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> AGENDA CYBER PHYSICAL SYSTEMS

OUTLINES OF A NEW RESEARCH DOMAIN

INTERMEDIARY RESULTS | 7TH DEC 2010

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MANAGEMENT SUMMARY

The rapid development of information technology (in terms of processing power, embedded systems, comprehensive IT management systems, networking and Internet growth) is producing more and more applications and opening new doors. Software-intensive systems and devices have become everyday consumables. Thanks to their multifaceted support for networking and inclusion of data and services from global networks, they are evolving to form integrated, overarching solutions that are increasingly penetrating all areas of life. The results are open, networked cyber-physical systems (CPS) that create system environments and socio-technological systems with revolutionary applications. This is driving a rapid change in the economy and society, with cross-domain value added networks and economic ecosystems. The result is a sustainable flow of innovations which requires targeted political, commercial, technological and methodological efforts. A complex combination of questions and challenges relating to the demand-driven design and usability of CPS and their applications must be tackled.

Europe – and Germany in particular – are global market leaders in major areas relating to CPS, such as embedded systems and mobile communication networks. This position can only be retained if Europe also lives up to its claim to be a leader in innovation in CPS, expands its market leadership in embedded systems and exploits the potential of information technology. The declared objective of the agendaCPS project is to establish an integrated research agenda and develop a catalogue of measures that will show the necessity not only of participating in this revolution, but also of making a tangible contribution towards shaping it in global competition with other industrial and technological players.

This document defines the rapidly growing research field of CPS. It provides a brief introduction to CPS, describing the capabilities and the many opportunities for application and new business models. The opportunities and challenges for technology, society and the economy associated with the profound change are analysed on the basis of an investigation into the characteristic features and capabilities of CPS. Overcoming these challenges is the aim of the as yet undefined CPS research agenda. This document thus contains an initial identification of the major areas in which action is required to support future research.

CONTENTS

1 MOTIVATIONS FOR AN INTEGRATED RESEARCH AGENDA FOR CYBER-PHYSICAL SYSTEMS

In line with Moore's Law, ongoing advances in very large scale digital circuits integration are producing electronic components that are ever smaller, more powerful and cheaper. As a result, devices and objects can increasingly be equipped with "invisible" embedded systems that are connected directly to the physical world through a range of sensors and actuators, and that, consequently, can be deployed in a broad range of applications in ways allowing them to be controlled, monitored and networked. Global networks, such as the Internet connect computers, their data, their services and their applications. At the same time, devices and objects are linked together through software-intensive systems and networks. The physical world merges seamlessly with cyberspace – the virtual world. Countless devices provide access to this virtual environment through their human-machine interfaces. New solutions and services are formed "in the cloud". The results are cyber-physical systems that offer revolutionary applications and benefits. The innovations that can be attained and realised in such systems and their impact extend well beyond anything we can currently imagine.

Attractive new opportunities and applications are quickly being adopted by a wide spectrum of users, despite attempts at fear mongering and raising resistance within society based on horror stories of an Orwellian world. The solutions that are produced by the high speed of innovation are never good enough or sufficiently comprehensive in their first iteration, due to their complexity and degree of innovation, and as a result demand evolutionary improvements. These open up new opportunities and consequently lead to yet more innovative solutions. Innovation enters a rapid spiral process. Associated with this development are not only rapidly changing habits and demands on users, but also new, disruptive business models and growing ecosystems within the economy. The full extent of the innovations can only be totally exploited by implementing targeted measures.

With its expertise and edge in the field of mechanical engineering and market leadership in embedded systems, Europe and Germany in particular have the opportunity to become one of the leaders in innovation in cyber-physical systems – as long as they are able to exploit the potential of information technology. However, due to the high speed of innovation, this demands fast and targeted action. The objective of the Agenda CPS project is to establish an integrated research agenda for cyber-physical systems, to allow us not only to participate in this revolution, but to make a tangible contribution towards shaping it, in competition with other industrial and technological players.

2 REVOLUTION – THE POTENTIAL OF CPS FOR DISRUPTIVE CHANGES TO INDUSTRIAL STRUCTURES

The development and feasibility of the technical basis for CPS can largely be forecast. Uncertainties relating to the economic feasibility and acceptance of CPS, however, do not allow secure forecasts to be made in relation to the emerging markets, their volumes and growth rates. Established companies will only capture these new markets with caution. There is great potential for the markets to be subjected to disruptive change. This will favour companies that use technological development to recognise new, initially small but fast-growing business opportunities, to develop and expand new markets, and to penetrate existing traditional neighbouring markets. As a result, industrial structures will change permanently. A well-known example of this pattern can be found in the technical progression from mechanical typewriters to ubiquitous PCs, and in the technical development from landline telephones to mobile telephones and ultimately to the world of smartphones that we cannot even imagine not existing today. The changes to industrial structures that accompanied these developments have been dramatic, like the decline of midrange computer systems and the decline of telephone manufacturing companies.

CPS will trigger similar fundamental upheaval in industrial structures through the blending of embedded system technologies and Internet/web technology, thus its specific shape cannot yet be foreseen. The effects on European business and on Europe as a business location may endanger the competitive position of European industrial companies as well as the continent's leadership in international innovation. On the other hand, there will be opportunities to exploit the disruptive potential to expand market leadership in new CPS application fields, and to prevent others from domination.

The technological foundations for CPS are being developed around the world using different concepts. Many countries have already started to determine the fields of application in which the expected benefits will outweigh the expected losses, which new solutions will be accepted under which conditions and where corresponding new markets will be created. The global revolution has long since started.

At first glance, the transition from "classic" embedded systems to CPS does not seem to represent a major leap. The increasing integration of two basic and largely established information and communications technologies – namely 1. the regulation of (especially technical) processes using embedded software-intensive systems (ESIS) and 2. the extensive global networks of these software-intensive systems – might lead to an initial assumption that CPS simply represent an evolutionary step. However, this technical evolution has the potential to trigger disruptive developments in numerous application domains, as already seen in some deployment scenarios today (such as fleet management in the air freight sector, from remote diagnosis to resource planning and scheduling).

In particular, the demand for CPS within the investment goods industry is a dual one and should not be underestimated. First, the manufacturing process for products can be made more efficient by using CPS. Second, the CPS that are actually integrated into the products themselves represent important drivers for innovation and a technical foundation for the creation of significant unique selling points.

A vertical integration of embedded systems with commercial application software opens up the door to completely new business models and has significant potential for optimisation, in areas such as logistics, discrete production of goods or in process industries. Many sectors in Europe are currently seeking out solutions that will allow them to thrive in global competition while maintaining production in a high-wage region. The most important objective is frequently even greater automation and monitoring, in order to control the business and entire value added networks in near to real time. CPS are finding broad scope for deployment here.

