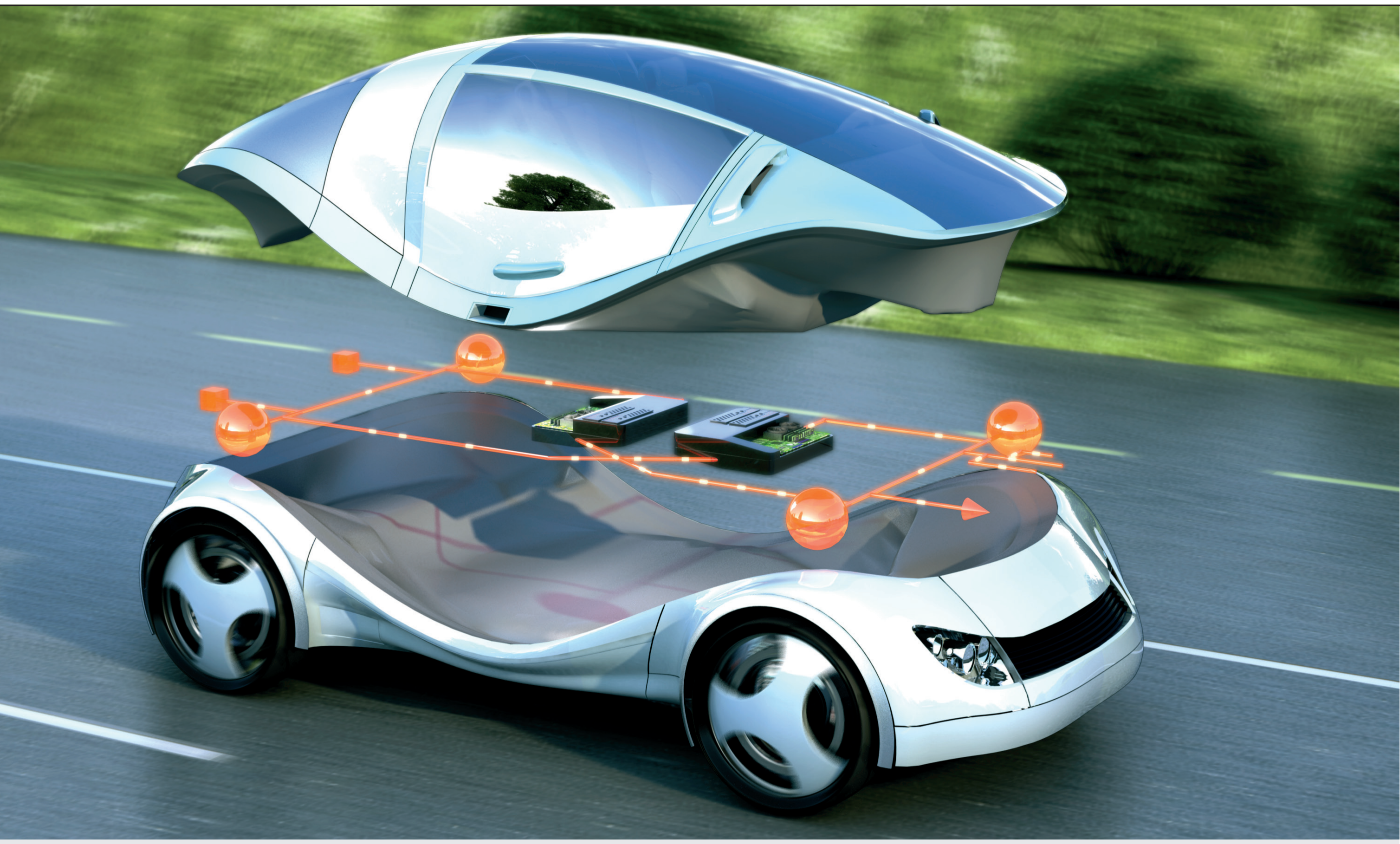

The Software Car:
Information and Communication Technology (ICT) as an Engine for the Electromobility of the Future




Summary of results of the ”eCar ICT System Architecture for Electromobility“ research project sponsored by the Federal Ministry of Economics and Technology

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Content

1 | Introduction

Disruptive technologies have the potential to change markets dramatically. In such a situation, market dominance can be achieved particularly by companies that have newly entered the market or that cut themselves free from traditional structures and implement major innovations without hesitation. Electromobility is such a disruptive change. But electric drives for cars are only the catalyst for the real change: most significantly, the architecture and role of information and communication technology (ICT architecture) will change for the vehicle of the future. ICT is growing increasingly important and will come to drive developments itself.

