An Application Map for Industrial Cyber-Physical Systems

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1 An Introduction to Cyber-Physical Systems

Cyber-physical systems are the foundation of many exciting visions and scenarios of the future: Self driving cars communicating with their surroundings, ambient assisted living for senior citizens who get automated assistance in case of medical emergencies and electricity generation and storage oriented at real time demand are just a few examples of the immense scope of application [11]. The mentioned examples show that cyber-physical systems are expected to have an impact in various domains such as: Mobility, healthcare, logistics, industrial production and further more. This comes along with noticeable change for citizens in their daily lives and routines on micro-, meso- as well as macro-level:

- Individuals can profit from cyber-physical systems personally (micro-level), residing in *smart homes* and supported by *ambient assisted living*. The engineering of new service systems based on cyber-physical systems, bringing together tangible and intangible resources, enable new value propositions [4].

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- Users benefit from the merge of physical status information and virtual data, like in the case of traffic estimator systems processing the location and travel speed of each system participant or other *smart mobility* applications (meso-level).
- A significant expansion of industrial production, transport and supply effectiveness and efficiency completes the expected improvements (macro-level).

This is the case, not just for national economies, but for the global economy, too. The domain of the value creation based on cyber-physical systems is especially to emphasize in the industrial context; the effects on micro-, meso-, as well as macro-level exist ranging from benefits for each individual of the value creation process to entire economies. With the implementation of industrial cyber-physical systems in factories and other industrial application areas, major potentials for improvement in terms of efficiency, process organization and work design are expected. The industrial value creation is believed to proceed with a reduction of required time and costs while the quality of products and services as well as the user benefits increase [1].

This chapter wants to give orientation to practitioners and researchers about the currently visible scope of application for cyber-physical systems according to the ongoing discussion in industry and academia. It proceeds in the following way: First, it introduces technical, human and organizational dimensions of industrial cyber-physical systems. Second, it describes categories with high potential for improvement in industrial practice by the introduction of cyber-physical systems. Third and finally, it links these categories to specific spheres and consisting application fields within the industrial value creation process. The findings are displayed in an application map, which illustrates the overall connectedness and interrelation of the spheres smart factory, industrial smart data, industrial smart services, smart products, product-related smart data, and product-related smart services and the particular application fields therein. This application map offers decision makers a compendium of application fields for industrial cyber-physical systems, which they can use as a template for their own business situation.

2 Foundations of Industrial Cyber-Physical Systems

Lee [16] lays the groundwork for the technical understanding of cyber-physical systems by describing them as “integrations of computation and physical processes”. Their application in practice, however, does not only have a technical dimension, but also a human dimension with respect to the people who use them, and an organizational dimension with respect to the surrounding economic structure. The following section gives a brief overview of the foundations of industrial cyber-physical systems in these dimensions.

2.1 Technical Dimension of Cyber-Physical Systems

From a technical point of view, cyber-physical systems are built upon the modular logic of embedded systems. Embedded systems are information processing devices which form often miniaturized components of larger computer systems. Every component has a specific functional purpose. In combination with each other, they determine the value proposition of the entire system [22]. Popular examples of embedded systems include cars, household appliances, entertainment electronics and many more. Before the times of ubiquitous computing, they were self-contained devices with limited sensor technology and marginal interconnectedness. Comprehensive intersystem organization and linkage based on context-awareness and adaptiveness leading to self-configuration, ambient intelligence and proactive behavior was missing. These characteristics became reality with *smart objects*, entities that have a definite identity, sensing capabilities of physical conditions, mechanisms for actuation, data processing ability and networking interfaces [10]. In order to equip embedded systems with digital intelligence to extend their dedicated functionality and thus, to make them parts of cyber-physical systems as beforehand described smart objects, certain extensions are necessary.

The first requirement is the installation of sensors, which allow the digitization of physical conditions. Sensors are available for a broad range of physical phenomena. The wealth of information collected about the physical environmental conditions can be as simple as the pure occurrence detection extending to the measurement of detailed values and grades about the phenomena. Each sensor should be chosen depending on the aspired exactitude of the state description based on task and the usage context of the to equip object. The ongoing miniaturization of the previously described technical components continuously extends their scope of application. The data aggregated by these sensors needs to be processed by the local processing capacity of the smart object. Decentralized computing entails an increase in the pace of data processing while simultaneously reducing data throughput within the network infrastructure. Subsequent centralized data evaluation, in form of big data processing enables the use of the gathered data for pattern recognition and forecasts based on the recognized patterns. Hence, in cyber-physical systems, decentralized real time computing of operative measures complements centralized data evaluation for developing strategic measures.

Furthermore, communication interfaces are necessary to merge self-contained embedded systems to cyber-physical systems. In addition to previously established interfaces like Ethernet and Wi-Fi the extensive implementation of RFID, GPS and near field communication technologies allow the interconnection of a myriad of objects [26]. In parallel to this development, the introduction of the internet protocol version 6 (IPv6) solves the obstacle of an insufficient global communications network. With this new protocol, the hypothetical interconnection of approximately 340 sextillion objects via the internet is possible [17]. The upgrade of industrial machines with machine communication protocols like the OPC Unified Architecture (OPC UA) ensures the interoperability of machines from various manufacturers [19].

Nonetheless, there are several interpretations of cyber-physical systems especially when it comes to visions for their utilization in different domains. In this context, the following agendas and roadmaps are good examples of the possible variety in domains: *Living in a networked world—Integrated research agenda Cyber-Physical Systems* (*agendaCPS*) from acatech [11], *CyPhERS—Cyber-Physical European Roadmap and Strategy* funded by the EU [8], and *Strategic Vision and Business Drivers for 21st Century Cyber-Physical Systems* from the National Institute of Standards and Technology of the US Department of Commerce [24].

2.2 Human Dimension of Cyber-Physical Systems

Besides the aforementioned technological preconditions, there is a human dimension to consider. The success of the introduction of cyber-physical systems depends significantly on the acceptance by the users. The interaction between people and cyber-physical systems differs depending on the type and function of the regarded systems.

Interactions with a high level of attention and awareness are performed with the use of human-machine interfaces. These human-machine interfaces have many different forms, naming classic computer input or voice control as examples. Especially the usage of mobile devices like smartphones and tablets as control devices offers great potential for the interaction between users and cyber-physical systems. The interactions have two aspects: First, smartphones and tablets have become a commodity in many societies due to a high value in use. The wider diffusion rates of smartphones compared to desktop PCs emphasizes this trend [12]. Second, mobile internet connection allows system usage without being tied to a specific geographic location. Moreover, with operating systems that allow the installation of third-party apps, smartphones and tablets are the ideal platform technology. In many cases of human-machine interface design, the focus is thus set on the software, since the hardware is already available in the form of mobile devices.

Mobile devices, especially *wearables* (wearable technology) also contribute to passive or unconscious interactions with cyber-physical systems. As mentioned previously, it is not just smartphones and tablets, but also smart watches and fitness trackers that have become widely accepted companions of users in daily life. Moreover, virtual reality interfaces are also increasing utilized. With ubiquitous computing and emerging smart environments, carried devices communicate with the overall system in the background unnoticed by the user. By sending parameters like location, travel speed, and destination, services such as traffic based navigation or smart home systems adapt corresponding to the user's preset preferences (e.g. travel route, room temperature, etc.). In professional surroundings, the same technology can be used for safety monitoring. Usage scenarios for this are construction and maintenance activities in industrial settings. Whenever personnel working in hazardous environments remains in a position unchanged for too long, the system alerts a rescue crew automatically. Of course, compliance with data security and protection of privacy need to be a matter of fact regarding this topic.