The as yet untapped potential of CPS will pose new technological, methodological, legal, economic and social challenges:

- **Methodological** challenges, due to different lifecycles of the systems and requirements for clear interfaces and configuration options. The technical development of products (solutions and services) will increasingly demand a methodology that not only integrates the new application opportunities but that is also specifically oriented towards the requirements of the processes that are to be optimised (e.g. the optimisation of the logistics chains, energy management, mobility concepts). The companies that will succeed will be those that can provide the best possible process support and develop solutions that people actually need.
- **Economic** challenges, such as overcoming traditional system limitations (moving from a device to a business process) and the creation of new associated ownership and business models.
- **Legal** challenges, such as cross-system processes and the associated security and safety issues (which can no longer be addressed locally, as it is done in current certification processes) and the resulting liability issues.
- **Technological** challenges, such as the more complex rule sets for regulating and controlling increasingly autonomous workflows that must include significantly more optimisation criteria than ever before.
- **Social** challenges, such as the growing acceptance of increasing opportunities for being supported by IT services in various processes, but also the way in which we perceive our environment and how we react to it. CPS have the potential to add a new dimension to applications that far exceeds what is offered by the existing Internet. The trend for ever-more differentiated human-machine interaction will also change our perceptions, from extensive in-car aids and assistance functions to tools at the workplace and the way in which we use media.

On the technical side, the wide distribution of software-based process control systems and the existing level of networking and communication mean that there is broad scope for CPS to be used in the affected application domains. The integration of these two capabilities is a catalyst that will ignite demand. This would indicate a fast and extensive change, which will be of great importance, especially for Europe as a centre for high technology.

If a successful contribution is to be made in shaping this change, the revolutionary potential of CPS must be recognised and incorporated into internal development processes at an early stage.

3 ABOUT THE TERM "CYBER-PHYSICAL SYSTEMS"

The term **cyber-physical systems** (CPS) is used to describe software-intensive embedded systems that are connected to services available around the world through global networks such as the Internet, and their diverse potential for development and utilisation.

Driven by increasing computing power and the continuing penetration of digital solutions into everyday processes in work and life, over the past few years research activities have expanded in the wide-ranging, interdisciplinary field of networking the digital and physical worlds, with the associated scientific, technical and economic challenges. The initial work referred to under the umbrella of CPS, and also triggered by varied scientific and socio-economic objectives, aims to integrate mechanical, control-system and digital aspects and the subsequent applications. Moreover, it is concerned with the potential of this networking (the "Internet of things" concept) and the resulting revolution in the economy and in society.

Researchers in Europe were not only quick to realise the importance of sharing their work in the field of software-intensive systems [ITEA2]. They also clearly appreciated the core role of embedded systems for the development of innovative applications, and implemented this understanding in the long-term research initiative/platform [ARTEMIS]. In the USA, the National Agenda Cyber-Physical Systems [NSF 2006] was launched on the basis of domestic initiatives, but also with a clear reference to activities in Europe. It deals explicitly with issues surrounding the evolution of such systems and the associated necessary capabilities, albeit with a stronger emphasis on questions relating to the integration of the physical and digital worlds in the context of highly sensitive embedded systems. In the USA, the networking of embedded systems through global networks and their services and data has initially been much less in focus. Characterised by the different research environments and the different fields of interest, the paths leading to an internationally consolidated definition of CPS are converging only slowly.

The Agenda CPS project therefore hopes to introduce an initial definition of CPS within Europe, as a core contribution to the international CPS research debate and as a basis for further research work.

Cyber-physical systems typically comprise embedded systems (as parts of devices, buildings, vehicles, routes, production plants, logistics and management processes etc.) that

- use sensors and actuators to gather physical data directly and to directly affect physical processes
- are connected to digital networks (wireless, wired, local, global)
- use globally available data and services
- possess a range of multi-modal human-machine interfaces (dedicated interfaces in devices, or unspecific interfaces accessed through browsers, etc.).

Due to their technical features and options, CPS can be

- largely independent of location
- but context-specific at the same time,
- adaptive
- autonomous and automated
- multifunctional
- networked, and provide distributed functions and services.

Resulting from these capabilities are a full range of profound and far-ranging opportunities to provide solutions and applications for our everyday lives.

CPS cover the following areas of technology:

- Embedded software-intensive systems (ESIS): Electronic devices and technical systems used in mechanical engineering, in which software is integrated through embedded electronics (for control and regulation purposes) so that the devices and systems are connected directly to their environment through sensors and actuators and so that they demonstrate adapted functionality and improved usability on the basis of dedicated user interfaces (for example: comfort and safety features in modern automobiles, including the e-car concept).
- Networked software-intensive systems, or Systems of Systems (SoSs): The targeted networking of individual ESIS in order to perform comprehensive coordinating and regulating activities and to generate additional functionality (for example: car-to-car communications, traffic flow control, modern aircraft, etc.).
- Integration of ESIS/SoSs to form comprehensive, non-domain-specific application systems (for example: fleet management and remote diagnosis/maintenance, Ambient Assisted Living).
- Open, flexibly networked cyber-physical systems and application environments: Integrated CPS are created from the alternating, application-driven integration of classic technical systems (ESIS/SoSs), operational information systems and web-based systems and services. Thanks to their open, fluid system boundaries, these face the challenges of situation-specific evaluation and the integration of potentially incorrect contextual data (for example: smart mobility and smart grid solutions).
- Interactions and flexible integration of CPS: The reciprocal use of data and services by CPS (for example: the interaction between smart grid systems and building management or traffic management in electromobility systems).

In the technological field of embedded software-intensive systems, there are already comprehensive technological and methodological challenges to overcome, without the resolution of which far-reaching CPS are inconceivable.

Complex technical and scientific questions also raise the issue of mastering the heterogeneity of CPS in the following context:

- The interplay between continuous processes and transactions, via sensors and actuators in control systems, and the discrete event-based systems of IT and their software applications for the purpose of coordination and control. This coordination and control is usually implemented through the several layers of abstraction of the system and application architecture of the CPS, from communication between CPUs or processor cores through communication between networked systems (ESIS, SoSs, IT/web services) to coordination and communication in alternating CPS applications.
- The interplay between intrinsically closed, comprehensively plannable embedded systems and the open interfaces, services and data in public networks with their associated restricted guarantees in terms of availability and accuracy.

The open nature of these systems allows them to be used commercially in many different ways in corporate networks and in other forms of cooperation (both public and private) with complementary business models. The combination of fast technical progress, freely available infrastructure and usable platforms, access to new application domains and innovative business concepts is creating powerful and extremely volatile market opportunities.

4 CPS APPLICATION SCENARIOS: MOBILITY, HEALTH CARE AND GRID ENERGY

A wide variety of application domains for CPS exits (cf. [NRMES] or [Broy 2010]). While first CPS (e.g. Toll Collect) – often with still restricted functionality – are already in use, others are still being planned or are yet to be defined. In the following sections three future application scenarios – mobility, health and climate/energy – are used to describe the key aspects of CPS, such as deployment, value added and associated capabilities. The mobility and health scenarios are written from an end user perspective, while the climate/energy scenario outlines the functionality and the requirements of a smart grid.