ICT, in the form of electrics and electronics in cars (automotive E/E), is already essential to the competitiveness of the German automotive industry. Its most notable effects are to improve driving performance and comfort, and to enhance both passive and active safety. But the effects go further in electric vehicles. Here ICT becomes the foundation of the driving functions themselves. For that reason, architectures and technologies for vehicle ICT cannot be viewed merely as a frame for gradual evolutionary innovations, as they were before. Instead, they must be revised so far-sightedly that they can perform their indispensable future role in the revolutionary evolution of the automobile.

Electromobility has a double impact. First, it necessitates a new ICT architecture in cars. But at the same time it opens up the opportunity for such a revolutionary architecture for the first time. It shifts the necessary core competences, lowers barriers to market entry, and thus changes the market's rules of the game. With a new ICT architecture, a newcomer can rise more easily from the low-cost to the premium segment of electromobility than a business in the premium segment can switch from conventional non-electromobility ICT architecture to the future architecture that includes electromobility. Consequently new competitors have a chance to penetrate into established, saturated markets.

The importance of future ICT architecture goes far beyond the change to electromobility. For historical reasons, the conventional architecture is highly complex. For that reason, it is more and more becoming an impediment to innovation, instead of an innovation driver. By contrast, a new architecture will make new approaches and functions possible – from greater autonomy in driving to a fuller integration of the vehicle into the ICT infrastructure – and thus help significantly to achieve sociopolitical goals like energy efficiency or lower accident rates.

Electromobility will make information and communication technology in cars much more important. That will have far-reaching effects on Germany as a business location. Skills and competences will shift, and structures for adding value will change. No doubt there will also inevitably be a certain amount of self-cannibalization within the automotive industry. For that reason, business, science and education, together with government, must cooperate in a concerted action to safeguard Germany's competitiveness in one of its core industries.

This document is a summary of the results of the "eCar ICT System Architecture for Electromobility" research project sponsored by the Federal Ministry of Economics and Technology. It describes the role of ICT architecture in a vehicle within the context of electromobility. It names the main societal and technological driving forces, and on that basis points out scenarios for electric vehicles and features of future ICT architectures. It also discusses the resulting changes in the value chain in the automotive sector. Based on all results, the strengths, weaknesses, opportunities and threats are listed (SWOT analysis), with consequent recommendations for action in government, industry and science.

The full report of results is available at
http://www.fortiss.org/ikt2030/

2 | ICT in today's automobile

Over the past 30 years, ICT – in other words, electronic control devices, including the associated software – has made significant innovations in automotive construction possible: from the anti-lock braking system in 1978 to electronic stability control in 1995 and emergency brake assist in 2010. In total, according to current estimates ICT contributes some 30 to 40 percent of total value added in automotive construction. At the same time, ICT architecture has also become more complex, and in multiple ways: because of the technologies employed, in terms of the functions performed, and in regard to the supply chain. Accordingly, ICT, and especially its software, has expanded significantly, from about 100 lines of program code (lines of code, LOC) in the 1970s to as much as ten million LOC.

The ICT infrastructure in an automobile of today – a combination of embedded functions and infotainment systems – has become a major prerequisite for optimized use and comfort. It plays a significant role in up to 80 percent of all innovations in the premium automotive segment, whether in engine control and electronic stability control or in driver assistance. Additionally, regulatory requirements to reduce emissions and accidents would be inconceivable without ICT.

Nevertheless, the use of ICT lags well behind the technical possibilities. Safety is achieved mainly by passive safety measures; proactive safety functions (such as emergency brake assist) that make heavy demands on ICT are treated with great wariness. "Drive-by-wire" – in other words, steering vehicles without mechanical steering mechanisms – is also being pursued only hesitantly, because its associated requirements for the reliability of ICT. In other areas as well that offer great potential to help products stand apart from the crowd, such as infotainment or telematics, ICT architecture in cars has not been keeping pace with developments in other sectors.

