economic effects of emissions trading for aviation

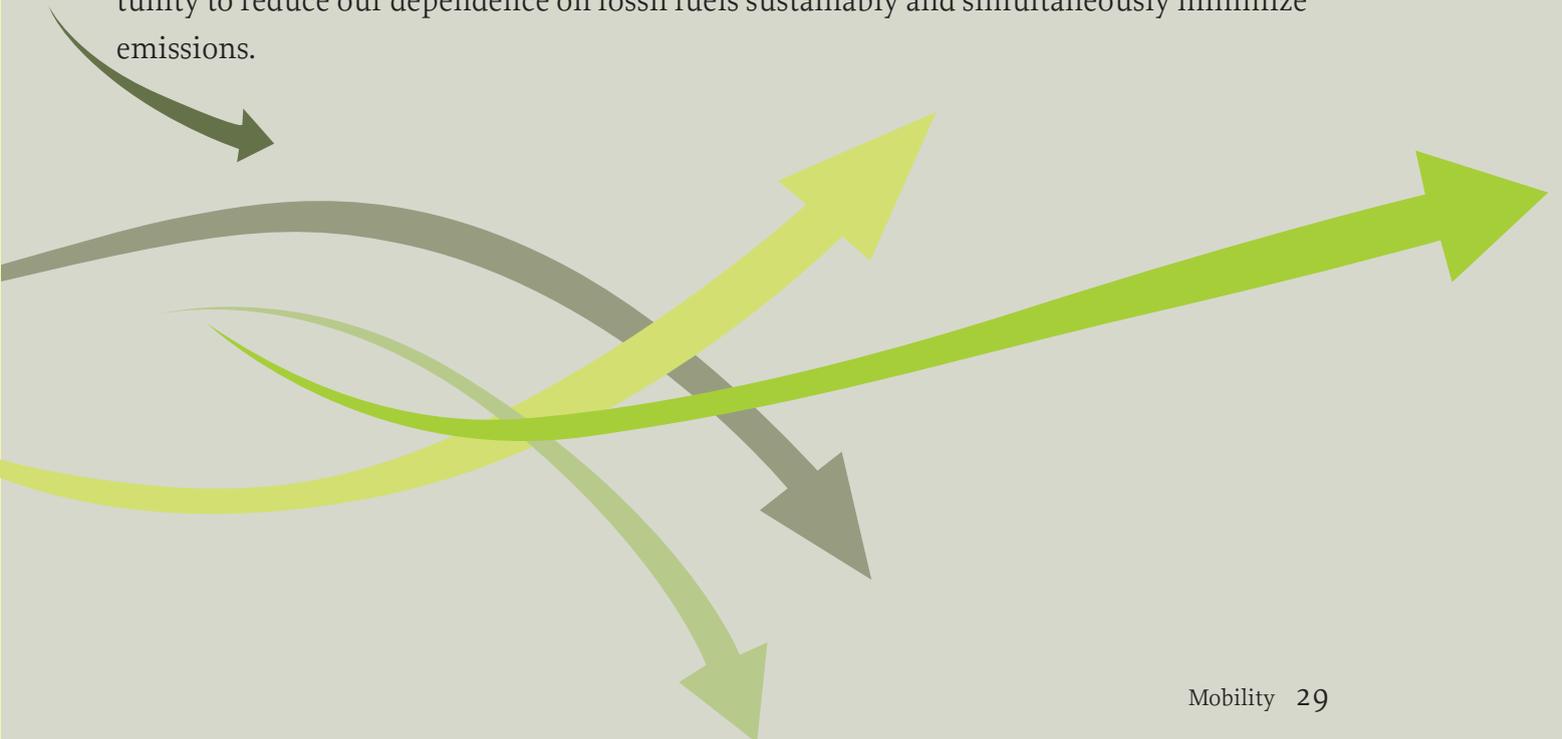
As part of the market-based measures for the limitation of aviation's CO₂ emissions' on behalf of the German Federal Ministry of Transport, Building and Urban Development, researchers developed an empirical simulation model for estimating the economic and environmental effects of the EU's emissions trading system (EU-ETS). This model makes it possible, for example, to calculate the total number of emissions permits required and the cost of purchasing additional emissions permits. If the EU succeeds in including airlines from outside the EU-ETS, it will enable ambitious reductions to be made in greenhouse gas emissions. It would mean that one-third of the CO₂ emissions generated by the international aviation industry would be covered by the system as from 2012.

Dr. Janina Scheelhaase
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Air Transport and Air Research
www.dlr.de/fw; janina.scheelhaase@dlr.de



More than just cars

Ever increasing traffic volumes on the one hand, and calls for more effective climate protection and conservation of resources on the other – this clash of interests is the driving force behind the global restructuring of our energy and transportation systems. After more than a century of development and refinement of the combustion engine, electromobility now marks the start of a new era both in terms of technology and our transportation systems. After all, the increasing use of electric drive systems in road vehicles offers us the opportunity to reduce our dependence on fossil fuels sustainably and simultaneously minimize emissions.



4 Electromobility



Electromobility is considered to be a concept with a very bright future.

Germany is looking to occupy a leading position in the electromobility market, and the goal is to have as many as one million electric vehicles on our roads by 2020. Based on Germany's National Development Plan, the National Platform for Electromobility (NPE) has devised measures to achieve this ambitious goal. The country's scientific organizations are involved in this process and are providing important input in terms of research and design. In response to the recommendations of the NPE, the federal government provided an additional

one billion euros for R&D work in its government program for electromobility in 2011.

Although combustion engines are bound to remain a major form of propulsion for road vehicles for the next two decades, the gradual transition to new technologies has to be organized today. It is not enough simply to continue developing automotive technology and the infrastructure needed for electromobility. In order to ensure the necessary acceptance of the technology



Electromobility research

How electromobility affects electricity supplies and the power grid

The German Aerospace Center (DLR) is leading a project funded by the German Federal Ministry of Economics and Technology entitled "Prospects for electric/hybrid vehicles in a power supply system dominated by decentralized, renewable energy sources." The first part of the project involves describing plausible concepts for vehicles of the future in terms of design, costs and customer groups. This data is used to calculate fleet scenarios and derive usage profiles over time. These fleets are integrated into an energy system model, followed by an analysis of the effects exerted on the power supply through the controlled charging of batteries. In cooperation with various partners, the project members then examine the technical implications for all levels of the network.

Dr. Thomas Pregger
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Technical Thermodynamics
www.dlr.de/tt; thomas.pregger@dlr.de

Integrating electric vehicles in the power grid

How will users behave?