Besides the wide distribution of mobile devices, it is the people's familiarity with using such technology in both private and professional contexts which leads to the expectation of high acceptance and adoption rates for them as human-machine interfaces for cyber-physical systems [7]. In sum, both the technical architecture and the user integration appear to provide a solid basis for the development and the implementation of cyber-physical systems in the contemporary scenario. Based on previous achievements and the ongoing advances, the remaining challenges seem manageable.

2.3 Organizational Dimension of Cyber-Physical Systems

Technically driven approaches tend to neglect that the organizational dimension plays an important role for the application of cyber-physical systems as well, particularly in a professional context. The introduction of cyber-physical systems poses as a challenge for many companies because they have to consider several layers (technology, divisional structure, business model, etc.) of the enterprise architecture at the same time. The organizational dimension with need for consideration in this process is described as follows.

Only in rare cases, cutting-edge technologies are introduced by building new production facilities solely designed to reach the maximum potential of the innovations. What usually happens is that the new technologies are integrated into an existing operational environment and thus they have to be aligned with other infrastructure [32]. For this purpose, machines need to be updated, and digital communication standards which allow the orchestration of new and old hardware at the same time need to be established. The changes in the production processes are most likely to have further effects on the structures of managerial processes and subsequently the organizational structure, as working times, supply, control routines etc. have to be revised. Therefore an effective change management does not only need to consider engineering but also business adjustments in the course of the introduction of cyber-physical systems. Companies are well-advised not to perform these adjustments in a reactive mode with respect to their overall strategy, but proactively in order to make use of the full potential offered by cyber-physical systems. New production processes and the opportunity to expand the existing range of products with new *smart products* allows extensive enhancement of the existing business model.

Especially hybrid and interactive value creation offer great potential, in this context. Hybrid value creation describes the combination of physical products with data driven services to service bundles [34]. Due to continuous points of contact between company and customer and a serial payment model, this approach is a key to long lasting customer ties accompanied by long-term income streams. Interactive value creation defines the process of cooperative collaboration between manufacturers and their customers in order to achieve a more user-oriented approach of value creation ultimately leading to products and services with a higher benefit for customers [29]. The simultaneous practice of both approaches offers increased usefulness actuated by the mutual enhancing effects of either procedure. Despite such advantages, many companies perceive these modifications to the established and existing business models more as a challenge than a chance. In case of cyber-physical systems, this is intensified by the potential changes that have to be considered simultaneously in the manufacturing process, the product portfolio and new, to be thought of, services all at once.

Nevertheless, despite the previously mentioned advantage of the common use of mobile communication devices for the user integration for cyber-physical systems, the introduction of new technologies and procedures generates a need for adjustment for the personnel. In most cases, these adjustments consist of changes in work routines and procedures that entail training courses and other qualification measures for the workforce. Since personnel might perceive such activities as additional efforts besides the usual tasks, it is a managerial challenge to clarify the resulting benefits for personnel and to motivate them to adopt the new technologies.

The availability of far more data than before, due to cyber-physical systems and smart products, offers companies a variety of exploitation scenarios (predictive maintenance, hybrid value creation, big data solutions, etc.). In this context, the potential of inter-organizational data exchange is to highlight for integrated logistics concepts, just-in-time production etc., as it brings a new efficiency level to inter-professional production networks. This can foster strategic alliances in between corporations while at the time reducing lock-in effects and stimulating markets. Inter-company cooperation on this level requires a major exchange of data in real time. For many companies, this seems synonymous to an inestimable risk of data loss, offering a wide range of potential targets for hacking and industry espionage [31]. The step toward larger collaboration across company boundaries is therefore often difficult to take for them. However, there are advanced cybersecurity standards available that can help prevent hacking and espionage effectively, if they are combined with a suitable data sharing strategy by the company [28]. This illustrates one more time the importance of the organizational dimension of cyber-physical systems.

Like any other rollout in the industrial context, the introduction of cyber-physical systems means an investment of financial capital. Based on the multitude of factors to consider, it is nearly impossible to take all into account at the same time without a systematic approach. The identification of proper application fields matching the unique and specific needs of an organization and the estimation of the overall benefit is difficult and it is even harder to estimate reliable figures of the return on investment. While this is already deterrent for large-scale enterprises, it especially hinders SMEs to utilize cyber-physical systems and the optimizations associated therewith [30].

In comparison, the technical and human dimensions of cyber-physical-systems seem more advanced, while the organizational dimension is still in lack of maturity. Figure 1 gives an overview of the current scenario and its various aspects.

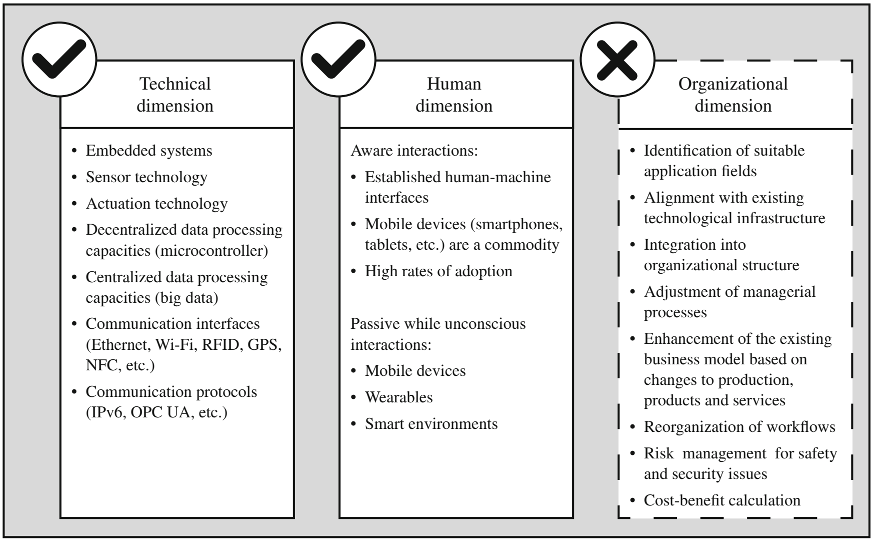

Fig. 1 Dimensions of the successful implementation of industrial cyber-physical systems

3 Categories of Potential Improvement for Industrial Cyber-Physical Systems

Like mentioned before, the adoption of cyber-physical systems in the industrial context offers great potentials ranging from benefits for each individual of the value creation process to entire economies. The expected effects include sustainable growth of a nation's GDP, accompanied by an increase of individual wealth and living standards [11]. Governmental institutions in many countries have recognized these highly promising anticipations and have therefore implemented funding initiatives with the goal to stimulate the adoption of cyber-physical systems in the industrial sector of their countries. While most of the worldwide public initiatives pursue this general aim, they differentiate in design and implementation structure as well as funding volume. Prominent examples are the following:

- In the United States, the National Network for Manufacturing pursues its initiative *Advanced Manufacturing Partnership 2.0* with the objective to "use new, often leading-edge machines and processes to make products that are unique, better, or even cheaper. Advanced manufacturing also facilitates rapid integration of process improvements, readily permits changes in design, such as new part features or substitute materials, and accommodates customization and cost-effective low-volume production." [20].
- The German initiative *Industrie 4.0* aims to strengthen the position of its mechanical engineering sector as a global market leader. Moreover, there is a focus on developing norms and standards for communication protocols as well

as providing SME-specific guidelines for the implementation of innovative technologies. The "4.0" symbolizes the great expectations attributed to the new technologies, lifting this development on a level with the three former industrial revolutions [6].