The discrepancy between the role of ICT as an "enabling technology" and inhibitions about innovation is based mainly in the characteristics of today's ICT. Today, German premium vehicles have some 70 to 100 control devices. These are often developed for a problem-specific use, as structural units in control devices with associated sensors and actuators. The control devices are networked by way of a highly complex tree of cables, using multiple bus systems – for example, for the engine chamber, chassis, passenger compartment and infotainment – as well as different communication protocols, including LIN, CAN, FlexRay and MOST. The ICT architecture in vehicles today is molded by the car makers and their suppliers, rather than by its functionality.

Decades of evolution in ICT architecture that have neglected to revise it fundamentally, and thus to adapt it to its importance today, have had an unfortunate effect. The result has been that in today's vehicles, ICT architecture is increasingly becoming a barrier to innovation.

3 | ICT in the car of 2030

Various trends affect the ICT architecture in a vehicle, and result in changes. In this project, societal and technological trends were studied, along with changes in industries related to the automotive sector. Based on these results, a potential development of the architecture was then laid out.

Societal trends

Individual mobility is driven primarily by two trends: the growing mobilization of the population in developing countries, and the waning importance of cars as a status symbol in developed countries. In developing countries, economical, thrifty vehicles are in demand that encourage the transition from motorcycles to cars. Since cars are less important as status symbols in developed countries than they used to be, similar vehicles are needed here, especially for urban residents and the growing group of aging singles. Driving is becoming less important as a function, while the real added value derives from customizing a car and fitting it into a larger context. Passengers want to travel economically, while at the same time enjoying comfort and convenience functions like a link to the Internet.

In essence, this results in a demand for economical, accident-free vehicles that can be individually customized to suit the driver and have sufficient driving range. As the report makes clear, a suitable ICT architecture offers a basis for meeting these requirements. Replacing mechanical and hydraulic components with electronic ones (such as "X by wire") reduces vehicle weight and increases range. It also eliminates high-cost components. Suitable middleware architectures make it possible to configure and upload functions that offer customers added value. On top of that, active safety functions will become established that drastically reduce the probability of an accident.

Technological trends

In technology, there is a trend toward greater miniaturization and toward developing intelligent modules. Highly integrated mechatronic components are evolving that can be integrated into vehicles by way of a data interface. Sensors and actuators are becoming more intelligent and more and more capable of universal use, including for pre-processing and simple adjustment tasks. One example is "software-defined radio" (SDR). Semiconductor, memory and communications technologies are offering substantial increases in performance at declining prices. In software technology, an intermeshing of concepts from safety-critical embedded systems and Internet technology is becoming evident, especially in middleware.

Societal trends make it necessary to fundamentally rethink ICT architecture. The analysis showed that the necessary technologies will be available by no later than 2030. Highly integrated mechatronic components are reinforcing the trend toward X-by-wire architectures. Additionally, integration can take place at a higher logical level, through the introduction of middleware architectures and by encapsulating the above mechatronic modules. Components to merge sensor data will become important elements of middleware architectures, as will a component that ensures that safety-critical functions are separated from non-critical ones, so that they can be performed on a single computer without interfering with one another. This in turn will result in a centralization of computers in a car, similarly to server technology.

Comparison with other sectors

Architectures have changed fundamentally in other regions of technology as well. In the late 1970s, solutions in industrial controls and PCs proved that modular hardware and standard operating systems can make lasting changes in industries. Open standards encouraged innovations in hardware and software applications. Economies of scale in production, with the associated cost reductions in modular hardware, made PCs attractive to end users.

In the 1990s, a new architecture was introduced in aviation, because of problems very similar to those in the automotive sector today. "Integrated modular avionics" (IMA) showed that a new architecture can help reduce complexity and create a viable basis for the future. Important concepts like centralizing and virtualizing computer architecture, local data concentrators, and X by wire can be adopted and adapted to the needs of automotive construction.

Robotics may also be of interest for a reorientation of ICT architecture in the automotive industry. The logical architecture for controlling humanoid robots, with its division into environmental perception, planning and action, can particularly serve as a model for a logical architecture in the automotive industry. Important concepts from middleware architectures in robotics may also be of interest for the automotive sector.