The selected scenarios are meant to illustrate on one side the potential of CPS to solve the upcoming European economic and social challenges – such as the shape of a future energy system, environmentally friendly transport systems using electric vehicles, or even integrated health care systems. On the other side the scenarios shall point out that a deep understanding of their design, the inner workings and the application of CPS are of crucial importance for their realisation.

4.1 CPS application domain – Smart mobility

The integrated management of traffic and assistance for individual travel is a typical application for cyber-physical systems. Besides the use of smartphones as individual mobile end-user devices, current innovations in the field of smart mobility focus heavily on the automotive sector and are largely based on the introduction of traditional IT system components. In order to finally realise the smart mobility scenario in the car, a wide range of dependencies must be taken into account, of which not all have been completely understood and therefore cannot be fully mastered yet. Today's luxury cars have more than 70 embedded control units (ECUs) installed in them. Reducing the number and complexity of these control units, centralising functionality and consolidating hardware is there a major topic for developing, centralised future-proof, reliable and energy-efficient central vehicular IT architectures.

Scenario: Smart mobility

Sabine Müller is a businesswoman who lives with her husband and two sons in a small town not far from Munich airport. Her position as divisional manager at a large, international technology provider means that she often has to travel on business. At the same time, she does not want to forego the quality of life offered by her rural surroundings at home. A good work-life balance is as important to her as living a sustainable lifestyle that cherishes the environment. For this reason, Sabine is open to mobility concepts that save energy and time. For the past year she has participated in a car-sharing project operated by the City of Munich, which allows the municipalities surrounding the city to be integrated into the central transport network.

Sabine has a home office and can also use her smartphone to connect to all the information and service portals she needs to plan her journeys, both through the corporate intranet and through the Internet. Her travel bookings are made by a travel service and automatically updated in the systems that she uses, so that she can access all the information she needs about hotels, flight schedules and planned meetings. This means she still has time to share breakfast with her husband and her eldest son, Jan, whom she wants to drop off at school on her way to the airport. While she is having breakfast, her smartphone shows her the latest traffic reports and provides a weather forecast for her route. It tells her the best time to start her journey, where she can find the closest CarMobil (car-sharing) vehicle, and the best route to take based on the traffic expected for the time at which she is travelling.

Sabine and her son start their journey on time. When she uses her smartphone to open the door of the car-sharing vehicle, the car's onboard navigation system is enabled automatically with her destination and the fastest route (calculated by the server-based personal organiser, for example). During the journey, she and Jan chat in depth about a birthday party he attended for one of his school friends. The car's onboard computer switches the navigation system to silent mode, so that the navigation system's audio commands do not disturb their conversation. At the same time, the vehicle's systems, which are connected to a back-end infrastructure and other traffic users, provide Sabine with a high degree of driving aids. As she passes a bus stop, where the speed limit reduces to 30 kph, the vehicle automatically reduces its own speed. If a pedestrian were to step out from between the buses, the vehicle's own environment sensors would detect this and the car would break sharply, warning the vehicle's occupants and securing them by actions such as tightening the seat belt, to prevent an accident. Communication between Sabine's car and the other vehicles on the road would allow any following vehicles to react appropriately and in time to any such sudden braking manoeuvre.

Once she has dropped Jan off at school, Sabine drives to the car-sharing company's dedicated parking spaces at the urban rail station. When she checks her smartphone it tells her that her flight is delayed. As there are now still two hours before her new departure time, she goes into a nearby café to have a small snack. She opens her laptop, while her calendar automatically tells her colleagues and the people she is due to meet that her flight has been delayed. The smartphone shows her what time the next train is due to leave, and she arrives at the air terminal punctually for the new boarding time. The delayed arrival means that a colleague is not able to pick her up at the airport as planned, however. Her server-based personal organiser automatically makes a booking for a rental car, based on Sabine's preferences. As a frequent flyer, Sabine has free access to the rental car app, but it is also installed on all mobile telephones that her company provides to its employees for work. The airport's service portal is used to retrieve and list the information about the car rental firms, and, out of curiosity, Sabine decides to try out an electric car made by her preferred manufacturer. Her smartphone indicates the route to where the rental car is parked. From the about 35 or so otherwise identical electric cars, she chooses the blue one, and activates it using her smartphone. Once she is in the car, her digital assistant reports that her meeting can be postponed to later that afternoon. Sabine decides to briefly go to her hotel first. While she is on the telephone, the electric car drives itself out of the parking space, and through the barriers which open automatically, stopping in a small parking bay on the other side.

Sabine sends the address of the hotel from her smartphone to the car's onboard navigation system, enabling the vehicle's autonomous driving function. The car drives itself through the city traffic, stopping first at the hotel and then taking her to her business appointment, which starts on time.

In this scenario, different devices must communicate automatically with each other, and exchange situation-specific information or data. This produces an environment that is known as context-aware computing[1]. The required networ-

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[1] Cf. the Research Focus "Distributed Real-Time Situation Gathering and Solution Building" in [NRMES]

king and connectivity of the devices used in the scenario and of the vehicle are already for the greater part provided by existing standards and mobile telecommunications networks.

The data generated in the vehicle and additional data of the individual user and the environment (weather, traffic, news, etc.) must also be served by a cloud infrastructure that pushes this data into the vehicle and the devices. On the other hand, they can also pull the data on request, so that communications with the vehicle/devices are conducted in push-pull mode. The same applies to pay-services (cash-free payments) for which charging and billing systems and new business models have to be developed. This remains a major challenge.

The technology of the future to realise such in-vehicle applications is a virtualised multicore architecture, which is already in use in traditional business IT environments. This architecture manages the available system resources for each application, making each resource available according to the situation at hand. The introduction of such technologies will allow several virtual control units to be hosted on a central system. In fact, however, no virtualisation solution has been found to date that can fulfill the specific automotive requirements (in terms of certification).

In this context, the centralisation of functions and consolidation of hardware is a key aspect for all areas of the vehicle, including comfort, drive train, chassis and infotainment. The validation of virtualisation technologies on multicore architectures is an important step on the way to future vehicular IT architecture that will form the core element of the future smart mobility concepts.

4.2 CPS application domain – Smart health

A more direct support of human life processes based on close multimodal human-machine interaction, is illustrated by the following CPS application scenario taken from the field of telemedicine. In this field, CPS or components are implanted in the human body, directly monitoring and supporting some of the patient's key vital functions.

Scenario: Smart health

Peter Müller is retired and lives with his wife in a small cottage in the countryside. A few years ago he was diagnosed with bradycardia, a heart condition that needs long-term care and that has required Peter to adopt a number of lifestyle changes. Health applications that are supported by cyber-physical systems still allow him to lead an active and independent life with a minimum of restrictions, while continuing to benefit from the best medical care.