Raising the number of electric vehicles on our roads could reduce local emissions, lower our dependence on energy imports and contribute toward protecting the climate, for example by recharging when there is a surplus of wind energy. In the NET-ELAN project, which is being funded by the German Federal Ministry of Economics and Technology and coordinated by Forschungszentrum Jülich (Jülich Research Center), scientists are examining how a certain proportion of electric vehicles on the road can best be integrated in the current and future energy supply infrastructure. The scientists at Jülich are taking into account parameters such as user behavior, including vehicle use and the resulting charging times, as well as the effects of electromobility on future energy supply scenarios.

Jochen Linssen
Forschungszentrum Jülich,
member of the Helmholtz Association,
Institute of Energy and Climate Research (IEK)
www.fz-juelich.de
j.linssen@fz-juelich.de



Hybrid vehicles combine the advantages of combustion engines and electric motors, but have a relatively complex structure.

by the public and thus a successful rollout, systematic research is called for across the entire spectrum: from demand for transportation and the needs of users, traffic and mobility management, to ideas for new vehicle concepts, automotive technology and integration in infrastructure, through to electricity and hydrogen production, economic and ecological system analyses, and strategies for a successful rollout and business models.

Research into electromobility generally centers around automotive technology, an arena in which all-electric vehicles are competing with hybrids and fuel-cell-powered vehicles. The key challenges faced here are to achieve longer distances between recharging, to lower costs and to shorten recharging times. Everything hinges on the battery system because its parameters – especially in all-electric vehicles – have a big impact on an electric vehicle’s overall performance. Weight and range, performance and durability are all directly de-



Smart grids for clean energy
Power grid for electric vehicles

How will we succeed in supplying millions of electric vehicles with energy in a safe and ecological manner? Researchers at the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg developed a system for the logistical control of an electricity-based transportation system that is primarily powered by renewable energy. Cooperating with 14 other partners in the “Harz.EE-mobility” project, they created a smart traffic and energy management system by means of which the electric vehicles can be provided with “clean” energy across a stable, broad-based network. Thanks to digital mobility control centers, smart charging stations and batteries that can feed energy back into the grid when needed, the vehicles themselves are transformed into autonomous mobile energy storage devices.

Dr.-Ing. Przemyslaw Komarnicki
 Fraunhofer Institute for Factory Operation and Automation IFF
www.iff.fraunhofer.de
przemyslaw.komarnicki@iff.fraunhofer.de

Recharging on the fly?
The CONGREEN project is examining contactless energy transmission

Electric vehicles currently have to be charged using a cable and connector. The Institute of Automotive Engineering (ika) at RWTH Aachen University is carrying out research to find a more convenient procedure – for example, fully automatic inductive contactless charging of the kind used in today’s electric toothbrushes. A transmitter integrated in the road surface emits up to 10 kW of electrical energy, which can breach a gap of 10 centimeters to reach a receiver located in the vehicle underbody. Whereas handling a charging cable in adverse weather conditions such as snow and rain is often an uncomfortable task, the inductive charging station is both robust and highly effective. The ika and its partners are currently examining the system’s electromagnetic compatibility and developing an overall system design in line with the needs of cars.

Univ.-Prof. Dr.-Ing. Lutz Eckstein
 RWTH Aachen University, Institute of Automotive Engineering
www.ika.rwth-aachen.de
eckstein@ika.rwth-aachen.de

4 Electromobility



The electrical components in hybrid vehicles have to be designed to withstand the demanding conditions encountered in driving.

pendent on the battery's energy density, power density and cycle stability.

Today, batteries with an acceptable combination of weight and price enable vehicle ranges of 150–200 km. However, these ranges can be substantially lessened by low ambient temperatures, use of the vehicle's heating or air-conditioning system as well as topographically demanding routes. These are the main reasons why current battery technology needs to be improved and new storage systems developed. Owing

to the properties of the elements used, however, there are limits to how far the energy density of electric vehicle batteries can be extended.

That is why researchers are also working on hybrid and fuel-cell technology. The combination of electric drive and combustion engine makes local zero-emissions driving possible without having to make concessions when it comes to the vehicle's range. The systems range from two parallel drive trains in a full-hybrid vehicle equipped with a combustion engine and electric



System research for electromobility **A system for mobility**

Electromobility needs to be systematically promoted in Germany to ensure that its auto industry, along with its power generation and storage industry, remain competitive and the country continues to be a key international player in this field. As part of the "Electromobility System Research" project, Fraunhofer intends to support the transition to a sustainable all-electric economy. This approach stands apart through its focus on coordinating research into all the value-creation stages of electromobility – from power generation, the transmission and distribution of energy via the power grids, interfaces between power grid and vehicle, energy storage, through to new vehicle concepts with a new infrastructure, and concepts for usage and billing. A particular challenge in this regard is evaluating the interplay of system components by means of system reliability methods.

Prof. Dr.-Ing. Holger Hanselka
Lead Coordinator Electromobility System Research,
Fraunhofer Institute for Structural Durability and
System Reliability LBF
www.lbf.fraunhofer.de; holger.hanselka@lbf.fraunhofer.de

Made-to-measure motors **Flexible design of electric drives for road vehicles**

Unlike combustion engines, electric motors are flexible in terms of both their design and how they are fitted. The possibilities range from direct drives integrated in wheel hubs through to high-speed, centrally located drives with very high power density – each of which boasts efficiency rates of well over 90 percent. The Institute for Drive Systems and Power Electronics (IAL) at Leibniz Universität Hannover develops electric drives of this kind, optimizes them within the complex comprising converter, motor and gearbox, and compares systems with reference to the vehicle specifications. Above and beyond this, the IAL develops and licenses specialized software that helps companies optimize their own drive concepts for production.

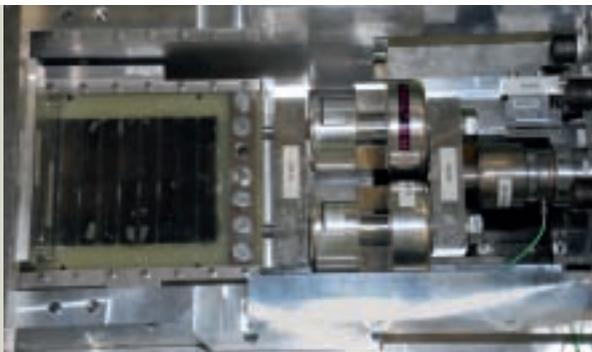
Prof. Dr.-Ing. Bernd Ponick
Leibniz Universität Hannover
Institute for Drive Systems and Power Electronics
www.ial.uni-hannover.de
ponick@ial.uni-hannover.de



In a hybrid bus, a fuel cell converts the fuel on board into electricity to power the motors driving the wheels.

motor, through to primarily battery-powered drives that produce electricity in a separate combustion engine when needed. Although hybrid drives are already available in series-production cars, the technology's potential is far from exhausted. There is also a need for research into fuel cell vehicles, which have admittedly reached a high state of the art, but whose lack of suitability for everyday use precludes wide-scale market introduction.