- *Catapult—High Value Manufacturing*, the initiative in the United Kingdom, strives among other things, to foster further digitization in manufacturing processes and to reinvigorate the industrial production that has been declining in the UK over the last decades [14].
- China aspires to update its manufacturing industry with the program *Made in China 2025* to leave the times of being the "workbench of the world" behind. The main goal is a better overall innovativeness in combination with superior quality of the manufactured products. Moreover, there is a focus on a more ecologically reasonable economic progress and education of native specialists [18].

Besides governmental initiatives, there is a multitude of initiatives and platforms run and funded by the private sector. To emphasize are e.g. the US based *Industrial Internet Consortium* or the *Industrial Value Chain Initiative* from Japan [21].

The frequent referral to cyber-physical systems as a key component of the implementation of *smart factories* in initiatives of both developed as well as emerging economies underlines once more the importance of these technologies.

Despite all the public attention and financial support, it remains widely unclear for many decision makers how cyber-physical systems can actually generate benefit for their companies in practice. The findings of this book chapter were achieved within the research project "Resource-Cockpit for Socio-Cyber-Physical-Systems" funded by the German Federal Ministry of Education and Research. In the course of the project experts out of the fields of management, industrial associations, research, labor unions and work committees as well as the federal employment agency were interviewed following a qualitative research design. The perception of the topic by the shop floor personnel was included via focus groups. The analysis of the interviews and focus groups in combination with desk research led to the upcoming categories and built the foundation for the elaboration of the application map. Before describing the actual fields of application for cyber-physical systems, the main categories in which the experts foresee high potential for improvement in industrial practice are listed.

These categories are automatization, autonomization, human-machine interaction, decentralization, digitization for process alignment, big data, cyber security, knowledge management and qualification. An overview of these categories of potential improvement is given in Table 1.

Table 1 Categories of potential improvement for industrial cyber-physical systems

Automatization	• Integrated flow of production • Machine-to-machine communication (M2M communication) • Plug-and-produce machinery interconnections • Automated guided vehicles (AGV)
Autonomization	• Supervisory control and data acquisition (SCADA) • Condition monitoring • System reconfiguration
Human-machine interaction	• Unrestrained human-machine collaboration • Robotic exoskeletons • Decision support systems • Resource cockpits • Augmented reality
Decentralization	• Decentralized computing in modular networks • Complex event processing
Digitization for process alignment	• Digitization of warehousing and logistics • Automated e-procurement • Industrial services in the field of maintenance, repair and operations (MRO) • Digital image of products • Document digitization
Big data	• Pattern detection • Data processing warehousing solutions
Cyber security	• Cyber security solutions • Engineering of safety system infrastructures
Knowledge management	• Systematic recording, categorizing and mapping of implicit knowledge • Action guidelines
Qualification	• Qualification concepts • E-learning

3.1 Automatization

Industries in developed and emerging countries rely strongly on a highly developed manufacturing process as a basis for their success on the market. This includes the extensive usage of technology in various ways and its automated operation. Over time, the motives for automatization have changed: Coming from the goal to lighten the workload of employees, automatization soon raised productivity due to new procedures of product assembling. Taylorism in 19th century and computer integrated manufacturing (CIM) in the 20th century are the most prominent development periods in the past [13]. Cyber-physical systems offer the potential for the next large developmental step in the application of automatization. Based on the stated foundations the following configurations can be identified.

The *integrated flow of production* profits from the situational context awareness of smart machines and smart production materials. A digital image of the product to be assembled is stored on a miniaturized data carrier attached to each production material. Whenever a production step is about to be executed the machine reads the production instructions out of the data carrier and processes the production material as required. In this way, automated batch size one production becomes executable. To prevent uneconomic sizes of lots and suboptimal retooling cycles, *machine-to-machine communication* (*M2M communication*) has an elevated importance in this context. Machines within one line of production exchange information about pending steps of procedure and optimize the sequence holistically based on previous determined algorithms. Moreover, the inter machinery communication is a key for the establishment of *plug-and-produce machinery interconnections*. Based on task and order, different compilations of machinery are needed to fulfill required process steps. In static assembly lines, this can mean that certain machines are unused but still not available for task performance. In the case of plug-and-produce machinery interconnection, only the needed machines are compiled to an assembly line. Vacant machines can be used for other tasks synchronously while machines with a malfunction can be exchanged easily. The basic requirement for these constantly changing machinery networks are cross vendor communication standards.

Besides the use in the production process itself, cyber-physical systems offer improvement potential for production supporting processes. *Automated guided vehicles* (*AGV*) interact via sensors and actuators with their environment and fulfill tasks like the transport of component groups and working materials as well as warehousing. The full potential benefits of automated guided vehicles become available when they are integrated into the network of the before mentioned machine-to-machine communication.

3.2 Autonomization

The term autonomization closely relates to automatization but is not an equivalent. Autonomization stands for the approach to control and coordinate automated processes without external (human) intervention but by system internal evaluation mechanisms. Based on self-optimizing algorithms the overall production system anticipates critical incidents and other occurrences of the operating history and optimizes the solution behavior.

A new level of *supervisory control and data acquisition* (*SCADA*) becomes possible in this way. Opposite to the up to now approach, based on continuously available real time data the future SCADA allows detailed *condition monitoring* and situation based *system reconfiguration*. Automated debugging in case of severe failure conditions is another advancement in this context. This offers both economic likewise work safety improvements: The automated batch size management facilitates the cost-efficient production of mass-customized products based on individual customer needs. In addition, autonomic procedures allow the reduction of the number of human operators. Besides the reduction of labor costs which enables competitive production in high wage economies [5], autonomic production can be a partial solution for the demographic change in western societies due to a declining workforce [15]. Furthermore, autonomization has obvious implications for the safety in manufacturing processes, especially during dangerous stages of fabrication, and while processing components and materials containing hazardous substances. The absence of personnel eliminates the danger of work accidents.

3.3 Human-Machine Interaction

Although the previous section noted certain advantages in the reduction of deployment of staff, the introduction of cyber-physical systems will not make men replaceable in the industrial context. Humans are still superior to machines in certain tasks and activities. In other areas, while machines could replace workers it would mean a financial disadvantage. Therefore, user integration is essential for the successful implementation of cyber-physical systems wherever humans are part the system or interact with it.