Implanted in his body, Peter has a miniature medical device that acts both as a pacemaker and an ECG. Tiny sensors in his clothing record his physical activity (to verify the measured heartbeat and vital parameters against his physical actions), while the body-analysis scales he uses every day in his bathroom "know" his bodyweight and other physiological data. All of these devices are connected to a telemedicine centre (TMC), where they store the data they have gathered in an electronic health record that can be accessed only by Peter Müller and his doctors.

One weekend, Peter and his wife decide to visit their children and grandchildren by train. While they are on the train, Peter suffers an abnormal heartbeat, although he is not doing any physical activity. The ECG device implanted in his body detects this abnormal heartbeat, or arrhythmia, and sends the information to the TMC using the communication infrastructure present in the train. At the same time, the integrated pacemaker undertakes the initial corrective measures, which are also recorded and forwarded to the TMC. As these measures successfully correct Peter's heartbeat, and communication with the TMC succeeded despite the movement of the train, the system did not need to issue any particular warning indication. The Müllers can continue their journey unhindered.

At the TMC, the incoming data is analysed and correlated against the information obtained from daily bodyweight measurements and the patient's physical activity. Peter's slightly increased bodyweight over the past few weeks and reduced level of physical activity have already been detected by the system, and Peter has been recommended to change his fitness programme accordingly. This bout of arrhythmia is a further trigger for sending this information to Peter's doctor.

After viewing the electronic patient health record and taking account of the medical history that it contains, the doctor decides to adjust Peter's medication and advises him to undergo a more in-depth examination. While still on the train, Peter receives this information, makes an appointment at a hospital near to his children's home and authorises the doctors there to consult his electronic patient health record. At the same time, he receives a list of local pharmacies that have his medication in stock.

The closely interconnected medical devices, service providers and the patient in this scenario create a virtual place for the doctor-patient relationship; competent treatment can be provided at any location, while a great deal of data that is key to monitoring and treating the patient's health can, in principle, be provided back to doctors at any time. Analysis stations such as the TMC described above use the current measurements and the patient's electronic health record to trigger timely alarms for the patient, nursing staff and doctors, even if the patient himself is unaware of any change in his health. At the same time, they allow the treating doctors to access the patient's complete medical history in order to make their diagnosis and determine a course of treatment.

4.3 CPS application domain – Smart grid

Electric power supply is another promising application domain for CPS. As integrated building blocks of the envisaged smart power grid they have the potential to enable a distributed, demand-oriented, economically and ecologically sound energy generation, supply and storage.

Beginning in the late 1990s, the energy sector in Europe has undergone significant changes. The first step was the deregulation and liberalisation of the national energy markets thereby braking up the state-owned monopolies and the in large parts centralised and rather static production structures. As an independent development, wide acceptance was gained that in order to prevent the worse scenarios of environmental changes as a result of CO2-driven global warming decisive efforts have to be taken to reduce CO2 output and to increase energy efficiency. The enormous price increases for resources on the global commodity markets represents an additional driver for the latter.

As a result, the largely intensified integration of renewable energy sources as well as the handling of decentralised energy generation has become important requirements, which today's energy systems have to face. Renewable energy sources to be integrated mainly comprise wind and solar energy. However, both are non-dispatchable as they mainly depend on the current weather situation. The latter requirement refers to smaller energy providers and down to single households that may neither have the expertise nor the resources to guarantee the same level of service as larger energy-generating companies are able to. Consequently, both developments add a high degree of unpredictability and uncontrollability to the formerly rather stable and predictable production side of the system and make matching energy supply and demand a much more complex and, to a certain extent, inefficient undertaking.

Smart power grids address these new challenges as they represent a concept for the integration of all involved parties and assets into a single system. The "classical" power grid – the generators, transformers, power lines, etc. – is amended by a monitoring and control network, which allows for a holistic management and optimisation of the overall system by keeping track of the individual electricity flows in the system and providing a unified view on the system. Currently, smart meters are the most prominent components that are part of this monitoring and control network. The smart power grid concept however goes much beyond an advanced metering infrastructure. It especially comprises intelligent and adaptive functions in the generation, transmission and distribution systems that take care of the efficient integration of renewable electricity sources by decentralised planning and forecasting – or that generally react or even take proactive measures in order to handle changing supply and demand situations. Thereby a much higher level of efficiency of satisfying the energy demand as well as of resilience against unforeseen disruptions becomes possible.

Additionally, resulting from the exact knowledge about the current situation in the power grid in combination with the enhanced communication capabilities, price adaptations can be used to level out peaks in demand or supply and give consumers an incentive to behave more economically. In greater detail, the monitoring and control network of a smart grid with CPS as integral parts provides four major functions:

- Supply side management

  Supply side management comprises all measures to achieve an efficient energy generation based on own and acquired (e.g. weather forecasts, requests/indications from the demand side) predictions and monitoring data, to dynamically adapt the supply to the current demand, to react to critical disruptions in order to protect the power grid in parts or as a whole from permanent damage and to automatically recover from blackouts if emergency shutdowns were necessary or catastrophes occurred. In all these cases, CPS will play an important role to implement these functionalities. Another application example for CPS is an approach to alleviate the predictability problem of non-dispatchable renewable energy sources by the formation of virtual power plants. By connecting a larger number of smaller power generators (e.g. solar panels on an house roof) or power plants of differing capacity and predictability by means of the smart grid's communication infrastructure and defining a managing entity that decides about the output of the constituent generators/plants. According to statistical principles this procedure leads to a predictability of the virtual power plant that is higher than that of the individual ones.

- Demand side management

  Demand side management addresses power consumption and tries to influence the consumer to behave in such a way that electric energy is economically and sustainably used (by consumption/cost transparency) and that deviations from the anticipated demand that is already reflected in the production plans are minimised or peak shaving and load shifting can be achieved such that supply side countermeasures can be avoided. The latter can take place indirectly by incentives (e.g. cheaper night tariff) to behave differently or directly by the customers' relinquishing control of their energy consumption pattern to the smart grid. In the latter case, the customer is compensated by monetary bonuses, for instance. Such procedures are obviously not novel and can already be found in practice but with the new means that the smart power grid provides, they can be employed on a much broader scale and much more dynamically and flexibly. Again, CPS will play an important role in such scenarios since these procedures will have to take place in an automated, rather ambient fashion based on the respective customer's preferences.

- Transmission and distribution network management
  The transmission and distribution networks play an important role in smart power grid scenarios since the generation of renewable energy will mostly not take place close to where the energy will then be consumed. The building of new power lines is therefore a prerequisite and an efficient utilisation of these networks will increase the overall robustness of the system. Especially, the larger the smart power grid becomes, the larger the balancing power will be and the less demand deviations will pose a problem. Cyber-physical systems will serve as important building blocks by monitoring power flows, detecting potential problems, reacting to disruptions by selecting alternative routes or by interacting with the other described functions in order to achieve a high level of energy supply quality.