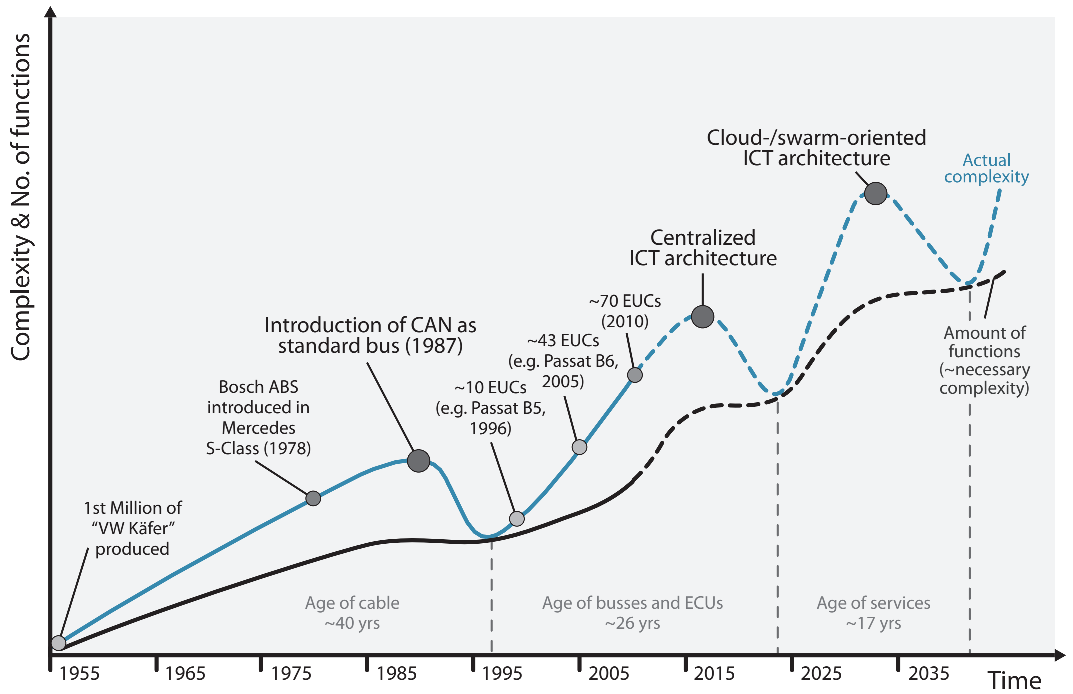
Scenarios for future architectures

In the evolutionary development of vehicle architectures, as *Figure 1* shows, there is an evident trend for the architecture actually to become much more complex than would really be necessary for the achieved gain in functionality. This results in the problem that new functions become more and more expensive to integrate, and the innovation trend therefore flags. Only a substantial revision of the architecture and a technology leap can bring the actual complexity back down to only the necessary level. In substance, the level of abstraction at which new functions are integrated must rise. For that purpose, part of the platform must be virtualized. The virtualized platform will become a standard component – a commodity – and the complexity and price of that platform will shrink.

This process has already been observed in the automotive industry in the past. To reduce emissions and improve comfort, in the 1980s it was necessary to use microcontrollers more widely. Complexity relatively quickly became a big problem, because it was almost impossible to cable all these electronics modules together. A solution came from communications busses like the CAN bus; they virtualized the physical connection – in this case, the cable. It thus became significantly easier to introduce new functions, because integration no longer had to take place at the cable level, but only at the information level.

Today's ICT architecture again faces similar problems, but in this case because of the large number of control devices. A new, centralized electric/electronics architecture, with a base middleware, analo-

Figure 1: Evolution of complexity



gous to the IMA in avionics, could reduce actual complexity. New functions would then be integrated not in the form of control devices, but as software. The third step, finally, would be a further virtualization of the necessary total system of hardware and software (the hardware/software stack) into a service-oriented architecture. The underlying execution platform, composed of control devices and busses, would be entirely virtualized by middleware. The middleware would also implement non-function features, such as error tolerance. Then it would be possible to distribute functions as desired, even outside the vehicle; the car would thus become part of a larger system.

As *Figure 2* shows, ICT architecture could thus develop in three steps. In a first step, which is already going on today, IT modules are integrated and encapsulated at a high level. In the second step, the ICT architecture could be reorganized with reference to all functions relevant to the vehicle. And finally, a middleware that integrates both the functions relevant to driving and the non-safety-critical functions for comfort and entertainment would make it possible to customize vehicles for their drivers by way of third-party software.

