

Matthias M. Herterich, Falk Uebernickel, Walter Brenner

# The Next Wave of Service Innovation

**HOW CYBER-PHYSICAL SYSTEMS  
CAN BE LEVERAGED FOR EFFECTIVE  
INDUSTRIAL EQUIPMENT  
OPERATIONS AND EMPOWER  
INDUSTRIAL SERVICE**





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\*Parts of this work have already been published as [1]: Herterich, MM., Uebernicketel, F., and Brenner, W. 2015. "The Impact of Cyber-Physical Systems on Industrial Services in Manufacturing," Procedia CIRP

# 4 Things to Remember

## 1

### **Cyber-physical systems are the new standard for managing and servicing industrial equipment.**

Digitalization in the equipment industry is often associated with smart manufacturing processes in the early phases of the product lifecycle. In a narrow sense, it serves as a tool to increase efficiency in product engineering and manufacturing at a shop floor level. With servitization in manufacturing the operations lifecycle stage is becoming increasingly important as manufacturers aim at also monetizing the operations phase of the equipment

they manufacture. Although the product lifecycles of industrial equipment often span around 20-30 years, digitalization of the installed base comes quicker than you might think. Cyber-physical systems (CPS) and smartified industrial equipment unlock unforeseen opportunities. Since the market is changing, it might be impossible to operate and service industrial equipment efficiently and effectively without using CPSs in a couple of years.

## 2

### **Take an end-to-end perspective and focus on stakeholders.**

The industrial service business is characterized by a high level of complexity in terms of service processes and involved organizational stakeholders. To leverage effectively the new technical capabilities of industrial equipment that become smartified and connected to the internet, taking an end-to-end perspective in terms of business processes is indispensable. Integrated success-

fully into field service processes and mobile work support systems, smartified industrial equipment is a highly valuable tool for ensuring reliable equipment operations. To maximize benefits from the new opportunities, managers should take an end-to-end perspective focusing on the added-value among the service processes and the stakeholders involved in service provisioning.

### 3

## Implement use scenarios in a modular way. Start with the easy ones. Develop define an appropriate platform.

The unforeseen new opportunities facilitated by cyber-physical industrial equipment can be overwhelming to decision makers. We recommend to start with implementing use scenarios that are highly relevant yet easy to implement. Combine modular and individual use scenarios in a later

stage for additional added-value. At any point of time, however, do not lose sight of the big picture to establish a robust IT-architecture enabling a sound foundation as well as flexibility for your business.

### 4

## Collaborate with partners and identify your value in the ecosystem.

With CPSs, the product and service business in the equipment industry is getting extremely complex and interwoven. More stakeholders are involved in value creation. Irrespective of the particular industry, your organization must compete and effectively collaborate with many stakeholders in the

extended CPSs ecosystem such as sensor manufacturers, software and analytics companies. Identify the value that your organization can provide within your ecosystem and try to harness the new technological capabilities effectively.

# Abstract

Both managers and researchers agree: Manufacturing as one of the most traditional and conservative industries is undergoing the most fundamental change in decades. Facing shrinking margins in their core business, manufacturing firms of industrial equipment and capital goods started to expand their business by also offering maintenance, repair and overhaul (MRO) services addressing technical support of equipment installed at the sites of equipment operators [2–5]. The term “servitization in manufacturing” was coined to describe the service-orientation of the manufacturing industry following a service-dominant logic [5,6]. Furthermore, digitalization and pervasive computing increasingly dominate our daily lives and change entire industries. Especially in rather traditional and physical industries such as manufacturing of industrial equipment and medical devices, tangible products such as industrial machinery become industrial CPSs equipped with connectivity and sensors and transform to programmable, addressable, sensible, communicable, memorable, traceable and associable products [7]. With the Industrial Internet [8] and the mega-trend of the Internet of Things [9], new opportunities for digital innovation (i.e. innovative product and service offerings) in the service business can be

realized leading to new revenue potential as well as increasing efficiency for the existing service business. Digitalization gives organizations in the manufacturing industry new possibilities for monitoring, controlling, optimizing, and automating operations of industrial equipment and provides new opportunities in terms of increased operational efficiency in the service business.