In order to compensate the additional weight of battery-powered vehicles, it is necessary to reduce the overall weight of the vehicle and simultaneously optimize power consumption and energy storage in relation to vehicle costs. In addition to metallic materials, fiber composites and non-reinforced plastics lend themselves to lightweight construction. The combination of different materials harbors huge, previously untapped potential for cost- and resource-efficient lightweight construction. What is more, it enables the



Free-piston linear generator
Range extender just in case

Despite the expected increase in energy and power density of batteries, the range of battery-electric vehicles will remain limited. Auxiliary motors, so-called range extenders, can increase the range, but more research is still needed. A range extender has to be light, compact and easily integrated into the vehicle. It also has to kick in smoothly. The German Aerospace Center (DLR) is developing the free-piston linear generator – a range extender that precisely meets these requirements. What is more, its variable compression and stroke give rise to high efficiency with low emissions, enabling the range extender to be powered with various fuels. Its ultraflat design also makes it easy to install the unit in the vehicle in the most favorable position.

Dr.-Ing. Christian Piehler
German Aerospace Center (DLR),
member of the Helmholtz Association
Program Directorate Transport
www.dlr.de/verkehr; christian.piehler@dlr.de



e performance
Electric vehicle design

Energy and thermal management in tomorrow's electric vehicles is one of the topics being researched by the Institute of Automotive Engineering (ika) as part of the "e performance" project, which brings together Audi, Bosch and RWTH Aachen University as partners. With the aid of simulations, the researchers are developing configuration options for the drive train and batteries, examining possible ways of reducing the cooling and heating requirements of the vehicle interior, and investigating how thermal management and air-conditioning can be integrated in order to enhance the efficiency of the system as a whole. This work has already resulted in networked simulation methods and innovative operating strategies. The guiding principle when designing the modular components is always to optimize the physical, electrical and functional interactions within the vehicle as a whole.

Univ.-Prof. Dr.-Ing. Lutz Eckstein
RWTH Aachen University, Institute of Automotive Engineering
www.ika.rwth-aachen.de
eckstein@ika.rwth-aachen.de

4 Electromobility



The success of electric vehicles depends on the installation of a broad and dense network of charging points.

implementation of innovative vehicle concepts that utilize the specific advantages of electric drives.

But electromobility offers potential to be exploited beyond vehicles too. The provision of a decentralized charging infrastructure, for example, is just one challenge. At the moment, there is still no network of "service stations" for electric vehicles, as there is for those running on combustion engines. It is not only the commercial development and operation of such a supply network that are still unresolved, but also how

"smart" such a network needs to be. This calls for a bidirectional connection between the vehicles and the power grid, in order to expand the feed-in of energy from renewable sources and to even out fluctuations in supply via intelligent load management. It is here that the interdependencies between energy supplies and the transportation system become evident.

Other issues being addressed are the need for adequate business models and a holistic system analysis. In this context, the specification of user requirements



Joint research into batteries

One goal

The success of electromobility hinges on the development of efficient, affordable and customer-friendly batteries. That requires not only research into innovative materials, but also the manufacture of promising battery systems in a viable size for production. The ultimate goal is to develop strategies for the safe and reliable operation of high-performance batteries and their integration in an overall system. In collaboration with partner universities, the Helmholtz Association is aiming to take a holistic approach to this topic on the basis of the system requirements and to come up with innovative solutions. The Energy Storage Initiative (Energiespeicherinitiative), the Competence Network North, the Electrochemical Alliance for Electromobility and the Helmholtz Institute Ulm are all providing valuable stimuli in pursuit of this goal.

Dr. Sören Wiesenfeldt
Helmholtz Association – Research field representative for
Key Technologies and Aeronautics, Space and Transport
www.helmholtz.de/forschung
soeren.wiesenfeldt@helmholtz.de



Lithium batteries

New impetus for electric vehicles

Nanotechnology could help make electric vehicles competitive. Scientists at the Max Planck Institute for Solid State Research are using it to enhance lithium batteries and extend the range of battery-powered vehicles. Nanostructured electrodes provide high storage capacity combined with fast charging and discharging. The batteries can also be charged faster if the researchers add nanoscopic silicon dioxide particles – basically tiny grains of sand – to the electrolytes. Ions wander to and fro between the poles in the battery through the electrolyte. The silicon dioxide separates negative and positive ions, thereby increasing the conductivity. This approach also makes the batteries sturdier and less inflammable.

Prof. Dr. Joachim Maier
Max Planck Institute for Solid State Research
www.fkf.mpg.de
s.weiglein@fkf.mpg.de



Unless electric vehicles are simple to operate and drive, they will not gain the acceptance of drivers.

and profiles is of crucial importance. The electrification of motor traffic is making the use of motor vehicles more demanding, and that means making more and more decisions. Particularly in view of our aging society, we need to make sure that the demands on drivers do not become excessive. Equipping vehicles with driving assistance systems, planning and monitoring the routes that best suit the vehicle's travel range, defining charging strategies, guiding drivers to charging points and automating billing procedures all represent examples of what needs to be done in this regard.

Making drivers aware of the need to plan their daily routes represents another important task, given that we are all creatures of habit. Breaking those habits calls for smart and attractive concepts that lead to new user patterns in motorized private transportation. These concepts could involve integrated mobility, for instance, in which electric vehicles represent one of several available alternatives. Information on the environmental impact of a journey could also help drivers to decide which route to take and which means of transportation to use. What is needed are innova-



Electromobility

More than just a technical innovation

In accordance with a decision of the European Commission, road traffic in urban centers is to be fully electric by 2050 in order to cut CO₂ emissions. Achieving this goal poses both technical and conceptual challenges. User acceptance is a key aspect in establishing this new technology, and one that scientists need to take into account. In order to determine the specific requirements in respect of electric transportation, a comprehensive survey of users was carried out in Berlin and North Rhine-Westphalia. 45 test persons used electric vehicles over a period of several months and were then interviewed about their qualitative experiences in order to record their specific requirements. The result was unequivocal: although electric vehicles are suitable for covering almost any distance within cities, users do not yet consider them suitable for everyday use. The project was funded by the German Federal Ministry of Economics and Technology.

Prof. Dr.-Ing. Christine Ahrend, Dr. Oliver Schwedes
Technische Universität Berlin,
Chair of Integrated Transportation Planning
www.verkehrsplanung.tu-berlin.de
christine.ahrend@tu-berlin.de, oliver.schwedes@tu-berlin.de

Electromobility fleet test

Hybrid vehicles in everyday use

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety is sponsoring a fleet test to investigate whether the batteries of future electric vehicles can be used for dynamic storage, thus enhancing the system integration of renewable energy. Twenty plug-in hybrids from Volkswagen are being deployed in everyday conditions to examine exactly how electrically powered passenger vehicles are used and whether they are suitable for feeding electricity back into the grid. Although the range of hybrid vehicles is not limited, the economic incentive to drive in all-electric mode means they are constantly being recharged. The German Aerospace Center (DLR) is using the trial to examine drivers' charging patterns and how electric vehicles influence mobility planning.