While today in general, due to safety regulations, machines and humans work physically separated from each other, cyber-physical systems allow unrestricted interaction. Sensor equipped shells which overlay machinery parts register contact in between machines and workers within milliseconds and stop harmful movements. Camera systems tracking positions and movements of both workers and machines are another method to prevent collisions and make protecting fences obsolete. The *unrestrained human-machine collaboration* enables each party to unfold their inherent strengths leading to an overall optimization. In addition, there is a high potential to reduce the workload for the personnel wherever physical strength is needed. Enabled by wearable support systems like *robotic exoskeletons* lifting and carrying activities become less tiring for the body [3]. Robotic exoskeletons have a positive influence on both the performance and the overall working lives of the personnel.

Besides the mentioned direct cooperation and interaction between humans and machines in fulfilling physical tasks, cyber-physical systems can be the basis for service systems [4]. In form of *decision support systems* users are supplied with needed data and information relevant to execute their job. When engineering these service systems several matters need to be considered: First, industrial processes include personnel with different positions of the organizational hierarchy with distinguished tasks. Therefore, a comprehensive role model should be utilized when conceptualizing these decision support systems [25]. By doing so, every role gets the appropriate reading-, writing-, or administrator rights. This ensures the supply with required information for task fulfillment while protecting the system from unintentional entry and outflow of critical information. Second, the right amount of information offered needs to be determined. Due to the plentitude of data gathered by machine attached sensors and other sources, an unfiltered supply of this data easily leads to an information overflow. Therefor the decision support systems need to be built on an evaluated reference architecture bringing together the knowledge about each task and the valuable information for the fulfillment of it. By doing so, each role is supplied with right data based information at the right time without the need for across systems information procurement. Third, the in this way composed *resource cockpits* do not just need a useful concept of information supply but also the right hardware and visualization methods for an optimal utilization. To integrate the information supply into the work flow ideally, solutions like *augmented reality* are very suitable. Using hardware like data glasses or other wearable technology, information can be presented as a graphic overlap over physical infrastructure. Operating data, work instructions and error localizations can be presented virtually in semantic context with real-world artefacts like machines. An additional advantage is that augmented reality enables the presentation of before mentioned information about covered modules of machines by offering a virtual insight into the machine without opening it physically.

3.4 Decentralization

Production aligned with CIM-standards is mainly based on centralized hierarchically structured computing processes. This owes to the characteristic of the hardware and software which was standard as the concept CIM was developed as well as to the at this time prevailing business logic. While in certain scenarios centralized data processing is still advantageous (e.g. big data analytics), for real time relevant tasks like production execution, *decentralized computing in modular networks* offers unequivocal benefits. Cyber-physical systems strongly link to the approach of decentralization [33]. Enabling factor is the continuous miniaturization of technical components along with an increase in processing power of these. Thus, c*omplex event processing* is no longer bound to centralized computing units but can be performed in a leaner and faster way based on decentralized computing network solutions.

3.5 Digitization for Process Alignment

The sensor based digitization of physical operational sequences of the production process only unfolds its full potential as part of an entirely digitized factory. Hence, digitization should be fostered not just in the core production process but also in all production supporting sectors. An extensive *digitization of warehousing and logistics* based on RFID or NFC systems enables self-organizing production networks to include the real time inventory into the production program. Furthermore, continuous inventory and stocktaking based on sensor and actuator equipped pallets, boxes, shelves and also production materials enable an *automated e-procurement*. This improves the in time availability of parts and materials delivered by suppliers and allows an extended use of just-in-time production. In this way, strategic partners like subcontractors can be integrated more profoundly into the value chain. This is not just the case for suppliers but especially for providers of *industrial services in the field of maintenance, repair and operations* (*MRO*). With comprehensive information and the option of remote control, several MRO activities in case of software or operational errors can be conducted from a distance. In the event of physical defects the maintenance personnel of the machine operator can be supported by experts of the machine manufacturer's company who can base their advice on real time data received via a secure connection.

On basis of the fact that in most cases the introduction of cyber-physical systems does not proceed in form of the construction of completely new production facilities from scratch but as a transition with an update of the existing machine fleet, digitization has to be considered as well from this point of view. When introducing new decision support systems to the plant personnel the requirement has to be that all relevant information can be made available via one decision support system on a single device. Media discontinuities are perceived as cumbersome by the user. Additional time consuming research work for e.g. blue prints or handbooks in paper-based filing systems and archives lead to only modest adoption rates of the decision support system. To counteract this, all relevant documents like handbooks, blueprints, protocols, etc. should be digitized. The act of *document digitization* needs to be completed by inventorying the content of the files to make the option of searching the document available.

Besides the advantages for the organization of the production process, digitization offers applicability for product improvements as well. The before introduced *digital image of each product* stored on a microchip attached to the product which is used during the production process for the communication between the to be assembled product and the executing machines, maps afterwards the individual product life cycle. With data of usage and every after-sales service, it provides valuable insights which can be utilized in form of further product development and offerings of product-enhancing services.

3.6 Big Data

The extensive installation of sensors on machines causes a massive increase in the volume of data collected within industrial processes. The data consist of operating data, error lists, history of maintenance activities and alike. In combination with the related business data, the overall plethora of data provides the raw material for process optimizations and other applications. To set this potential for optimizations free, the raw data needs to be processed systematically, passing through various algorithms. The results are prepared information with specific application objectives. Especially *pattern detection* is to mention in this context, since this method identifies and quantifies cause and effect correlations and allows predictions of state changes. The significance of the information given out by the analysis depends on the amount of data processed. Therefore, it can be in the interest of individual companies to unite their data sets with the goal of a joint asset in form of more precise and meaningful informational results. Requirements for these joint operations are *data processing warehousing* solutions with extremely large computing and storage capacities.

3.7 Cyber Security

Many of the before described categories of potential improvement have in common that the functioning of the introduced cyber-physical systems is dependent on data interchange between separate system components. In various cases, the data interchange does not just proceed within enclosed IT systems but also web based across company boundaries. Especially in case of close integration into value-adding networks or in interdependent systems of systems, a widely distributed data flow is a fundamental prerequisite. The extended value in use comes with the risk of an increased vulnerability due to cyber threats. These cyber threats consist of data theft, sabotage, industrial espionage, and further more. In the event of a successful outcome of these digital attacks, the negative consequences for the affected companies are incalculable. The range includes malfunctioning machines, an endangering of the work safety up to the loss of customer confidence. These alarming consequences underline the need for reasonable *cyber security solutions*. A reliable security concept should consist of measures both on individual system participant's level as well as on the overall system's level [9].

Especially for the scope of direct cooperation and interaction between personnel and machines, manipulability needs to be eliminated. Therefore, the *engineering of safety system infrastructures* is a notable aspect with regard of operating cyber-physical systems.

3.8 Knowledge Management

Among other things, cyber-physical systems enable an increased level of effectivity and efficiency in the industrial value creation because of the amount of real time information they provide about technical processes. However, for the utilization of the full potential of cyber-physical systems the collected information should include non-technical sources of data, too. Implicit knowledge of the personnel falls into this category. Activities proceeded during the work process are based on the practical knowledge of the staff. In many cases this knowledge is only available informally and difficult to be formalized. However, due to the great value of this knowledge, methods should be introduced to systematically record, categorize, and map it. The availability of this knowledge can be used for the design of *action guidelines,* which are an essential part of decision support systems. An example can be the repair of a malfunctioning machine. When an error occurs for the first time, the problem-solving process should be documented, so when it occurs for the next time an action guideline is available and whoever fulfills the repair, can profit from the experience curve effect. However, the process of *systematically recording, categorizing, and mapping implicit knowledge* implies an additional effort for the employees. Consequently, it is essential to clarify the overall added value based on the availability of the action guidelines once the decision support system is engineered and implemented. Incentive systems are a proper instrument to ensure the participation of all involved stakeholders.