Based on these observations, the report identifies three different scenarios for how the automotive industry could manage the upcoming changes:

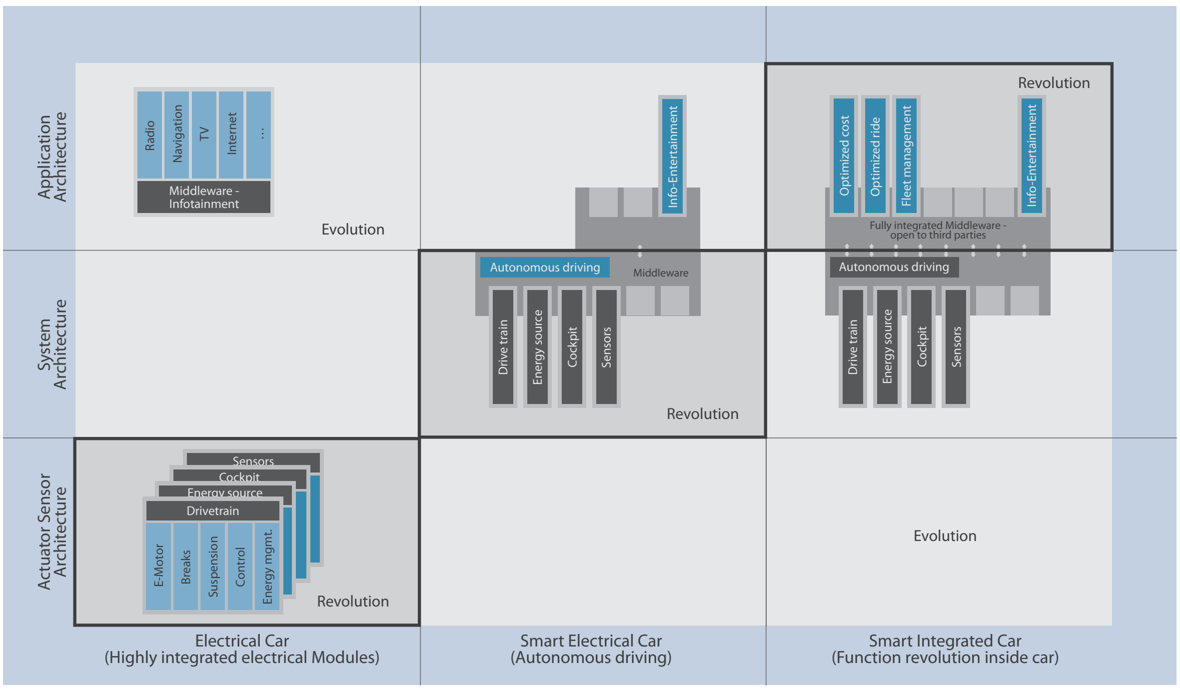
1. Low Function/Low Cost for 2020

This scenario is the most probable for new market participants focusing on low-cost vehicles. The vehicles' functionality and customers' expectations about comfort and reliability are relatively low. The scenario is well suited for introducing a revised, simplified ICT architecture that includes a drive-by-wire approach; actuator components are connected directly to the power electronics and the ICT. In that way, actuators can draw energy locally and be triggered via software protocols, reducing the amount of cabling and the number of control devices.

2. High Function/Low Cost for 2030

The considerations behind this scenario are based on a further development of the revolutionary approach to ICT architecture that was described in the "Low Function/Low Cost" scenario above.
ICT has been optimized over the years and is now very reliable, so that even customers with high expectations buy this kind of vehicle. This trend is

Figure 2: Evolution of ICT architecture



reinforced by the ability to integrate new functions easily into vehicles, and to customize them.

3. High Function/High Cost

This scenario addresses electric cars in 2020 whose architecture concept builds very largely on what is already known from conventional internal-combustion-engine vehicles. What is primarily electrified is the drive train; the existing ICT architecture is still used with no developmental advances. Higher-value functions with a substantial need for cooperation, such as energy management, can be achieved only at great expense, since there is little provision for interaction and coordination among vehicle components. Especially with regard to the adaptability and driving autonomy requirements expected for 2030, this scenario will prove to be a dead end, because the complexity of the system means that fundamentally new functions will hardly be integrable at reasonable expense.

4 | Change in the value chain to 2030

The largest direct changes in value chains will result from the introduction of a new ICT architecture and from the electrification of the drive train with the associated use of new key components like batteries, power electronics and electric engines.