Stefan Trommer
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Transport Research
www.dlr.de/vf
stefan.trommer@dlr.de

4 Electromobility



The future of “fill it up” – a charging plug.

tive and attractive options that break down monomodal patterns of transportation, and support multimodal and intermodal travel.

The German Aerospace Center (DLR), the Fraunhofer-Gesellschaft and a number of major technical universities have opted for a systemic approach to research that pools together the expertise of their relevant institutes. Numerous other research institutions and universities are also contributing their specialist strengths

to research into electromobility. They are all united by one aim: to play an active part in enabling automotive electromobility. To achieve this aim, they are making a commitment together with their cooperation partners from business, industry and local government. The “Electromobility Showcases,” large regional demonstration and pilot projects that began in October 2011, will provide valuable input here.



Electromobility in urban areas

From pioneering product to mass acceptance

More than twenty different departments at the Technische Universität München are collaborating to find out how electric vehicles can be transformed from a niche to a household product through technical measures, intelligent mobility options and clever product and communication strategies. Through their pilot project MUTE, which comprises the development of an actual vehicle and the associated mobility concepts, the scientists are bringing together technical challenges and socioeconomic conditions in a comprehensive approach. They are also examining whether and, if so, how these strategies can be implemented in reality. The MUTE vehicle is to cost no more than a comparable conventionally powered small car when driven an average of 1,000 km a month. The resulting concept car was presented at the 2011 international Frankfurt Motor Show (IAA).

Prof. Dr.-Ing. Markus Lienkamp
Technische Universität München
TUM Science Center for Electromobility
www.mute-automobile.de; lienkamp@ftm.mw.tum.de



Controlling vibrations

Lighter, quieter and safer travel

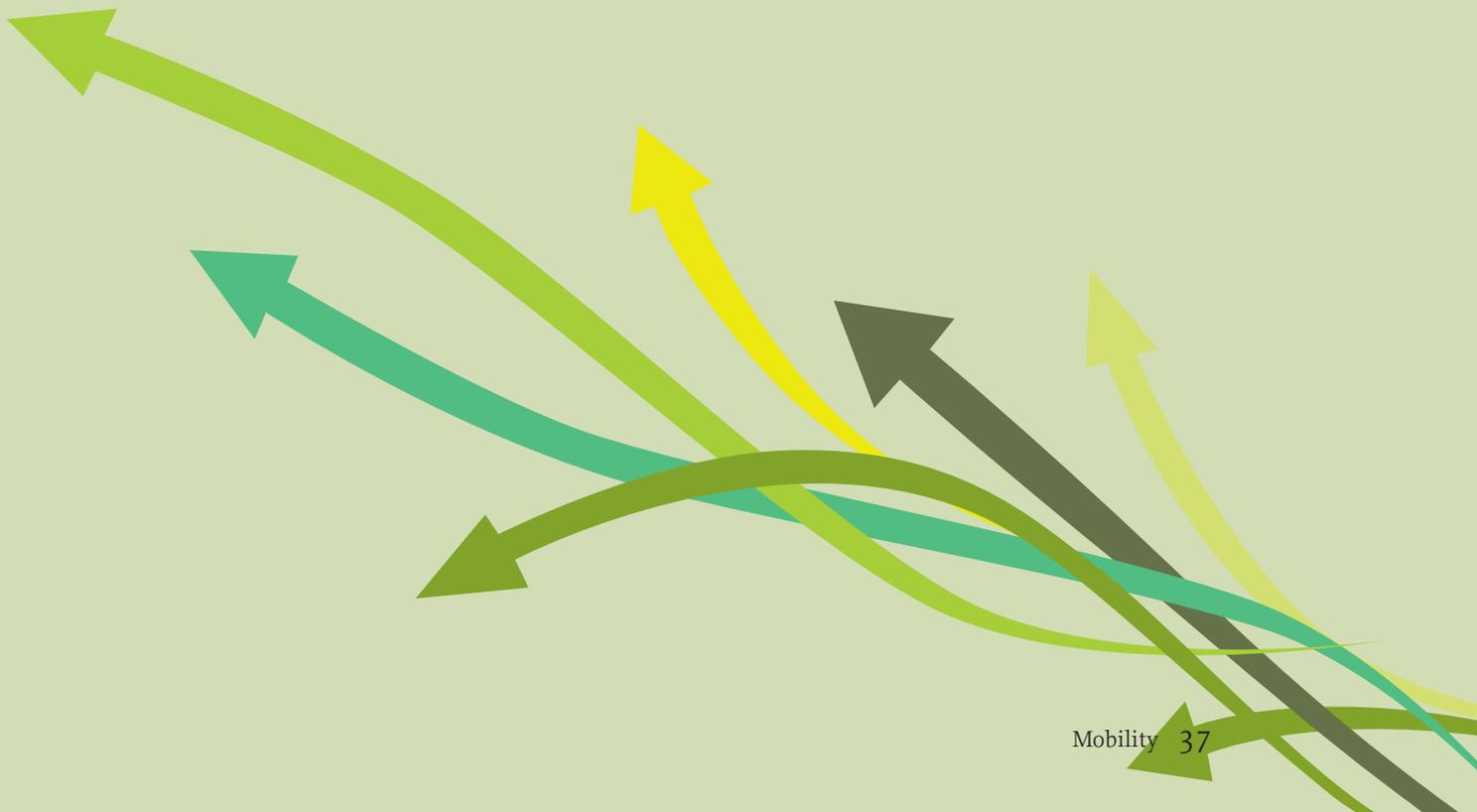
Compared with vehicles fitted with combustion engines, the vibration and acoustic behavior of electric vehicles is determined by different factors, such as the noise generated by contact between the tires and road surface, by the gearbox or the range extender. What is more, electric vehicles need to be light, which means exploiting every option for lightweight construction. The Fraunhofer Institute for Structural Durability and System Reliability LBF is developing methods for assessing these properties as well as innovative solutions for active, function-integrated lightweight construction. This will enable the safety-relevant monitoring of lightweight components, accompanied by concrete improvements in vibration behavior and comfort. The Fraunhofer LBF is thus making a key contribution toward improving the acceptance of electric vehicles.

Prof. Dr.- Ing. Tobias Melz
Fraunhofer Institute for Structural Durability and System Reliability LBF
www.lbf.fraunhofer.de
tobias.melz@lbf.fraunhofer.de



Reaching customers the clever way

Whether we are looking at urban supply chains or the international division of labor, trade and logistics have become central pillars of our modern way of life. Growth in the transportation sector is much more dynamic than in other industries, which throws up challenges for scientists and researchers. They are responding with a variety of contributions toward the efficient and sustainable transportation of goods.