3.9 Qualification

The implementation of cyber-physical systems entails major change in the process of industrial value creation. This affects in many areas the role of men within this process as well. Tasks, roles, and requirements of the personnel pass through a major transformation. Education concepts and study contents of apprentices need to be adjusted to the new needs. A particular challenge in this regard is the retraining and teaching of content to the existing workforce. Methods for employee motivation and integration into new training measures are necessary. Sometimes even longstanding customs, biases, and other means of resistance need to be managed. The elaboration of new *qualification concepts* for both trainees as well as experienced staff, ensuring the ability to operate and interact with cyber-physical systems, are an important measure for a successful change management.

Beyond the recording, categorizing and mapping of implicit knowledge and the digitization of information that was formerly decentralized and difficult to access, it enables the introduction of new *e-learning* methods. E-learning offers are exploited by the use of mobile devices as human-machine interfaces, since they can also be used for this purpose.

4 Elaboration of an Application Map for Industrial Cyber-Physical Systems

In this final part of the chapter, the pointed out categories with high potential of improvement are matched with specific spheres and inherent application fields of the industrial value creation process. To structure these application fields the following spheres categorize them: Smart factory, industrial smart data, industrial smart services, smart products, product-related smart data, and product-related smart services. Even though the spheres of smart products as well as product-related smart data and product-related smart services do not directly belong in the industrial sector, they have strong interdependencies with it and influence the introduction of cyber-physical systems in industrial processes significantly. Therefore, the application fields that fall into these spheres will be illustrated as well. Foregone, the strong interconnectedness and combined effects of the spheres and application fields are to emphasize. Only a few applications fields within these spheres can be classified as stand-alone application scenarios.

As the core of cyber-physical system based industrial manufacturing, the sphere smart factory will be approached first.

4.1 Smart Factory

The fabrication and assembling of products and the underlying and contributing processes in the smart factory offer a great variety of application fields for cyber-physical systems. First to mention is the *production* itself. Production planning and control have to take more factors into account than before and orchestrate a great amount of technical, mechanical and digital processes with minimal tolerance of process time. Therefore, the production management needs to achieve a new level of automatization and autonomization. To reach the requirements of a forward-pointing and competitive production planning and control, these systems should be self-(re)configuring, self-optimizing, adaptive, context-aware, and real-time capable. To reach this overall goal, cyber-physical systems should be installed throughout the *assembly line*. In particular, the implementation of features in the area of automatization and autonomization (machine-to-machine communication, plug-and-produce machinery interconnections and automated guided vehicles as well as supervisory control and data acquisition and system reconfiguration mechanisms) are promising. Moreover, the assembly line is the application field for most cyber-physical systems allowing an integrated human-machine interaction. Jointly these measures lead to a reengineered production procedure allowing the economic manufacturing of batch size one.

To ensure an integrated flow of production, further application fields offer great potential for the implementation of cyber-physical systems. Incoming *logistics* are one of these. An automated e-procurement ensures a sufficient inflow of production materials and precursors. The optimum of order quantity is automatically calculated with real-time data from production, warehousing, and incoming orders. Moreover, market trends, price developments and other company external data can be integrated for an optimized e-procurement. With strategic suppliers and subcontractors, an integrated supply chain can be established based on cyber-physical systems. For this purpose, the interwoven production processes of several companies can be linked virtually to a strategic production network.

Once the production materials and precursors arrive at the smart factory, a cyber-physical system based *resource management* ensures the automated influx of these into the production process. Automated guided vehicles collect the means of production from warehouses with virtual commissioning. Another field of application in the context of resource management is the alignment of production with smart grids. In these intelligent electricity networks, the production of energy is closely tied to the actual demand [2]. Depending on current outstanding orders and potential future orders, a cyber-physical system based energy management can schedule energy intensive stages of production for timeframes with favorable electricity rates. The general increase of efficiency both in processes and resource usage combined with the optimized energy consumption allows cost reductions and a more "green production" at the same time.

The *quality management* profits of the use of cyber-physical systems, too. With real time data from the production process as well as from products in use (especially of smart products), deviations to estimated values throughout the production process can be detected precisely. This contributes to the continuous quality assurance of the production but also supports the understanding of causes of product failure and linking it to manufacturing problems.

Research and development profit in an analogical manner of the wide spectrum of data availability due the application of cyber-physical systems within production and smart products. A digital image of each product stored on a microchip attached to the product, holding record about assembling, services activities, repairs and other related incidents of the individual product lifecycle, allow an evaluation of product's strengths and weaknesses. These conclusions are helpful for the continued development of new product versions. Furthermore, data from products in use is valuable for this purpose. The ways and manners how customers use the products, give an overview how well the product is aligned to customer needs.

The application of cyber-physical systems is also beneficial for the customer relationship management: In the context of *distribution*, the customer can keep track of his order until it arrives. While for standardized products this is nothing new, for individualized and custom-made products an extension can be made to the present shipping tracking. For customized products a tracking through the entire manufacturing process becomes available due to the application of cyber-physical system along the assembly line. Since the traceability of every order is a requirement for the automated production procedures, it can be converted to a service for the customer as well. By doing so, the customer cannot just track the order through the production but can also still modify it during the production for forthcoming production steps. The *value proposition* can be extended to further areas. The new manufacturing capabilities due to the application of cyber-physical systems enable the extensive production of smart products with potential for an extended customer benefit. The specifics of smart products and the interconnection of them to the smart factory will be described in the upcoming Sect. 4.4 (smart products).

Before that, the focus is directed towards *industrial smart data* and the generation of it.

4.2 Industrial Smart Data

In the previous section, application fields for cyber-physical systems in the smart factory were described. Remarkable is the broad variety but also the indirectly affected business units profiting from the application. What all application fields have in common is the generation of large amounts of data. However, all the accruing data captured by sensors installed in the smart factory is only then from value, when it is stored, processed and aggregated and thus transferred into contextualize information.

For the reason alone of the sheer number of sensors and the amount of data collected by them in the smart factory, special *industrial data warehousing* solutions are in need. Therefore, when companies apply cyber-physical systems within their production and surrounding application fields, a connected adequate data storing solution is essential.

The continuously inflowing and then stored data needs to be processed and interpreted. Like described in the section about the smart factory, there are several contexts for which the analyzed data can be utilized. To achieve this objective in a systematic way, the application field of *process engineering for industrial data analysis* is appointed. The continuous development and advancement of algorithms to process the data to valuable information is the main task of this application field.

The elaborated algorithms are employed in the process of *industrial data analysis*. In this application field, the data sets from different sources within the smart factory are evaluated and interpreted. The focus of these actions is the detection of data patterns which can be correlated to certain events. The determination of the likelihood of occurrence and the deduction of forecasts is a further ambition of these activities. Overall, the process of industrial data analysis can be summarized by the term “big data to smart data”.