The most obvious point is the electrification of the drive train. Here the core competences that auto makers have built up in all aspects of internal-combustion engines will rapidly lose value. Additional skills are needed, which in many cases only new suppliers entering the market can provide. Access to batteries and electric engines is crucial to the OEMs' success, but it will remain exceptional for them to take on this stage of the value chain themselves.

In vehicle ICT, the necessary standardization of control devices will lead to increasing competition among the makers of those devices. Addition of value in computer technology will shift from direct suppliers (tier 1) to ICT providers in tier 2. These will no longer supply individual components, but standardized control devices. There is an acute risk that this sub-function in the value chain will no longer be feasible within Germany, because there is intense competition from other countries, and currently there are only a few German tier 2 providers for the computer technology of a new ICT architecture. In mechatronic modules, a high level of integration of mechanics, sensors, and actuators can be expected. German suppliers are the world leaders in this field, and have a chance to expand their market shares. In software, uncoupling hardware specifics from one another will make it possible for the various application areas to interact at the software level. This opens up the leeway to design new, entirely software-based applications. At the same time, the market will open up to software providers outside the industry. To stand out from the competition, OEMs might once again develop more functions themselves. Thus the supplier industry will come under pressure from two directions here.

In quality assurance, the OEMs have strong skills. For that reason, this function can serve as a barrier to entry. New kinds of ICT systems will initially pose a challenge for quality assurance, but over the long term QA can be automated and optimized via ICT.

In addition to these direct influences on vehicle production, the introduction of a new ICT architecture will also entail important indirect changes. These will concern functions that will follow after the value chain in vehicle delivery, particularly including mobility services that can be offered to the end user in place of a personal vehicle. Here various business models are conceivable that range from simple car sharing to intermodal mobility services with an individually optimized mix of means of transportation. In this context, the OEMs will come into direct competition with established mobility providers (such as railways, rental cars) and new companies.

The after-sales segment in the vehicle business will also gain in importance, since the new ICT architecture will make many vehicle functions more easily upgradable or customizable. In the simplest case this can be done merely at the software level, through upgrades or apps. Since electric vehicles are less maintenance-intensive, this segment will be especially important in compensating for the income from maintenance work on internal-combustion vehicles, which will now be lost.

All in all it must be borne in mind that the existing market structure will come under pressure from the arrival of companies that have until now been strangers to the industry. In some cases this may even be the case as early as vehicle conception and design; it must increasingly be expected in the area of drive trains and ICT components, and as already described above, it will end with mobility services.

The German automotive industry is encouraged to build up the skills it lacks for the new market conditions, or to tap them through acquisitions or cooperative ventures, and to take advantage of the potential of the new ICT architecture, so as to avoid being overtaken by foreign competitors.

5 | Recommendations for action

By 2020 and beyond, Germany is expected to become a leading market and a leading provider of electromobility, and to secure a long-term competitive advantage for itself. This challenge has been described in a SWOT analysis (*Figure 3*). Here the aim is for the automotive industry and the energy industry – and thus Germany as a business location as a whole – to stand out from the international competition through intelligent networking via ICT. These goals call for concentrated, concerted action among government, business, and science.

Figure 4 provides an overview of the main recommendations for action that were developed on the basis of the scenarios, changes in the value networks, and interviews.

Figure 3: SWOT Analysis

STRENGTHS

- Government encourages innovation by reinforcing training, science & technology, through regulations & by founding NPE
- Creativity compensates for site disadvantages (high wages, no oil)
- Well-positioned, profitable industries (automotive, energy, chemicals)
- Strong clusters (metalworking, machine construction, optics, sensor engineering)
- Technological leadership in automotive construction, lightweight metal construction, e-engines, vehicle electronics, sensor engineering, mechatronics, embedded systems, car-to-X, renewable energy sources
- Very high systems competence
- Demanding customers

WEAKNESSES

- Underestimation of relevance of ICT
- Unsatisfactory cooperation between automotive, energy and ICT industries
- Lack of criteria, priorities, organizational structures
- Resources squandered in uncoordinated activities
- Lack of transparency – inadequate knowledge management
- Hesitation and loss of time (“paralysis through analysis”)
- Satiation and inertia due to high level of prosperity
- NPE: organized by industry, dominated by powerful associations; “small” players missing; no task force for ICT; customer’s perspective missing