5 Freight transportation and logistics



The technologies involved in transportation and logistics are interdisciplinary and exert an impact on virtually every branch of industry.

In Germany, transportation sector services generate around €74 billion, and account for 4 percent of gross value added. But beyond that, transportation logistics has a strong impact on other industries. Including expenditure for transportation-related services, one euro in every ten in Germany is spent on transportation. In a country that is highly dependent on the division of labor and strongly geared toward exports and imports, the economic benefits of this cannot be overestimated. The transportation sector is changing at a startling

pace: the international division of labor in the economy as a whole, and in production in particular, is generating disproportionately high growth, while the diminishing size of shipped consignments is triggering structural changes. More and more people are shopping online or are themselves offering new or used goods for sale via the Internet.

In order to facilitate this qualitative and quantitative growth in the transportation sector and render it both



Logistics between production and transportation **Networking for better performance**

The economy's exposure to globalization, urbanization and volatile markets is having an ever greater impact on value creation (in production and logistics). To make sure we take the right action, we need to view transportation as an enabler of value creation. In order to improve the responsiveness of directly relevant systems, we need to be able to understand, analyze and forecast the parameters of adjacent systems. In conjunction with the European Business School, the Technische Universität Darmstadt has set up the "Dynamo PLV" research project, in which it is striving to take an interdisciplinary approach to decision-making in the fields of production, logistics and transportation and thus achieve a qualitative leap in the flexibility and sustainability of value creation.

Prof. Dr. Dr. h. c. Hans-Christian Pfohl
Technische Universität Darmstadt
Department of Law and Economics
www.dynamo-plv.de
pfohl@bw.tu-darmstadt.de



Dynamic route planning **Changes are factored in**

Resource-conserving logistics requires careful planning, and yet it is also important to be able to respond flexibly to last-minute inquiries and adapt to disruptions in the normal process flow. That is why researchers at the Fraunhofer Institute for Transportation and Infrastructure Systems IVI are developing models and algorithms for robust and dynamic route planning. Once integrated in a logistics software program, they make it possible to respond automatically and in real time to changes that arise when planning transportation routes and when the shipment is already in progress. A new dimension in route planning can be achieved through the inclusion of uncertain information and events. The route plans created are thereby rendered more robust in the face of unavoidable alterations.

Dipl.-Math. oec. Axel Simroth
Fraunhofer Institute for Transportation and
Infrastructure Systems IVI
www.ivi.fraunhofer.de
axel.simroth@ivi.fraunhofer.de



The worldwide volume of freight will continue to grow. That is why logistics must be made more efficient, in both economic and ecological terms.

economically an ecologically sustainable, a large number of challenges must be tackled. Shipping has to be made more energy-efficient; logistics sites and company locations need to be scrutinized, and supply chains optimized. That is not only a prerequisite for meeting the climate goals set by the federal government, but also the best response, in economic terms, to rising oil prices. Money spent to maintain and expand transportation infrastructure has always been seen as money well spent, and in many cases this will remain so in

future too. In fact, global expenditure on transportation infrastructure would need to double by the year 2030 from its current level of around US\$41 trillion simply to satisfy the growing demand for transportation routes.

Science is playing a key role in ensuring that highly efficient use is made of transportation routes and transportation logistics facilities. Optimized operating strategies are essential for container terminals or forwarding facilities if the ever rising number of shipments is to



Traffic volumes at Hamburg Port
Optimizing processes to reduce traffic

On behalf of the Hamburg Port Authority (HPA), the German Aerospace Center (DLR) analyzed traffic movements on the port's premises. Over the period of one week these movements were monitored by the means of screen counts. Furthermore, over 1,700 interviews of truck drivers were carried out and the routes of 50 trucks driving within the harbour area or beginning or completing their journeys there were recorded and logged by GPS. The information gained provides insights into hot spots of noise and exhaust emissions; it reveals parking patterns of long-distance trucks, options for utilizing electric vehicles on the port premises and potential measures to reduce on-site traffic. In addition, based on the findings it was possible to establish the impact of pre-gate parking areas for trucks on the traffic situation of the port.

Dr.-Ing. Verena Ehrler
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Transport Research
www.dlr.de/vf; verena.ehrler@dlr.de



Self-regulating transportation processes
Smart containers

Road and rail networks are having to cope with ever greater volumes of traffic. Researchers at the Collaborative Research Centre "Autonomous Cooperating Logistic Processes," which is funded by the German Research Foundation, are searching for ways to maintain and even improve the high quality of mobility. Logistical objects such as an intelligent refrigerated container, or the perishable freight it holds, can record and exchange the latest information – on the state of the perishable goods, on traffic conditions, etc. – and can make decisions, for instance on the basis of a multi-agent system, that can help ensure a positive outcome even when unexpected events occur. In this way, the volume of unnecessary traffic can be reduced and better use made of shipments that would otherwise suffer in highly dynamic situations.

Prof. Dr.-Ing. Bernd Scholz-Reiter
University of Bremen
Bremer Institut für Produktion und Logistik (BIBA)
www.sfb637.uni-bremen.de
bsr@biba.uni-bremen.de

5 Freight transportation and logistics



Neither the current nor future volume of freight can be transported without specialized IT solutions.

remain manageable. Innovative IT solutions allow more information to be assigned to shipments, thus enabling more autonomous, decentralized decision-making. Basic research into the interfaces between logistics, production and transportation result in better explanatory models, which in turn help politicians, public authorities and companies to make decisions.

As the volume of freight grows, so too do our expectations of the reliability of the corresponding technolo-

gies. That means that safety and control systems have to be continually developed so that the efficiency and safety of all means of transportation and transportation routes can be constantly improved. IT systems and innovative transportation and cargo-handling technologies can help maximize the environmental compatibility of freight transportation logistics, thus ensuring the future supply of goods to – and the removal of waste products from – companies and private households.



Stability needs change

Logistics requirements at Airbus

Transnational corporations have to navigate the space between national dependencies and the requirements of the global market. The Social Science Research Center in Berlin is investigating the complex logistics requirements of such corporations, using Airbus as an example. The focus is on the division of labor within the company between its different locations in Germany, France, the U.K. and Spain. An analysis of the period from 1970 to 2010 reveals that the division of labor has remained essentially stable and that the logistics processes are well oiled. But it is also evident that both the continual “migration” of small work packages and ever more complex production processes are placing greater demands on the company’s internal and external logistics systems. The A380 is a prime example of this.