- Storage Management
  Although energy storage is currently rather costly and of restricted capacity, it may proof to be the game changer for the integration of renewable energy sources into a power grid as it will allow to decouple production and consumption. Then, also truly decentralised energy systems, in which everyone can become an energy provider and actor at an energy exchange, can be realised. A new ecosystem can be conceived that features CPS that trade energy, negotiate transmission and decide about whether to buy, store or to sell electrical energy. Electric energy will become a commodity as any other good.

As was already mentioned, smart power grids and the constituent CPS, respectively, will have to interoperate with other systems and the services these latter provide, in order to fully realise the functions and with them their potential. Here, cloud computing infrastructures both as providers for processing power and data access (c.f. multi-core architectures, in-memory technology) and access to specialised applications (e.g. weather forecasting with very detailed granularity for planning purposes) will play an important role. One important reason for this is that there will not be a single organisation that controls the entire power grid, but there will be a plethora of companies, organisations and also private actors ("everyone can become an energy provider") that will interact in this smart grid ecosystem and that need access to information and services that are relevant for their specific role in the grid.

Additionally market entrance for start-up companies with new, innovative business models and service offerings should be enabled. Besides, privacy and security have to be guaranteed and the system has to be protected against cyber-attacks that may threaten its operation and integrity.

The three draft scenarios described in the previous sections provide a clear illustration of the diverse and far-reaching innovative functions, services, potentials and applications of CPS. Their technical capabilities and properties allow not only the location-independent, distributed and effective communication and coordination of IT applications and systems (data, services and things), but also the provision of context-specific interpretation, processing and appropriate reactions according to the situation, and of information for people, therefore enabling processes, devices and systems to be controlled in an integrated and interactive way. Associated with the capability to provide varied services and functions comprehensively is the far-reaching and in-depth support for but also changes to working and application processes throughout nearly all aspects of life.

5 CYBER-PHYSICAL SYSTEMS – CAPABILITIES

Potential benefits of CPS range from the provision of globally usable applications and functions to frame and control industrial and administrative business processes, from mobility and health applications to usage scenarios in nearly all areas of public and private life, as well as systems for sustainable energy supply and safety. When designed correctly, CPS contribute to an improved quality of life and more efficient usage of resources in many application domains.

From the current perspective, the benefit and value added of CPS have not been fully and finally described. The required capabilities of CPS are also not known to the last detail. However, the following requirements of CPS can be foreseen:

- Adaptability of networked systems and user devices to situations, locations and environmental conditions, tailored to the user (e.g. networking, input/output devices, external factors)
- Transparency of communication between mobile and stationary systems (devices, data and content acting according to the context)
- Behaviours, capabilities and functions that adapt to usage and situations, as a valuable complement to daily life
- Flexible ecosystems require different levels of integration, tailored to users, system class and use case

The next section describes these core requirements, which will be investigated and refined in detail in the second phase of the project.

5.1 Deriving technological and methodological requirements

Beyond the domain-specific potential of smart, embedded systems as described in [NRMES], the previously presented scenarios clearly indicate the cross-domain networking capabilities and usage potentials of CPS to create new applications and sustainable solutions, as well as the variety of requirements in terms of design, implementation and security of such CPS applications and services. Two central aspects have clearly emerged as being major challenges:

- The mastery of core CPS technologies, methods and techniques
- The required usefulness and usability as well as the acceptance of the CPS and their applications.

The investigation of long-term opportunities and risks that are associated with CPS is key, along with the questions of safety and security and social acceptance.

The major objective of the research agenda CPS is to develop a corresponding classification of all essential viewpoints to achieve sustainable development and design of CPS by means of a structured analysis and systematic deduction of the potentials, capabilities and technologies, the leverage that they can exert and their basis for innovation. The characteristic properties and required capabilities of CPS are derived systematically and identified on the basis of the description of contributions made by those CPS to overcome major social challenges, such as “global competition”, “energy”, “sustainable supply of resources”, “mobility”, “megacities”, “functional safety”, “aging society”, “affordable healthcare” and the “context-based provision of expertise and information”. The methods and technologies that are required to ensure these capabilities, and therefore the resulting research topics, are derived systematically and comprehensively.

The findings of agendaCPS will reveal the prerequisites and requirements, as well as the efforts that are needed in research and development to master the technology and create novel applications that can finally be brought to market as significant innovations. The project enables the targeted, integrated support, promotion and sustainable realisation of a CPS innovation space and market, including the creation of a flexible, open industrial ecosystem for network, component and platform manufacturers as well as systems and service providers (value creation networks with diverse business models and product/service lifecycles).

5.2 Functions, services and required capabilities of CPS

Cross-domain integration (communication and cooperation) of ESSI/SoS and CPS to support complex applications (such as those outlined in the smart mobility application scenario, etc.) allows devices and systems to offer increasing levels of functionality on the basis of the following capabilities:

- Collection, interpretation and utilisation of situational/environmental data for adaptation
- Communication and coordination through flexible networking and targeted information processing and calculation
- Appropriate monitoring and control of devices
- Targeted acquisition and utilisation of globally available data and services (including "untrusted" sources)
- Seamless integration with human activities and in tasks relating to smooth human-machine interaction

The combined result of these capabilities allows a situation-independent, strategic, long-term prioritisation and evaluation of alternative actions and sustainable support for objectives (for example in the field of medical care or the flexible, sustainable supply of energy).

5.3 Added value and quality gains from CPS

On the basis of the aforementioned capabilities, CPS provide a wide range of coordinated and integrated services with extensive benefits, depending on their intended purpose. This equates to manifold quality gains in the areas of life that have been described. Therefore, CPS provide and augment functions and opportunities in the following areas:

- Comfort functions and efficiency in many applications (adaptive cruise control, navigation, seamless travel planning, improved quality of life for the chronically ill, etc.).
- Safety functions, such as ESP, traffic safety systems (junction monitoring and control, automated vehicle warning and braking), flight safety (collision avoidance, storm detection and warning and diversion), catastrophe warning, disaster management, etc.
- Monitoring, guidance and control functions (traffic/rail networks, toll collection, traffic flow control, energy generation/consumption/distribution, water quality and supply, man/group/mass systems from navigation and coordination to catastrophe management, controlled evacuation, panic situations, etc.
- Infrastructure services (provision, coordination and control of materials, transportation and remote maintenance/repairs to infrastructure components, etc.)
- Supply and logistics services (energy, water, medicine, food, consumer goods, industrial goods, etc.)

5.4 The challenge of human-machine interaction, usability and acceptance of CPS

CPS require expanded and adapted concepts for new forms of integrated human-machine interaction, both seamless and multimodal (voice, movement, haptic, keyboard, displays, audio, etc.) with active operation and control by the user as well as passive monitoring (via cameras and sensors) with appropriate control of human responses by the system. This represents a major challenge in relation to establishing the appropriate form of human-machine interaction, to the handling of questions of who or what may make specific decisions in given situations, and how corresponding actions are implemented, controlled or required (including options for shared control). Such challenges include

- The analysis of a (sub) system as an integral part of human existence, thought and action, both physical and logical/causal within the context of the action (cf. the smart health scenario, traffic guidance systems and controlling energy consumption through incentive-based systems).