In certain cases, the information resulting from industrial data analysis is not meaningful enough on its own. In these cases, the required information cannot be extracted exclusively out of the data pool generated by the factory internal cyber-physical systems. In order to fill this gap, *industrial data enrichment* needs to be applied. The concept of industrial data enrichment can be described as followed: Depending on the task to be fulfilled and the availability of data within the company, external data sources are identified and added to the database. Examples of these external data are market analysis, economic and political forecast, exchange rates or alike. Moreover, collected data from the manufactured products that are now in use are to mention in this context. The used data sources can be both free of charge or payable services.

Another case of missing data can be attributed to the reason that certain data exists within the company but not in a suitable form. This is the case, if documents are only available as hard copies or processing steps are executed with media discontinuity, leaving data in an analog form. To address this problem, methods for systematic *digitization* are necessary. However, the process of digitization goes beyond the pure activity of transferring information from an analog in a digital state: The systematic tagging and filing of the new digitized data ensures the finding and utilizing of it in a practicable way.

The applications of cyber-physical systems create and require great amounts of data at the same time. To ensure unhindered process sequence and flow of data, the interconnection of all involved cyber-physical systems is required. In certain scenarios like strategic production networks, this means an exchange of information in between independent companies via the internet. To secure safety and security, *industrial cyber security* is an application field to emphasize for the safe operation of cyber-physical systems.

4.3 Industrial Smart Services

The information and conclusions gained from industrial smart data do not only directly reenter the production execution process but constitute the foundations for a broad range of *industrial smart services*, too. These data driven services can be in-house services, supporting the own value creation processes or services offered to external customers. Therefore, the gathered data can be seen as an enabling foundation for new services, which have the aim to further optimize the value creating process. Besides the smart data based services, there are services, e.g. qualification courses, which operate with limited usage of data. Both smart data intensive as well as less data requiring, internal and external service offerings are described in the following precisely.

The application of industrial cyber-physical systems is often associated with the opportunity for the enhancement of existing business models or the creation of entirely new ones. Therefore, the conclusions gained out of the industrial smart data can be used for *business model development*. The availability of detailed information about both production processes and products in use enriched with data from other contexts, facilitate the systematic development or adjustment of business models.

While the application field of business model development shows the potential for strategic usage of smart services, there are also operative scenarios. In this sense, *employee qualification* is a necessary action to enable a functioning integration of users into cyber-physical systems. The compiling and execution of contemporary training concepts ensure the familiarity and appropriate interaction of employees with cyber-physical systems.

Based on conducted employee qualification measures and systematic user integration into cyber-physical systems, advanced forms of *knowledge management* can be introduced. The objective of these knowledge management systems is to gather implicit knowledge of employees for a reintroduction in case of need. By doing so, the implicit knowledge of the staff becomes another data source for the application field of industrial data enrichment. To assure the willingness of the workforce to contribute to these knowledge management systems the process of knowledge collection must not be unnecessary disruptive and the benefits offered must outdo the effort.

A very illustrative example for the advantageous utilization of knowledge management systems is *maintenance*. Maintenance activities aim to assure the availability of production capacities. They include upkeeps and inspections during the running process as well as repairs and overhauls in the case of malfunctions and errors. While the handling of recurring task in the field of upkeeps and inspections are standardized and scheduled, the repair of malfunctions and the solving of errors can be considered as a predominantly diverse with a high degree of freedom in execution. Especially when malfunctions and errors with a high complexity come in presence, knowledge from previous occurrences about the solving comes in hand. Ideally, this knowledge is presented in a structured way in form of an action guideline. Resource cockpits are a suitable platform for the accumulation of these and other context based information provided to the maintenance personnel. The value in use of the resource cockpit increases over time since every solution to a malfunction or error is entered into the system and linked to an event (collection of industrial smart data). Whenever the malfunction or error occurs again, the assigned worker can profit of the preparatory work of colleagues. Overtime the positive effects of a non-personal learning curve set in.

Besides the described potentials for maintenance due to advanced knowledge management, cyber-physical systems can be applied to improve the overall maintenance process. The objective is the reduction of machine downtime by continuously analyzing the condition of the machinery components (condition based maintenance). Entering both the data collected by the installed sensors of all machinery components and the occurrences of errors into the industrial data analysis, patterns, and causal correlations can be identified. Based on this information the accuracy of predictive maintenance can be improved. The application of predictive maintenance can have a positive effect on the availability of production capacities due to fewer disorders in the production process and optimized periods of use of each machinery component. Furthermore, the application of cyber-physical systems enhances the use of remote maintenance. Based on the vast availability of information extracted from industrial smart data, remote activities to solve problems or to support personnel which are at the scene from a distance can be offered.

All previously introduced industrial smart services can be implemented as in-house solutions but also as services offered to external companies as service seekers. The market commercialization of *industrial service systems* provides an opportunity to gain further financial returns based on cyber-physical systems. These services range from consulting activities to strategic cooperation between manufacturer and service provider within production or data evaluation.

4.4 Smart Products

Besides the until here presented potentials within the several application fields of the so far introduced spheres, the industrial value creation can profit significantly due to the integration of cyber-physical systems into the after sales period of the product life cycle.

Accordingly, smart products and the related smart data and smart services in the customer context offer the possibility to maintain a continuous connection between the customer and the product in use on the one side and the manufacturer on the other side. The benefits of this after sales connection accrue for both the manufacturer and the customer. The manufacturer receives information about how customers use their products and can therefore align future hard- and software design due to customer needs and give out updates if necessary but most importantly adjust the production process if malfunctioning of products in use is detected. The product quality is hereby improved continuously. So the business units of marketing, product development, and production benefit from the described data backflow in general. Of course anonymization and data security are the fundamental prerequisite for these procedures. The customer also profits from the cyber-physical components of the product. This becomes clear when analyzing the characteristics and *functionalities* of smart products. With identifiable, situated, pro-active, adaptive, context-aware and real-time capable the attributes of smart products are very similar to those of the production mechanisms in the smart factory. Based on these, smart products can offer innovative forms of customer value. This becomes comprehensible when considering the *product in use*: In combination with ubiquitous computing surroundings like in smart home applications, smart products adapt to preset preferences and user behavior. With adaptive *system integration,* these products access *product-related smart services*. In this way, the smart product is the tangible platform for a variety of services used depending on situation and context. Smart products can also be composed modular, giving the chance to extended functionalities if needed. *Modularity* allows the adjustment of products with regard of the users' preferences.

The inclusion of smart products into the product portfolio offers companies multiple benefits. First, the use of cyber-physical systems is not just for the advancement of the production process itself but also for the manufacturing of products with innovative forms of customer value. Second, with smart products it becomes easier to gather data about the product in use, which is valuable for the application fields of quality management and research and development.

4.5 Product-Related Smart Data

Just like in the sphere of industrial smart data, *product-related smart data* needs to be evaluated by an analytical process. As well as in the industrial process, the following application fields are preconditions for the derivation of valuable information: *Data warehousing, process engineering for data analysis, data analysis* and *data enrichment*. The outcomes of the data processing are used for two purposes. On the one hand, it is an enabling element for product-related smart services, on the other hand it enters the industrial value-adding process by being integrated as data from another context in the process of industrial data enrichment. Synonymous to industrial data processing, the product-related counterpart is dependent on reliable *cyber security* solutions.