Lisa Maria Arnold
Social Science Research Center in Berlin (WZB),
member of the Leibniz Association
Modes of Economic Governance Project Group
www.wzb.eu
arnold@wzb.eu



Facility logistics

Statistics and simulations ensure success

Owing to the temporal links between them and the resulting internal and external dependencies, processes in logistics facilities – such as container terminals or freight forwarding centers – are extraordinarily complex. For this reason, a group of researchers at the TU Dortmund University is developing a method for identifying logistical operating strategies or bundles of strategies, and testing it in a sample freight forwarding facility. The method combines a discrete-event simulation with the statistical method of recursive partitioning, enabling a systematic comparison of logistics strategies and simultaneously reducing the cost of simulation projects with actual logistics facilities.

Prof. Dr.-Ing. Uwe Clausen
TU Dortmund University
Institute for Transport Logistics
clausen@itl.tu-dortmund.de



Imagining tomorrow today

Hardly any other topic ignites people's imagination as much as the future of mobility. At the very latest since the spectacular success of the automobile in the 20th century, we have come to take our almost unrestricted mobility for granted, and we often forget just what high expectations we have. Now, however, we need to accept the fact that quite new, and much more difficult, problems await us if we are going to satisfy to our high expectations of mobility in a constantly changing environment.



6 Future mobility



When planning future technologies and systems we must take into account that the demand for mobility – whether for the transportation of people or goods – will continue to increase.

If we take a brief look at the history of mobility, we see that things essentially always turned out differently than originally imagined. A comparison of yesterday's forecasts with today's reality teaches us caution when it comes to making prognoses about the future. Instead of surrendering to boundless optimism and entertaining daring visions of the future, it does in fact appear more sensible to take a much closer look at the problems and risks involved. After all, some facts simply cannot be ignored. People are often quick to refer to expected scientific progress, but much of this belief

is based on hope, and hope is the seed of uncertainty when it comes to forecasts. Obviously, mobility needs to be viewed within a global context; it is of little use limiting our view to Germany or even Central Europe.

Taking a global view, we first of all recognize that the world's population is growing dramatically, and that people everywhere increasingly share the same expectations of mobility that we have. Secondly, cities everywhere are growing, and more than half of the world population already lives in urban agglomerations.



Alternatives to private transport **Moving people in rural areas**

People in rural areas rely heavily on private cars. Because of rising mobility costs, this poses a huge challenge in the near future. Although alternative forms of transport for rural areas exist, it is not known how they meet the needs of families. To help in the search for environmentally compatible, family-oriented mobility options, families in country areas of eastern and western Germany have been surveyed about their daily mobility patterns and their expectations for the future. In cooperation with the Wuppertal Institute for Climate, Environment and Energy, examples of alternative forms of mobility have been compiled and assessed in terms of their contribution to environmental protection. The project is being funded by Deutsche Bundesstiftung Umwelt.

Prof. Dr.-Ing. Christine Ahrend, Melanie Herget
Technische Universität Berlin
Chair of Integrated Transportation Planning
www.verkehrsplanung.tu-berlin.de/ufm
christine.ahrend@tu-berlin.de; melanie.herget@tu-berlin.de



"Mobility 2050" **Combining rail transport and taxi services**

When trains stop to let just a few passengers on or off it is neither convenient for other passengers nor is it favorable from an economic perspective. Forming part of the sustainability strategy of the state of Hesse, the "Mobility 2050" sub-project is examining the pros and cons of using taxi services to ferry passengers from train stops with little passenger traffic to busier ones nearby. The project participants are not only looking into travel times, acceptance levels, user costs and operating costs, but also identifying the parameters according to which the idea could be rolled out in other regions. The project goal is to evaluate substitute services of this kind, taking flexible forms of operation into account in an integrated approach that may involve a partial redesign of the train network.

Prof. Dr.-Ing. Manfred Boltze
Technische Universität Darmstadt
Chair of Transport Planning and Traffic Engineering
www.verkehr.tu-darmstadt.de/vv
boltze@verkehr.tu-darmstadt.de



Organizing mobility in urban conurbations will always pose a particular challenge.

Unfortunately, transportation is one of the last things growing economies get around to planning, which inevitably gives rise to problems.

In Germany, the population is shrinking, which will reduce the amount of domestic traffic; but as an east-west transit country we have to cope with the growing volume of freight traffic. Our infrastructure is unlikely to grow to any great extent; at most, existing roads will be widened, depending on the availability of funds. The task at hand, then, is to make optimal use of existing

resources, and there are many different approaches to doing just that. One of the key ones involves traffic information and forecasts. Although many traffic information systems already exist, there is still plenty of potential when it comes to improving their forecasts.

In this context, human behavior cannot be underestimated as an element of uncertainty – this was the case in the past and will remain so in future. People are changing more than we previously assumed or could even have thought possible. The Internet is



Forecasting with simulations

Analyzing transportation planning measures

How can transportation be improved? How will the building of a new road affect the transportation system as a whole? Are there options for lowering construction costs? The Chair of Transport System Planning and Transport Telematics at the Technische Universität Berlin is trying to answer these questions with the aid of simulation software being developed in cooperation with the Swiss Federal Institute of Technology Zurich and partners from industry. The project is focusing on the development, modeling and simulation of transportation planning measures, which include improvements in infrastructure as well as non-structural measures such as tolls, telematics or innovative mobility concepts. On the basis of the simulations, the impact of measures on people and the environment can be analyzed and evaluated.

Prof. Dr. Kai Nagel
Technische Universität Berlin
Chair of Transport System Planning and Transport Telematics,
School V, Department of Land and Sea Transport Systems
www.vsp.tu-berlin.de
nagel@vsp.tu-berlin.de

Putting sustainability to the test

Public transportation – new challenges for urban planning

Demographic trends and changes in transportation routes brought about by the digital economy are continually posing new challenges for urban planning and public transportation systems. The growing number of people living on the urban periphery makes for more traffic, thus countering efforts to make transportation sustainable. Michal Beim, since 2009 the holder of a scholarship from the Alexander von Humboldt Foundation at the Technische Universität Kaiserslautern, is using case studies to carry out a comparative analysis of the relationship between regional and transportation planning, taking into account demographic trends, the needs of the public, and sustainability policy. The goal is to develop recommendations for decision-makers and to make the results available to the international research community.

Dr. Michal Beim
University of Kaiserslautern
Institute for Mobility and Transport (imove)
www.bauing.uni-kl.de/imove
michal.beim@imove-kl.de

6 Future mobility



Mobility needs energy. Today, the fuels we use – like gasoline and diesel – are still almost exclusively oil-based.

replacing many forms of human contact that used to involve mobility. Among the younger generation, the automobile no longer plays such an important role as it did 20 to 30 years ago. No end to this trend is in sight.

The picture is further complicated by demographic trends. How mobile will the over-sixties be in 25 years' time? How will public transportation develop? And, finally, how will the direct financing of infrastructure through toll charges help reduce the volume of traffic or even steer traffic flows? Of course, all this is exacer-

bated by regulations to reduce environmental pollution, whatever form they might take.