Moreover, they require
- The observance and also medical monitoring of humans, their health functions and their behaviours as a component of the behaviour of the system and application, with corresponding analysis and well-directed information, assistance, interaction and control (e.g. in traffic-jam detection systems, by making local proposals for alternative routes, or by targeted steering intervention by the traffic guidance systems).

Usability and usefulness, culminating in overall acceptance, represent the decisive capability of CPS. Their influence on the design of CPS will be to:
- Adapt to the corresponding situation and actual needs of the user in terms of tasks, profiles and capabilities
- Enable a seamless design and implementation of human-machine interaction (without any discontinuity of medium, mode or workflow/usage process)
- Create the required level of transparency for the user, indicating the appropriate states (situation, application, system) and available actions, plus consequences and potential risks

This requires appropriate research, technologies and methods of requirements analysis as well as a clear system definition and the possibility of a reproducible implementation within the system. Transparency in particular, and a realistic assessment of the capabilities of the CPS, give the user confidence and ultimately generate acceptance.

5.5 Interoperability and integratability of CPS

CPS integrate data and services from different systems which were developed independently and with disparate objectives, thereby enabling new functionalities and benefits. Currently there is a lack of well-defined interfaces that on the one hand define the standards for the form and content of the data being exchanged, but on the other hand take account of non-functional aspects of this data, such as differing levels of data quality or reliability.

The technological prerequisite for the design of the aforementioned various functions and value added services of CPS is the interoperability[2] and integratability of these systems as well as their capability to be adapted flexibly and application-specifically as well as extended at the different levels of abstraction. Dependent on the objective and scope of the application, it may be necessary to integrate component functions (ES, SoS, CPS), to establish communication and interfaces, and to ensure the required level of quality of interaction and also of the overall system beha-

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[2] Cf. Research Focus "Principles of Architecture“ in [NRMES]

viour. This requires cross-domain concepts for architecture, communication and compatibility at all levels.

The effects of these factors on existing or yet undeveloped systems and architectures represent a major challenge. Investigation into these factors is the objective of current national and international studies and research projects.

5.6 Reliability, safety, security and privacy

The basic prerequisite for demand-driven, reliable and secure usage, and also for the acceptance of CPS, especially in mission-critical areas, comprises a generic concept of safety, accuracy and reliability. In view of their high degree of interconnection in particular, the safety and security-related requirements of CPS represent one of the key research topics. "Safety and security" refers equally to the requirement that

- Usage and operation of the systems should not generate risks ("functional safety")

and also that

- The system should be protected against attack and unauthorised usage by external sources ("access security").

Specifically, this requires methods and technologies that detect threats and risks, and that determine the resulting safety and security requirements, to increase reliability, ensure accuracy and safety and security, even in the event of malfunction.

- Gathering and analysing safety and security related requirements
- Ensuring the reliability and robustness of components and communication
- Guaranteeing accuracy
- Ensuring safety and security through validation and verification, testing and certification
- Implementing measures to detect and suppress attacks, risks, malfunctions (error tolerance through redundancy, fail-safe systems, self-stabilisation)

The integration of embedded systems into larger, global networks in particular provides completely new opportunities for ensuring functional safety, but also opens up new risks of attack and malicious software.

The key safety and security related capabilities of CPS require holistic safety and security concepts to be included in the development process in order to ensure that the systems can detect insecure communication, unreliable services or even risky situations, as well as unwanted feature interactions. Issues relating to human-machine interaction (transparency of the system response for the user, and questions of shared and distributed control) increase this complexity.

5.6.1 Safety

As CPS directly affect physical processes, an incorrect response can have devastating effects on humans and technology, as well as it can cause significant economic losses. In many domains, such as in avionics and medical care, there are, therefore, explicit approval and certification procedures that comprise documentation of an appropriate level of safety and security[3]. The accuracy of a system is neither necessary nor sufficient evidence of its functional safety. Rather, documenting safety and security must pursue distinct, specific procedures that require risks to be determined and evaluated ("risk acceptance"), for example.

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[3] Cf. Research Focus "Safe and Secure Systems" in [NRMES]

In this context, quality assurance procedures (testing, analysis, formal documentation procedures) play an important role. They contribute to the approval of the system, but cannot replace it.

When it comes to proving the safety of CPS, their properties and capabilities produce a range of challenges.

- CPS are deployed in dynamically changing environments (location-independent, changing usage contexts – cf. the previous section) and adapt their responses to the situation at hand (adapting to context – cf. the smart mobility scenario). This dynamicity makes high demands on the processes, methods and technologies used to prove the safety of such systems, since their properties and responses may not be fully known when the safety is documented.
- In addition, it must also be possible to verify subsequent integrations of new services and functionalities into the existing system to document non-interference and to handle a potential (including temporary) loss of subcomponents, in particular those relating to communication channels. A neat combination of safety with access security must also be taken into account (see below).
- A further challenge is found in the integration of new technologies, such as new hardware architectures and new communication protocols, into existing certification processes.

With the increasingly open, heterogeneous, interconnected and distributed CPS and their level of integration into “everyday” processes in life and work, existing safety and security concepts must be expanded. Insecure communication, insecure services, heterogeneous interfaces, the identification of safety-specific usage, circumstances and environment-based responses all represent new challenges.

5.6.2 Security

The integration of CPS into global networks makes them vulnerable to potential attacks by cyber criminals, ranging from unauthorised usage of private data, through data theft (e.g. industrial espionage) to affecting the response of CPS by manipulating or forging data. This therefore also has an effect on safety. For this reason, reliable protection against current and future cyber attacks that could result in damage or loss is essential. A key research challenge here is the creation of protocols to reliably establish the authenticity of a communication partner and the security of data transfer. While such protocols are already known for general IT-based systems, they cannot be simply transferred over, in general due to the additional non-functional requirements for CPS (such as energy consumption and processing power available in end-user devices).

A further particular challenge for CPS is found in the use of data from information systems (cf. smart mobility scenario). If this data is manipulated, deliberately or accidentally, this may have effects on the response and therefore on the safety of the system. This interplay of access security and safety has still not been researched to a greater extent. Appropriate investigations and solutions are essential if CPS are to be used successfully and accepted.

Confidence in the systems is the central prerequisite for acceptance. This demands transparency for the user in relation to key needs such as privacy, anonymity and protection against attack, manipulation and unauthorised disclosure.

6 CHALLENGES AND OPPORTUNITIES

In its high-tech strategy, the German government has set the objective to contribute to Europe's position as a leading technology power and making the EU a pioneer in solving global challenges in many different fields.