OPPORTUNITIES

- Need for mobility in mature industrialized nations and developing countries, especially BRIC (Brazil, Russia, India, China)
- Urbanization, mega-cities
- Mitigate adverse side effects of driving (oil consumption, CO_2 emissions, accidents, slow-moving traffic jams). Reduction of traffic jams; greater traffic safety
- Convergence of automotive and ICT industry encourages economic development
- ICT encourages innovation and growth, reduces complexity and costs. New architecture expands functionality
- Sustainable mobility: easy on environment and resources, reliable, with new applications, economical

RISKS

- Aggressive programs in multiple countries (USA, PRC, Japan, etc.)
- Others are faster in developing e-cars and mobility Internet
- German car industry fixated on premium segment
- Underestimation/ignorance of disruptive innovations; new market participants might carry out “Low Cost/High Functionality” scenario
- Electromobility not viewed as a whole, but as individual technologies
- Lack of understanding of customer desires
- ICT drives up costs if old architecture is developed further
- Weakening of automotive industry in international comparison would adversely impact overall productivity and standard of living in Germany.

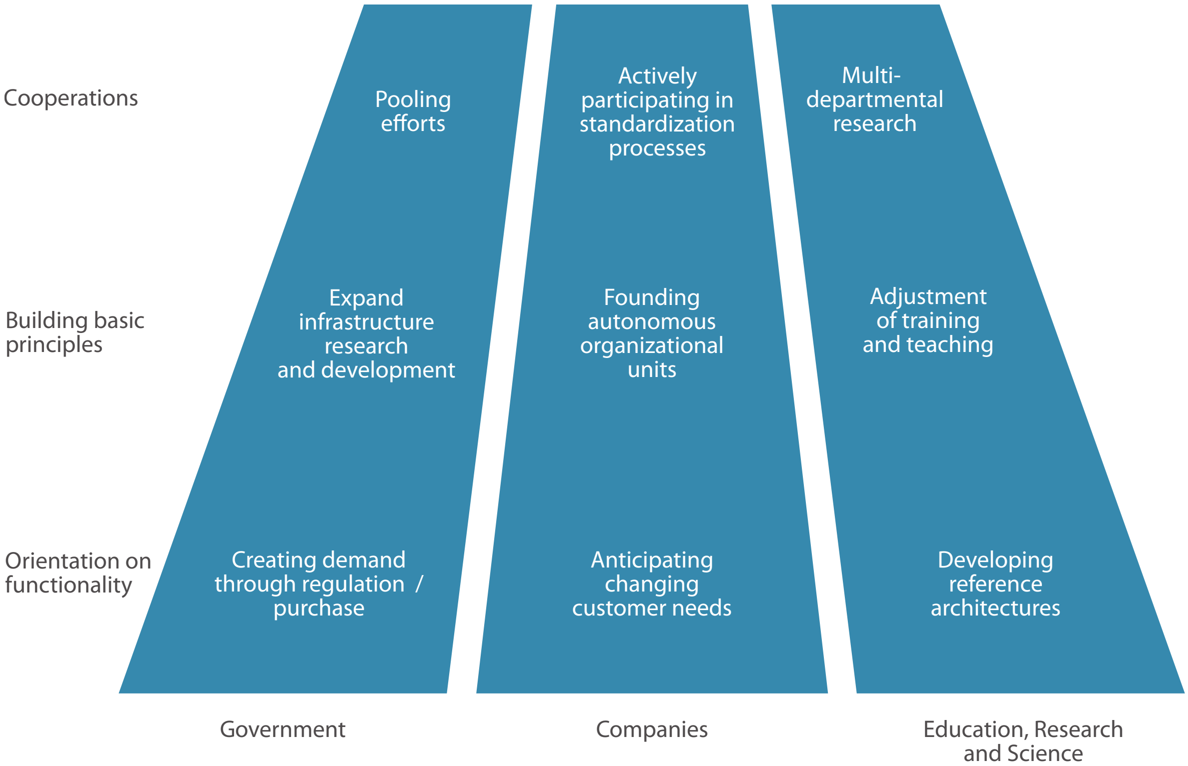


Figure 4: Overview of main recommendations for action

Recommendations to government

Government can accelerate the change toward a viable future ICT architecture through regulation, public purchasing policy, a pooling of all efforts, and an expansion of infrastructure.