4.6 Product-Related Smart Services

Product-related smart services constitute as the intangible part of the hybrid value creation complementing the tangible part, the smart product. In this context, c*onsumer service systems* act as a content aggregator, combining several independent services to a service package which suits to the individual needs determined by the consumer and the usage scenario. In most cases, these consumer service systems are controlled via apps installed from *app stores* on smartphones or other smart products. *User communities* can be used to gain information about user perceptions and usage behavior as well as to foster user driven innovations expanding the function ability of smart products and services. Another application field is the a*fter sales support* offered by the product manufacturer. With live support, customer service can provide assistance in case of functional problems. Software updates enable a continuous implementation of improvements coming from findings of smart data analysis of both industrial and product-related origin.

4.7 Utilization of the Application Map

In conclusion, a broad variety of application fields for industrial cyber-physical systems as well as their mutual influence on each other becomes apparent. Once more, it is to emphasize how cross-linked and interdependent the various application fields are. To give a complete overview of all application fields and related domains within this section, they are displayed in Fig. 2.

The reasons for the introduction of cyber-physical systems in the industrial value creation process are manifold: First, it offers the chance for further process efficiency with higher output and lower non-rectifiable rejects. Second, in many markets the customer demands have oriented towards individualizable products equipped with features pooled under the term smart as described in Sect. 4.4 of this chapter [23]. Often, for manufacturing these products the application of cyber-physical systems is a requirement. With an optimized production and an improved value proposition the own market position can be strengthened. Third, cyber-physical systems and the new level of data availability can give the basis for new business models and therefor an extension of companies' service spectrums or a repositioning on the market [27]. Summarizing, whether triggered by technology push or market pull and whether updating existing or building new structures, the introduction of cyber-physicals systems holds out the prospect of improvement of business success.

The decisive factors in this context are which application fields to choose, where to start, and how to proceed. Besides the aim to give a comprehensive overview of application fields for cyber-physical systems in the industrial context, the application map of this chapter is designed to support decision makers confronted with the stated above questions. How to use the map in a systematical way is described in the following.

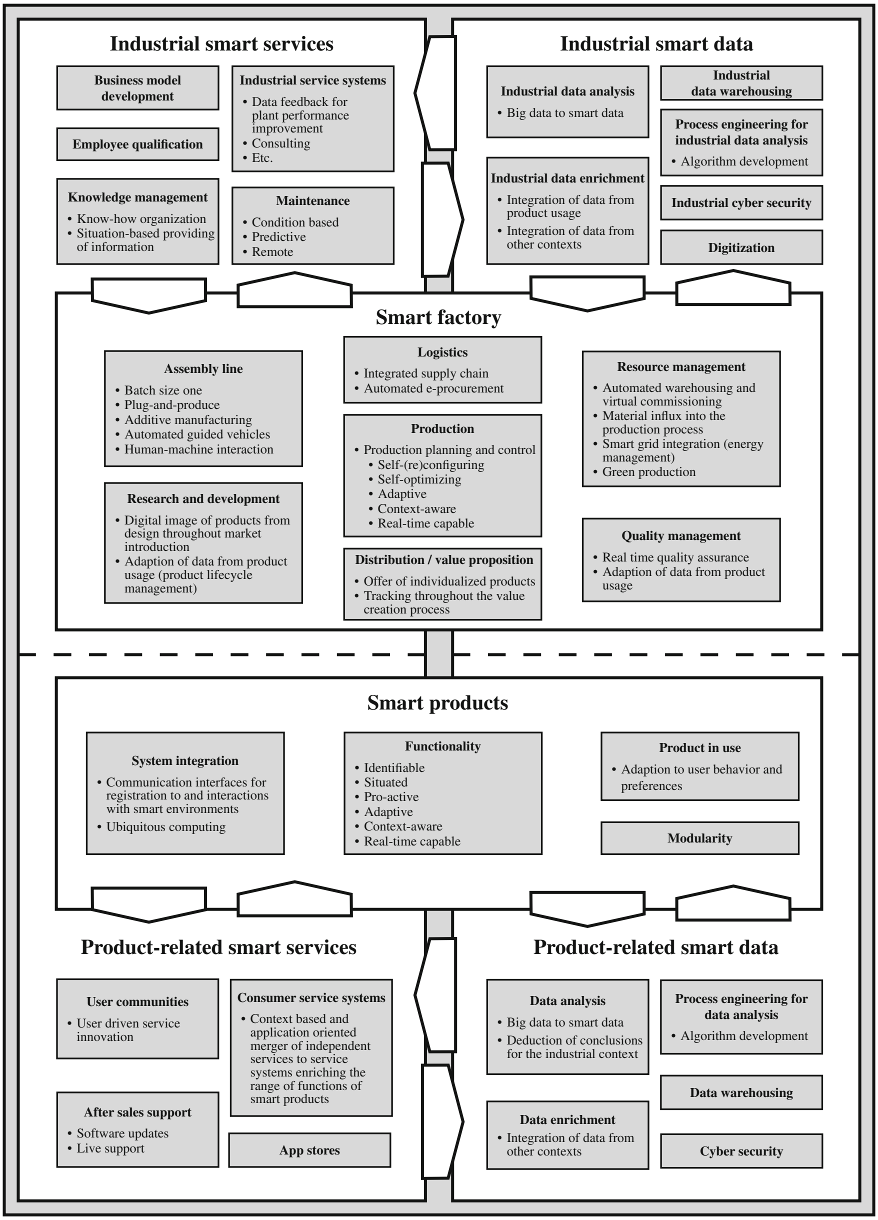

Fig. 2 An application map for industrial cyber-physical systems

Depending on the business scope of the company, a suiting sphere of the application map needs to be chosen. For companies with core competencies in the manufacturing process this is the sphere of the smart factory, for IT companies the spheres of smart data and for service providers the spheres of smart services. Once the suiting sphere is selected, specific applications fields within this sphere need to be chosen based on the individual companies' characteristics. These can be fields with pronounced expertise to strengthen but also fields of concern with potential for improvement. Then dependencies on surrounding application fields as well as potential synergy effects need to be estimate and anticipated. As the following step, again dependencies and synergy effects need to be estimated but this time not on field but sphere level. For example, an improvement within the field of maintenance is depending pronouncedly on the field of knowledge management within its own sphere (industrial smart services) but also on the fields assembly line, production and industrial data analysis from neighboring spheres (smart factory and industrial smart data). Depending on competencies, relevance for the business model and capital availability the decision needs to be made between in-house solutions or recourse on external service providers. This process should be repeated for every aimed application field with iterative cycles until the intended application scenarios for cyber-physical systems are planed satisfactory. During the process of implementation the map can be used for orientation and tuning continually. Once the implementation is done the map can serve as an underlying structure for validation and benchmarking.

The application map supports the decision making process on several levels, showing opportunities to improve and expand the own value creation concept with scopes for the establishment of value-adding networks with short term or strategic business partners. In this process the map is especially helpful due to the comprehensive view it gives on the implementation of cyber-physical systems in form of a holistic framework both on technological as well as on managerial level. Supporting this, the elaborated categories of Sect. 3 give a good orientation in which general topics expertise is needed for the professional handling of industrial cyber-physical systems.