But the biggest problem for future mobility will be the type of energy used for propulsion. "Peak oil" – the point in time when the maximum rate of petroleum extraction is reached – is imminent, if it has not already been reached. Whereas new reserves may indeed be discovered and exploited, the end of oil production is foreseeable. Up till now, drivers have not given much thought to energy supplies.



Urban renaissance

Future opportunities for public transportation

Although public transportation faces challenges from sociodemographic trends in the decades ahead, the same trends also present it with new opportunities. Initial empiric evidence points to a return to city centers. Inner-city precincts are increasingly being seen as attractive places to live owing to their proximity to a wide array of products and services needed in daily life. Research in this area is focused on assessing the risks and opportunities for public transportation thrown up by this "urban renaissance". The researchers want to clarify whether such an urban renaissance can have a positive impact on the demand for public transportation, and if so, to what extent this is true. In addition, they are examining which measures of urban and transportation planning encourage or inhibit this trend.

Univ.-Prof. Dr.-Ing. Dirk Vallée
RWTH Aachen University
Chair and Institute of Urban and Transport Planning (ISB)
www.isb.rwth-aachen.de
vallee@isb.rwth-aachen.de



Application platform for intelligent mobility

The city as a research lab

Through the Application platform for Intelligent Mobility (AIM), the German Aerospace Center (DLR) and several partners are transforming the city of Braunschweig and the surrounding region into a complex mobility research lab. AIM uses the actual transportation environment of Braunschweig and incorporates both specially equipped test stretches on roads and various simulations. Open and flexible, the AIM is geared to sustainability and reusability. In the interests of enhanced safety, efficient traffic flows and resource conservation, five key research areas are anchored in the AIM: traffic flow optimization, intermodal mobility, future mobility concepts, market introduction and migration, and mobility awareness.

Dr. Lars Schnieder
German Aerospace Center (DLR),
member of the Helmholtz Association,
Institute of Transportation Systems
www.dlr.de/ts
lars.schnieder@dlr.de



Progress is being made on the technology and logistics fronts: the mobility of tomorrow will be better for both the environment and humankind.

Now, boundaries and obstacles are visible on all fronts: the shutting-down of nuclear power plants; the imminent bottleneck with oil; the debate on the ethics of biofuels ("table or tank"); or the uncertainties surrounding the development of fuel cells. Trains will have to use less electricity, a replacement for kerosene will have to be found for aircraft, and drivers will have to get used to paying high prices for gasoline and diesel – no matter where we look, we see the need to adapt. Electric vehicles will play a part in urban areas. Based on what we know today, however, they will not be suitable

for long-distance transport. Private transport will nevertheless retain its key role because people will not be prepared to renounce the freedom it has brought them.

This is where science is called upon more than ever before to develop ways of maintaining today's high level of mobility. Copying cooperative(!) behavior in the animal kingdom may just be the way forward. The projects in progress are many and varied, but the question of energy is the one that will make or break our future mobility.



Electromobility in goods transportation
Zero-emissions transportation in cities

In order to maintain the attractiveness of inner-city areas, transportation structures must be changed without precipitating economic disadvantages. But alternative approaches to inner-city supply systems call for new vehicle and transportation concepts that reduce costs and enable the distribution of goods in traffic-restricted zones. The Fraunhofer Institute for Production Systems and Design Technology IPK is therefore testing the operational deployment of fully electric goods vehicles as part of the "Electric Mobility in Pilot Regions" program sponsored by the German Federal Ministry of Transport, Building and Urban Development. The goal is to calculate the potentials this holds for for transportation, logistics and the environment. One result of the test is the MicroCarrier, which can substantially reduce the costs of handling goods and transporting them that expensive "last mile."

Prof. Dr. h. c. Dr.-Ing. Eckart Uhlmann
Fraunhofer Institute for Production Systems and Design Technology IPK
www.ipk.fraunhofer.de; eckart.uhlmann@ipk.fraunhofer.de



Car-2-X Communication
Exploiting swarm intelligence

By communicating with each other, the individual members of a swarm of animals can move in a certain direction without colliding with each other or disrupting the flow of the swarm. In future, motor vehicles will communicate each other on the basis of the same principle, using special wireless networks with a range of about 300 meters. The "Next Generation Car-2-X Communication" research project at the University of Duisburg-Essen is investigating how swarm intelligence can be transposed to road traffic by means of vehicle-to-vehicle communication. Computer simulations with cellular automata reveal that, if a mere 5 percent of vehicles communicate with each other in rush-hour traffic, the travel times of all road users can be significantly improved. If one in four cars were equipped for wireless communication, many traffic jams could virtually be avoided altogether.

Prof. Dr. Michael Schreckenberg
Universität Duisburg-Essen; Physics of Transport and Traffic
www.uni-due.de/ptt/schreckenberg@ptt.uni-due.de

Alliance of Scientific Organizations

The Alliance of Scientific Organizations is an amalgamation of major German research organizations. The partners involved take on the lead management function on a rotating basis. The Alliance includes:

Alexander von Humboldt Stiftung

Jean-Paul-Strasse 12
53173 Bonn
Phone +49 228 833-0
Fax +49 228 833-199
info@avh.de
www.humboldt-foundation.de
President: Prof. Dr. Helmut Schwarz

The Alexander von Humboldt Foundation promotes academic collaboration between excellent scientists and scholars from abroad and from Germany.

Deutscher Akademischer Austauschdienst e.V.

Kennedyallee 50
53175 Bonn
Phone +49 228 882-0
Fax +49 228 882-444
postmaster@daad.de
www.daad.de
President:
Prof. Dr. Margret Wintermantel

The German Academic Exchange Service (DAAD) is the largest funding organization in the world supporting international exchange of students and scholars. The DAAD supports the internationalization of German universities, promotes the German language abroad, assists developing countries in establishing effective universities and advises decision-makers on matters of cultural, educational and development policy.

Deutsche Forschungsgemeinschaft e.V.

Kennedyallee 40
53175 Bonn
Phone +49 228 885-1
Fax +49 228 885-2777
postmaster@dfg.de
www.dfg.de
President: Prof. Dr.-Ing. Matthias Kleiner

The German Research Foundation (DFG) is the self-governing organization for science and research in Germany. It serves all branches of science and the humanities by funding research and promoting cooperation among researchers.

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

Hansastraße 27 c
80686 München
Phone +49 89 1205-0
info@zv.fraunhofer.de
www.fraunhofer.de
President: Prof. Dr. Hans-Jörg Bullinger

The Fraunhofer-Gesellschaft carries out applied research for the benefit of business and society. Its areas of research are geared directly to the needs of people: healthcare, security, communication, mobility, energy and environment.