The step from embedded software-intensive systems to cyber-physical systems is such a technological driver for innovation in core sectors of the economy. The technological and economical ability to exploit these potentials and opportunities represents a major challenge for traditional industries. Europe – and in particular Germany with its expertise in mechanical engineering (utilisation of b2b potentials), the quality of its products in the area of embedded software-intensive systems and its pool of innovative software start-ups – is in a good starting position. However, this could be endangered by an insufficient response to the expected fast pace of change. In order to successfully utilise and shape the CPS sector, the associated technological, economic and social issues must be analysed and resolved.

6.1 Technological and scientific challenges

CPS create core technological challenges for traditional system architectures, especially because of their high degree of connectivity. This is because CPS are not constructed for one specific purpose or function, but rather are open for many different services and processes, and must therefore be adaptable. In view of their evolutionary nature, they are only controllable to a limited extent. This creates new demands for greater interoperability and communication within CPS that cannot be met by current closed systems. In particular, the differences in the characteristics of embedded systems in relation to IT systems and services and data in networks lead to outstanding questions in relation to the form of architectures, the definition of system and communication interfaces and requirements for underlying CPS platforms with basic services and parallel architectures at different levels of abstraction.

Key research problems must be resolved in order to ensure the development, control and evolution of CPS systems, in particular in respect of the required capabilities.

The required capabilities of the systems can only be achieved by mastering the development processes that are intended to produce them. Accordingly, the aspects of methodology and engineering are discussed in the following sections.

As part of an integrated, consistent approach to developing systems and evolution it is necessary to investigate in particular those questions relating to methodology and engineering and to systematically construct domain-specific methodological components. The core challenges are CPS research, particularly for the creation of innovative, sustainable CPS products and overcoming the issues relating to the value added, usability, safety, security and acceptance, as well as the adaptability and integrability of the systems.

These technical topics should be considered in close conjunction with economic issues. Therefore, the following overview of the economic challenges serves as a basis for further study into these topics in agendaCPS.

6.2 Economic challenges

Due to their interconnection and the resulting complexity, CPS make high demands on each of the different levels in terms of the need for a willingness to cooperate on behalf of the individual players, in particular in a competitive world. Within a large-scale CPS, services can no longer be developed and operated by a single provider, but can only function in an integrative fashion within the system infrastructure, adapted to existing technologies, services and solutions.

The rapid technological evolution creates new economic frameworks and business opportunities that are especially accessible to young, agile firms. The consequence of this are highly disruptive business situations that require much greater flexibility and adaptability from market players than value added scenarios involving traditional products. Rather, CPS enable the creation of new, web-based services, identified as the "Internet of services", which is closely related to the "Internet of things". Innovative services can quickly be created within the system, themselves supporting innovative business models and demanding the adaptation of tried-and-tested business processes. As a result there are issues relating to value added within a CPS, ranging from the suitable customer model through payment solutions to new forms of operator models. Differentiated economic eco-systems will develop, in which companies occupy different roles and interact on the basis of complementary business models.

CPS offer a great opportunity to act as stimulators and receptors for new, emerging forms of business that provide individualised services – for example linking traditional services with partial or complete automation, from the physical transport of goods to the "bits not atoms" model (multimedia streaming, e-mail, etc.). The development of individual value chains to form singular value networks will create gaps in provision and service needs that will have to be detected and remedied.

In particular, the integration and networking as a part of a CPS will offer companies the opportunity to focus on their individual core competences and therefore reinforce their market position, since they no longer need to bridge the entire value chain to bring their product to market (from the patient to the hospital, in telemedicine for example). CPS also offer opportunities for SMEs and start-ups that provide individual services directly as part of the CPS, and that use and simultaneously refine existing economic systems.

This evolution nevertheless requires the development of standards in the individual application domains, as well as basic infrastructure investments that cannot be borne by individual companies alone. The development and operation of uniform platforms to migrate individual services and products will therefore be as much of a challenge as joint specification standards. The creation of such quasi standards, less in the traditional mould of classic industry norms and standards and more in the sense of de facto standards that become established on the basis of technological and market dominance, will become an essential part of technological and market leadership.

These technical topics should be considered in close conjunction with economic issues. Therefore, the following overview of the economic challenges serves as a basis for further study into these topics in agendaCPS.

6.3 Social and political challenges

The effects of CPS as the drivers of enormous technological and economic changes have significant impact on the user, not only as a consumer. However, the success of a technological innovation is primarily dependent on the acceptance by consumers – to that extent the successful exploitation of the potential of a CPS is also strongly linked to its ease of use and its functional benefits. This relates not only to the actual "human-machine interface" exposed by the CPS, but also to core questions of data protection (especially data privacy), the interplay of system processes as well as accessibility and qualification. It must appear to the user to be transparent and uncomplicated, and must generate confidence. In addition, using the services and applications offered within the CPS not only demands (basic) understanding of information technology (e-skills). Designing and developing CPS, with their complex requirements, demands specialist expertise and an interdisciplinary methodical approach that requires greater efforts in terms of training and CPD. Moreover, in order to support the economic ecosystem surrounding the CPS, there needs to be all sorts of political support for innovation, to create a culture of innovation that enables SMEs and start-ups to develop and offer new solutions and services quickly and easily.

Not least, CPS are complex socio-technical systems that change the way we perceive and experience reality, and the way we undertake certain activities. Within these socio-technical systems there are interconnected embedded systems and services, linked to different user groups. The user interfaces expose functionality that is used to control and monitor physical systems, as well as the use of services in networks and communication and interaction between users. This enables various communication flows and workflows, both in private and professional contexts. For users, CPS should ideally appear as an integrated supportive system that allows them to do what they want flexibly, and that provides wide-ranging support for social interaction, communication and cooperation between user groups, including assistance functions and automated processes for controlling and monitoring technical and organisational workflows.

6.4 Major Challenge: Integrated action

The illustrated application scenarios and the potentials/capabilities of CPS that have been listed demonstrate the far-reaching integrative effect and scope of application of these systems across nearly all areas of life. This and also the technologies and methodologies required to gain control, develop and refine CPS underline the fact that there must be an interdisciplinary and integrated approach. Such an approach must also encompass cooperation by many different development disciplines (IT, electronical engineering, mechanical engineering, natural sciences, etc.), with inclusion of domain experts, customers and end users, and the application of methods from cognitive/behavioural psychology and the social and economic sciences in defining and designing systems and applications, as well as collaboration between research, training, economy, society and politics.

The following key points should remain in focus:

- Cooperation (research and development, economy and society): Innovations can no longer be developed by one company/individual system participants
- Interoperability: When developing individual components, the system as a whole, and its "orchestration" must be in the spotlight (compatibility, interplay)
- Interdisciplinarity in education and training, integrated action and the creation of innovations and innovative potential through corporate networks, open platforms and interdisciplinary experimentation
- Consequences for politics (legislation, frameworks)

The realisation of CPS requires a concerted dialogue between the different groups in society, not least in order to agree envisaged objectives and secure acceptance.