5 Summary and Outlook

In this chapter, the foundations of cyber-physical systems were looked at in different dimensions. The organizational dimension was identified as most critical for the further development in the field. The categories in which improvements can be expected in the future were discussed and displayed in detail. There are nine categories with different scopes but all relevant and necessary for various applications of cyber-physical systems. Finally, concrete fields of application for the implementation of cyber-physical systems to reach such improvements were named and categorized and linked among each other. The application map is expected to help decision makers in the process of identifying suitable application fields for industrial cyber-physical systems and then implementing them into these matching to their business situation.

Due to the dynamic development of the field and the large research and development funding on offer, the future direction of cyber-physical systems is hard to foresee. The ability of managers to gain orientation about the possibilities for technical progress and the opportunities for business success will play a decisive role. The application map introduced in this chapter is only a starting point for providing research-based support for the extensive implementation and fruition of potentials of cyber-physical systems in industrial value creation processes.

References

1. acatech (ed) (2011) Cyber-physical systems-Innovationsmotor für Mobilität, Gesundheit Energie und Produktion., acatech POSITIONSpringer, Heidelberg
2. Ali ABMS, Azad S (2013) Demand forecasting in smart grid. In: Ali ABMS (ed) Smart grids—opportunities, developments, and trends. Springer, London, pp 135–150
3. Bock T, Linner T, Ikeda W (2012) Exoskeleton and humanoid robotic technology in construction and built environment. In: Zaier R (ed) The future of humanoid robots—research and applications. InTech, Rijeka, pp 111–146
4. Böhmann T, Leimeister JM, Möslein KM (2014) Service systems engineering—a field for future information systems research. Bus Inf Syst Eng (BISE) 6(2):73–79
5. Brecher C, Jeschke S, Schuh G et al (2011) Integrative Produktionstechnik für Hochlohnländer. In: Brecher C (ed) Integrative Produktionstechnik für Hochlohnländer. Springer, Berlin, pp 17–82
6. Bundesministerium für Bildung und Forschung (ed) (2014) Industrie 4.0-Innovationen für die Produktion von morgen. BMBF
7. Byoungsoo K, Minhyung K, Hyeon J (2014) Determinants of postadoption behaviors of mobile communications applications: a dual-model perspective. Int J Hum Comput Interact 30 (7):547–559
8. Cyphers.eu (2014). http://www.cyphers.eu/sites/default/files/D2.2.pdf. Accessed 14 Apr 2015
9. Fallenbeck N, Eckert C (2014) IT-Sicherheit und Cloud Computing. In: Bauernhansl T, ten Hompel M, Vogel-Heuser B (eds) Industrie 4.0 in Produktion, Automatisierung und Logistik. Springer, Wiesbaden, pp 397–431
10. Fortino G, Guerrieri A, Russo W, Savaglio C (2014) Middlewares for smart objects and smart environments: overview and comparison. In: Fortino G, Trunfio P (eds) Internet of things based on smart objects—technology, middleware and applications. Springer International Publishing, Heidelberg, pp 1–27
11. Geisberger E, Broy M (eds) (2015) Living in a networked world—integrated research agenda cyber-physical systems (agendaCPS). acatech Study. Herbert Utz Verlag, Munich
12. Gutierrez A, Dreslinski RG, Wenisch TF et al (2011) Full-system analysis and characterization of interactive smartphone applications. In: IEEE international symposium on workload characterization, Austin, 6–8 November 2011, pp 81–90
13. Heinrich B, Linke P, Glöckler P (2015) Grundlagen Automatisierung-Sensorik, Regelung, Steuerung. Springer, Wiesbaden
14. hvm.catapult.org.uk (2016). https://hvm.catapult.org.uk/. Accessed 17 Apr 2016
15. Jeschke S, Vossen R, Leisten I et al (2014) Industrie 4.0 als Treiber der demografischen Chancen. In: Jeschke S, Isenhardt I, Hees F, Henning K (eds) Automation, communication and cybernetics in science and engineering 2013/2014. Springer International Publishing, pp 75–85
16. Lee EA (2008) Cyber physical systems: design challenges. In: 11th IEEE international symposium on object/component/service-oriented real-time distributed computing, Orlando, 5–7 May 2008, pp 440–451
17. Levin SL, Schmidt S (2014) IPv4 to IPv6: challenges, solutions, and lessons. Telecommun Policy 38(11):1059–1068

18. Liu SX (2016) Innovation design: made in China 2025. Des Manage Rev 27(1):52–58
19. Mahnke W, Leitner SH, Damm M (2009) OPC unified architecture. Springer, Heidelberg
20. manufacturing.gov (2015). http://www.manufacturing.gov/advanced_manufacturing.html. Accessed 30 Sept 2015
21. Manzei C, Schleupner L, Heinze R (eds) (2016) Industrie 4.0 im internationalen Kontext-Kernkonzepte, Ergebnisse, Trends. VDE, Berlin
22. Marwalder P (2011) Embedded system design: embedded systems foundations of cyber-physical systems. Springer, Netherlands
23. Mühlhäuser M (2008) Smart products: an introduction. In: Mühlhäuser M, Ferscha A, Aitenbichler E (eds) Constructing ambient intelligence. Springer, Berlin, pp 158–164
24. Nist.gov (2013). http://www.nist.gov/el/upload/Exec-Roundtable-SumReport-Final-1-30-13.pdf. Accessed 14 Apr 2016
25. Oks SJ, Fritzsche A (2015) Importance of user role concepts for the implementation and operation of service systems based on cyber-physical architectures. In: Innteract conference, Chemnitz, 7–8 May 2015, pp 379–382
26. Pflaum A, Hupp J (2007) Auf dem Weg zum Internet der Dinge-das Versprechen innovativer Smart-Object-Technologien. In: Bullinger HJ, ten Hompel M (eds) Internet der Dinge. Springer, Berlin
27. Porter ME, Heppelmann JE (2014) How smart, connected products are transforming competition. Harv Bus Rev (HBR) 92(11):64–88
28. Purser S (2014) Standards for cyber security. Best Pract Comput Netw Def Incid Detect Response 35:97–106
29. Reichwald R, Piller F (2009) Interaktive Wertschöpfung-Open Innovation, Individualisierung und neue Formen der Arbeitsteilung. 2, vollständig überarbeitete und erweiterte Auflage. Gabler, Wiesbaden
30. Sommer L (2015) Industrial revolution—industry 4.0: are german manufacturing SMEs the first victims of this revolution? J Ind Eng Manage (JIEM) 8(5):1512–1532
31. Thiel C, Thiel C (2015) Industry 4.0—challenges in anti-counterfeiting. In: Reimer H, Pohlmann N, Schneider W (eds) ISSE 2015—highlights of the information security solutions Europe 2015 conference. Springer, Wiesbaden, pp 111–120
32. Tolio T (ed) (2009) Design of flexible production systems: methodologies and tools. Springer, Berlin
33. VDI (2013) Thesen und Handlungsfelder-Cyber-Physical Systems: Chancen und Nutzen aus Sicht der automation
34. Velamuri VK, Neyer A-K, Möslein KM (2011) Hybrid value creation: a systematic review of an evolving research area. J für Betriebswirtschaft (JfB) 61(1):3–35

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