Creating demand

Government can stimulate demand through regulation, but also set a good example by converting public fleets. To achieve the above goals, the government should generate a maximum demand for functionality through astute regulation. In this way it might stimulate industry, suppliers and demand, all at the same time, so as to initiate a change in ICT architecture and raise the barriers to entry. Additionally, federal, state and local governments should provide opportunities to experience electric cars first-hand, and ensure that the public is aware of them. One possibility would be to convert government fleets to electromobility: for example, Germany has more than 120,000 municipal delivery and service vehicles.

Expand infrastructure research and development

An especially important and urgent need is political initiatives, investment and legislative action regarding the infrastructures and standards needed for mature electromobility. Here, research in ICT for electromobility must especially be promoted. In addition to the feasibility of ICT for a future "smart car," the focus should especially be on networking with the energy industry (smart grid), and traffic infrastructure (smart traffic). Here ICT will play a key role as the multi-system driver for the interaction between smart cars, smart grid and smart traffic.

Pooling efforts

Not until all efforts in government and business have been pooled – for example by promoting cooperative ventures or by companies' participating in standardization processes – will Germany be able to unfold its full potential in regard to the above changes. Most partners interviewed in the project recommend setting up a special organizational unit for the next decade to coordinate or guide all initiatives in connection with electromobility. One of its key competences will be the opportunity for all industries and all social groups to collaborate.

Recommendations to companies

Companies must steadily enhance their competitiveness through continuous improvement, innovation and change. Of course, competitiveness often presupposes painful change, and sometimes even "creative destruction."

Anticipating changing customer needs

Companies should be especially concerned with the needs of customers who do not own a car yet, or who are oversupplied. In electric vehicles, German industry is concentrating especially heavily on high-cost market segments, such as sports cars. But many experts believe the low-cost segment is better suited for gathering initial experiences with electromobility. Market watchers encourage makers of premium vehicles first to develop and sell inexpensive vehicles through autonomous companies, so as not to affect their traditional brand image. But anticipating changing customer needs also means considering not just the vehicle alone, but innovative business models.

Founding autonomous organizational units

An autonomous organization whose resources, processes and values are focused entirely on electromobility, and whose cost structure makes a profitable business possible, is the right answer to the disruptive challenge. In such an organization, the best employees could concentrate on electric cars, instead of constantly being diverted from their work on conventional technology that is still accepted in the market. Though companies should start small in such spin-offs to develop electromobility, they should not by any means hesitate. This is especially important because many advantages of electromobility can be realized only with a significantly altered ICT architecture, which is unlikely to be possible in established companies.

Actively participating in standardization processes

Standardization is undoubtedly becoming more and more important for market success. Here European companies' role specifically in ICT will be watched closely and critically by experts who have noted a withdrawal of European companies from standardization bodies. They fear that that future standards will be set mainly in America and Asia. For that reason, German companies should participate more extensively again in standardizing processes, and thus ensure that they can offer products that meet standards at an early stage.

Recommendations to education, research and science

Education, research and science are encouraged to provide methods, technologies and skilled workers to develop electromobility. Research results must be processed for transfer to industrial applications, and companies must be helped to achieve their goals within the terms set by the government.

Building up reference architecture

To promote cooperation between research and industry and to transfer the state of the art in electromobility to companies, development of reference architectures should be encouraged. Here a close interaction should be sought with the federal government's research and development activities to build up ICT infrastructures. The development of reference architectures should especially focus on autonomous driving, X-by-wire steering, openness and expandability, as well as integration of the vehicle into the environment. So that the low-price segment can be served as well, components that will be inexpensively available by 2030 should be used to build up the new architectures.

Adjustment of training and teaching

University-level institutions must focus their pertinent courses of study more extensively on electromobility, bearing in mind that demands upon engineers will rise because they will have to deal with much more complex systems in the future. Disciplines like electrical engineering, computer engineering, and microsystems technology must evolve further, especially in regard to interdisciplinary fields like mechatronics. The possibility of establishing new, multi-departmental courses of study should be considered.

Multi-departmental research

Many of the relevant research topics are on interdisciplinary issues that can be resolved only with a multi-departmental approach. That includes new fields like cyber-physical systems and mobility Internet, but also established areas like sensor engineering, embedded systems, functional safety and data security, as well as cognitive systems and architectures.

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