7 OBJECTIVE – EXTENSIVE LEADERSHIP IN INNOVATION

As already described, CPS are a significant driver for innovation. This is the result, in particular, of the potentials arising from linking up disparate information and services, available on the Internet on the one hand and in embedded systems on the other. In the many fields of application this will enable the creation of new types of solution, new business models and, ultimately independent economic ecosystems with multifaceted various economic, technical and social usage scenarios. Realising these potentials demands a range of capabilities. These affect scientific, technical, organisational and entrepreneurial levels. Therefore, there is a need for target-oriented and coordinated research efforts to create the technical and methodological frameworks for designing and developing CPS. Implementation of the research findings will require new business opportunities to be realised, with fast, goal-oriented entrepreneurial action. It may also be necessary to adapt political frameworks.

In successful and established fields of the economy, CPS may trigger a rapid revolution due to their disruptive technologies. A possible example of this is the foreseeable change in the behaviour of customers in the automotive market. If the existing paradigm of individual car ownership is replaced by comprehensive mobile services that offer the customer flexible, integrated mobility service packages, then the automobile market will be completely revolutionised within just a few years. The creation of new technologies and applications, and their implementation in the market (technology push, e.g. the rapid penetration of the market with smartphones) and demand (technology pull, e.g. the demand for powerful batteries to support mobile electronics) for solutions to a range of social challenges (aging society, sustainable energy, high-quality, affordable healthcare, smart cities) will require a range of interlinking capabilities. This will involve overcoming the following problem areas:

- Creation of technical foundations in relevant areas following targeted research
- Understanding the challenge and definition of the problem
- Recognition of new technical options, and corresponding research and development
- Systematic development of appropriate, sustainable solutions
- Entrepreneurial awareness for business opportunities and the ability to realise them quickly

Innovation, as the successful implementation of new research-based technology and methods in commercially successful products and services will not be just another decisive issue, but the key challenge facing established companies and industries and start-ups alike. Leadership in innovation in CPS will require a bundling of capabilities and conditions to rapidly identify and realise innovations. This means being fully aware of the economic and technical opportunities, and committing to investments in training and research. CPS innovations can only arise in a global context. No country will enjoy success from a regional approach or going it alone. Innovation leadership for CPS means creating the technical prerequisites through research, and actively shaping, controlling and monitoring the innovation. This requires mastery of core technical fields and leadership in economic networks and value chains.

A precise identification of the specific potential for Europe in taking an (extensive) lead in innovation on the basis of its existing strengths in the field of embedded systems will be explored in greater depth in the second part of the project.

8 SUMMARY OF INITIAL FINDINGS AND NEXT STEPS

The CPS domain, due to its scope, requires careful analysis in order to work out effective recommendations for action. Nevertheless, the speed of developments means that it is not particularly advisable to simply wait until a comprehensive analysis is produced.

Embedded systems will be increasingly incorporated into CPS in the future. However, there are already major technological challenges to be overcome in the ES sector, which, if not resolved, will make it impossible to conceive of powerful and effective CPS.

This introduction to the domain of CPS
- provides a terminological definition and lays out an initial structure for the relevant application and technology fields
- provides representative application scenarios that demonstrate the use and importance of CPS for the economy and society
- emphasises the profound revolution in technology, science (the fundamental and interdisciplinary nature of the systems) and society (application of the systems will affect all areas of life)
- describes the resulting disruptive changes in the economy (the evolutionary and explorative character of CPS)

The complexity of the subject in terms of the required technologies and capabilities of CPS, as well as the capabilities and competences required to develop, control and design/create innovative, usable CPS applications, demand fundamentally integrated action, interdisciplinarity (research and development, economy and society) and vertical and horizontal efforts in
- The creation of open, cross-domain platforms with fundamental services (communication, networking, interoperability) and architectures (including domain-specific architectures)
- The complementary expansion and integration of application fields and environments with vertical experimentation platforms and correspondingly integrated interdisciplinary efforts
- The systematic enhancement with respect to methods and technologies across all involved disciplines to create innovative CPS

The aim of the second part of the agendaCPS project is to clarify these objectives and systematically develop detailed recommendations for action.

ACATECH PROJECT: AGENDA CYBER PHYSICAL SYSTEMS

The majority of processor chips does not control desktop and notebook computers, but is at work in embedded systems and applications used in many aspects of daily life. They are used in devices and systems in buildings, in transport, in medicine, in mechanical systems and in energy provision. Germany occupies a strong position in the billion-euro market for embedded systems, and can further expand this role through the evolution and global networking of embedded systems to form cyber-physical systems. Germany must exploit the potential and opportunities that are offered by global networking of systems across applications. It is vital that new sustainable services, solutions and markets be accessed. For this reason, acatech – the German Academy for Technical Sciences – has joined forces with academics, associations and entrepreneurs to launch the project "Integrated research agenda Cyber-Physical Systems. The project has the following objectives.

1. Determine the enormous social and economic importance of cyber-physical systems
2. Determine the state of knowledge and technology by international standards and establish a benchmark to reflect Germany's position
3. Determine the measures to exploit the potential of CPS and disseminate proposals for leading projects
4. Prioritise research objectives and develop an integrated research agenda for cyber-physical systems

The expert management of the project will be provided by acatech member Professor Manfred Broy of the Technical University of Munich, and fortiss GmbHPartners in the team include SafeTRANS e.V. and Oldenburg-based OFFIS. The project is supported by the Federal Ministry for Education and Research, and by BMW AG, ROBERT BOSCH GmbH and INTEL Deutschland GmbH. Project partners also include Daimler AG, EADS Deutschland GmbH, ESG GmbH and the associations BITKOM, VDMA and ZVEI.

acatech - the GERMAN ACADEMY OF SCIENCE AND ENGINEERING represents the interests of German sciences and technology in Germany and abroad. As a working academy, acatech supports policy makers and society with technically qualified evaluations and far-sighted recommendations. acatech perceives itself as a flexible working academy and as a science and business network. Outstanding scientists are the driving force behind its core work, while experts from industry bring about the transfer of knowledge arising from practical applications in industry. They engage in the central issues of science and technology and in policy questions within a techno-political context. These issues are structured into topical networks that give rise to project groups in which academy members work closely with external experts.

The results are presented to policy makers, the business sector and the interested public in scientific series, symposia, forums and discussion panels. acatech is a non-profit agency. Its funding derives from the federal government and states. Additional funding comes from donations and project-related third-party sources.
acatech works to promote sustained growth through innovation and focuses on four core areas:

- Scientific recommendations: acatech advises policy makers and the public on future technology issues based on the best of research.
- Transfer of expertise: acatech provides a platform for exchange between the sciences and business.
- Promotion of young scientists and engineers: acatech is committed to supporting young scientists and engineers.
- Voice for science and engineering: acatech represents the interests of scientists and engineers at a national and international level.

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