**Helmholtz-Gemeinschaft Deutscher
Forschungszentren e.V.**

Ahrstrasse 45
53175 Bonn
Phone +49 228 30818-0
Fax +49 228 30818-30
org@helmholtz.de
www.helmholtz.de
President: Prof. Dr. Jürgen Mlynek

The Helmholtz Association aims to contribute significantly to solving the grand challenges which face society, science and industry. Helmholtz Centres perform top-class research in six core fields: Energy, Earth and Environment, Health, Key Technologies, Structure of Matter, and Aeronautics, Space and Transport.

Hochschulrektorenkonferenz

Ahrstrasse 39
53175 Bonn
Phone +49 228 887-0
Fax +49 228 887-110
post@hrk.de
www.hrk.de
President: Prof. Dr. Horst Hippler

The German Rectors' Conference (HRK) is a voluntary amalgamation of state and state-approved universities in Germany. It is the voice of universities vis-à-vis the government and the general public, and a forum through which universities can together shape opinion.

**Wissenschaftsgemeinschaft
Gottfried Wilhelm Leibniz e.V.**

Chausseestrasse 111
10115 Berlin
Phone +49 228 30815-0
Fax +49 228 30815-255
info@leibniz-gemeinschaft.de
www.wgl.de
President: Prof. Dr. Karl Ulrich Mayer

The Leibniz Association is the umbrella organization for 86 institutions conducting research into scientific issues relevant to the whole of society. They provide infrastructure for science and research and perform research-based services – liaison, consulting, transfer – for the public, policy-makers, academia and business.

**Max-Planck-Gesellschaft zur
Förderung der Wissenschaften e.V.**

Hofgartenstrasse 8
80539 München
Phone +49 89 2108-0
presse@gv.mpg.de
www.mpg.de
President: Prof. Dr. Peter Gruss

The Max Planck Society performs basic research in the interest of the general public in the natural sciences, life sciences, social sciences, and the humanities. Its institutes take up new and innovative research areas that German universities are not in a position to accommodate or deal with adequately.

**Deutsche Akademie der
Naturforscher
Leopoldina –
Nationale Akademie der
Wissenschaften**

Emil-Abderhalden-Strasse 37
06108 Halle (Saale)
Phone +49 345 47239-0
Fax +49 345 47239-19
leopoldina@leopoldina.org
www.leopoldina.org
President: Prof. Dr. Jörg Hacker

The German National Academy of Sciences Leopoldina is Germany's oldest academy in the field of natural and medical sciences. Its members include prominent scientists from around the world.

Wissenschaftsrat

Brohler Strasse 11
50968 Köln
Phone +49 221 3776-0
Fax +49 221 388440
post@wissenschaftsrat.de
www.wissenschaftsrat.de
Chairman:
Prof. Dr. Peter Strohschneider

The German Council of Science and Humanities in Cologne provides advice to the German federal government and the state (*Länder*) governments on the structure and development of higher education and research.

Published by

Alliance of Scientific Organizations

Brochure series

Researching: Energy
Researching: Health Care
Researching: Communications
Researching: Security
Researching: Mobility

Brochure editorial team

“Researching: Mobility”

Dr.-Ing. Christian Piehler
German Aerospace Center (DLR)
Linder Höhe
51147 Köln
christian.piehler@dlr.de

Christa Schraivogel (pictures)
Fraunhofer-Gesellschaft

Brochure authors

“Researching: Mobility”

- Prof. Dr.-Ing. Horst E. Friedrich, DLR
- Prof. Dr.-Ing. Karsten Lemmer, DLR
- Prof. Dr. Barbara Lenz, DLR
- Dr.-Ing. Christian Piehler, DLR
- Prof. Dr.-Ing. Uwe Clausen, Fraunhofer-Gesellschaft
- Prof. Dr. Michael Schreckenber, Universität Duisburg-Essen

Photo acknowledgments

- plainpicture: title image, 41
- panthermedia: 6, 7 top to 9 top, 11 top to 13 top, 13 bottom left, 16 top, 20 top, 21 top, 24 top, 26 top, 27 top, 35 top, 39 bottom right, 42 top, 43 top
- IPEK: 7 bottom right
- BMW: 8 bottom left
- Stöckelhuber, Klaus-Werner: 8 bottom right
- Universität Paderborn: 10 bottom right
- dpa: 10 top, 28 top, 31 top, 33 top, 36 top, 39 top, 40 top
- TU München: 11 bottom left, 12 bottom right, 36 bottom left
- MEV: 14 top, 16 bottom right, 17 bottom right, 22 top, 23, 37, 40 top, 44 top
- Euroluftbild.de: 15
- Bombardier Transportation: 17 top
- Munich Airport: 18 top
- Getty Images: 21 top
- Universität Braunschweig: 18 bottom right, 21 bottom right
- RWTH Aachen University: 20 bottom left
- TU Dresden: 21 bottom left
- Hoppe, Michael (FVT): 22 bottom left
- Verkehrsverbund Rhein Ruhr: 28 bottom left
- Meyer, Gereon: 29
- Nationale Plattform Elektromobilität: 30 top
- Siemens AG: 30 bottom left
- Autocluster.NRW: 31 bottom right
- Audi AG, page 33 bottom right
- Griesch, Axel: 34 bottom right
- TU Berlin: 35 bottom left, 42 bottom left, 43 bottom left
- Classen, Bernhard: 38 top
- fotolia: 30 bottom left, 38 bottom left
- TU Dortmund University: 40 bottom right
- Beim, Michal: 43 bottom right
- MVG München: 44 bottom left
- Caro/Muhs: 45 top
- Daimler AG: 45 bottom right

All other photos:

© Fraunhofer-Gesellschaft, Helmholtz Association/German Aerospace Center(DLR), Leibniz Association, Max Planck Society

Reproduction of an material is subject to editorial authorization.

Editorial Team

- Adelheid Adam, Fraunhofer-Gesellschaft
- Dr. Christina Beck, Max Planck Society
- Peter Hergersberg, Max Planck Society
- Dr. Thomas Köster, German Research Foundation
- Franz Miller, Fraunhofer-Gesellschaft
- Simon Neuenhöfer, Helmholtz Association
- Dr.-Ing. Christian Piehler, Helmholtz Association
- Dr. Georg Rosenfeld, Fraunhofer-Gesellschaft
- Christa Schraivogel, Fraunhofer-Gesellschaft
- Dr. Eva-Maria Streier, German Research Foundation
- Dr. Martin Thum, Fraunhofer-Gesellschaft
- Janine Tychsen, Helmholtz Association
- Josef Zens, Leibniz Association
- Dr. Detlef Zukunft, Helmholtz Association

Design, layout and lithography

Vierthaler & Braun, Munich

Printing

J. Gotteswintter GmbH, Munich

May 2012

Alliance of
Scientific Organizations