This report is an attempt to reveal the myriad opportunities of creating business value enabled by digitalization and new technological capabilities in the equipment manufacturing industry. After introducing relevant terms and concepts, an overview of the service ecosystem in the equipment manufacturing industry is given. On that basis, seven clusters of application scenarios are presented. The presented universal application scenario clusters are enriched with illustrative use scenarios from various industries. With the servitization trend in the manufacturing industry, the main focus of this investigation lies on the service business and the operations lifecycle phase of industrial equipment. The report ends with a conclusion and recommendations for practitioners in the manufacturing industry on how to reap the benefits of industrial equipment becoming digitalized.

# List of Abbreviations

<b>API</b>	Application Programmable Interface
<b>B2B</b>	Business to Business
<b>B2C</b>	Business to Customer
<b>BOL</b>	Beginning of Life
<b>CPS</b>	Cyber-Physical Systems
<b>EBIT</b>	Earnings before Interest and Taxes
<b>EOL</b>	End of Life
<b>IOT</b>	Internet of Things
<b>IS</b>	Information Systems
<b>IT</b>	Information Technology
<b>KPI</b>	Key Performance Indicator
<b>M2M</b>	Machine-to-Machine (Communication)
<b>MOL</b>	Mid of Life
<b>MRO</b>	Maintenance, Repair and Overhaul
<b>PLM</b>	Product Lifecycle Management
<b>SCPS</b>	Smart, Connected Products
<b>SLA</b>	Service Level Agreement
<b>TCO</b>	Total Cost of Ownership

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# Why we wrote this report

With digital innovation, our everyday personal lives become increasingly dominated by technology. The convergence of the digital and the physical world has huge implications on the added value that can be realized by using innovative information technology. Unlike industries with non-tangible products (e.g. financial or pure service industries) physical and mechanical goods have first to be connected to the internet to benefit from digitalization. Sensor technology and ubiquitous connectivity now become part of industrial capital goods and serve as a game-change for an entire industry. In particular CPSs enable digital innovation for the industrial product- and service business in the traditional manufacturing industry.

Metcalf's law states that the value of a communication network increases with every new node that is connected to the network. With just two phones connected to each other, the benefits are limited. Having millions or even billions of devices connected to each other increases drastically the value of a phone. With industrial machinery getting digitalized, this example can be taken one step further: According to McKinsey Global Institute, the trend of equipping tangible products, such as industrial equipment, with sensors and connecting them to the internet will drive productivity growth between 2.5% and 5% over the next ten years, based on highly conservative assumptions. In the manufacturing industry, this would result in combined revenue growth and cost savings of \$900 billion per year [10]. By 2025, 80-100% of all manufacturing organizations will use CPSs, leading to

an economic impact of \$2.3 trillion for the global manufacturing industry exclusively.

In addition to tangible products becoming connected to the digital world, the trend of servitization has far reaching implications for the manufacturing industry. Product offerings gradually transit to service offerings. With servitization as a major trend in manufacturing, the service business and thus the operations phase of industrial equipment is gaining in importance. CPSs give organizations in the manufacturing industry unimagined capabilities for monitoring, controlling, optimizing and automating operations of industrial equipment. They provide new opportunities to increase operational efficiency in the service business and enable new hybrid business models. Those capabilities are particularly important for industrial equipment in operation that is installed in field at the site of equipment operators. All equipment instances in the field, referred to as 'installed base', are connected to a central system – such as an equipment cloud - where all relevant operational data about the industrial equipment is stored. With advanced analytical capabilities and vast amounts of historic operational data, valuable insights about the entire installed base or individual equipment instances can be derived. Those insights can be used in myriad ways during the lifecycle of industrial equipment to fuel the trend of servitization in manufacturing by generating operational efficiencies for established service offerings and new service opportunities.

On the one hand, the new technological capabilities help to make the delivery and operations of existing service business models more efficient. Having the ability to derive insights ad hoc, service technicians can be equipped with mobile technology (e.g. tablets, smartphones, or wearable technology) supporting their jobs in the field. With CPSs, field service technicians not only see which units are broken and the location of the broken equipment, but they also get detailed information about which components are the reason for the breakdown and what spare parts are needed to fix the problem. On the other hand, the new technological capabilities can be leveraged to offer new

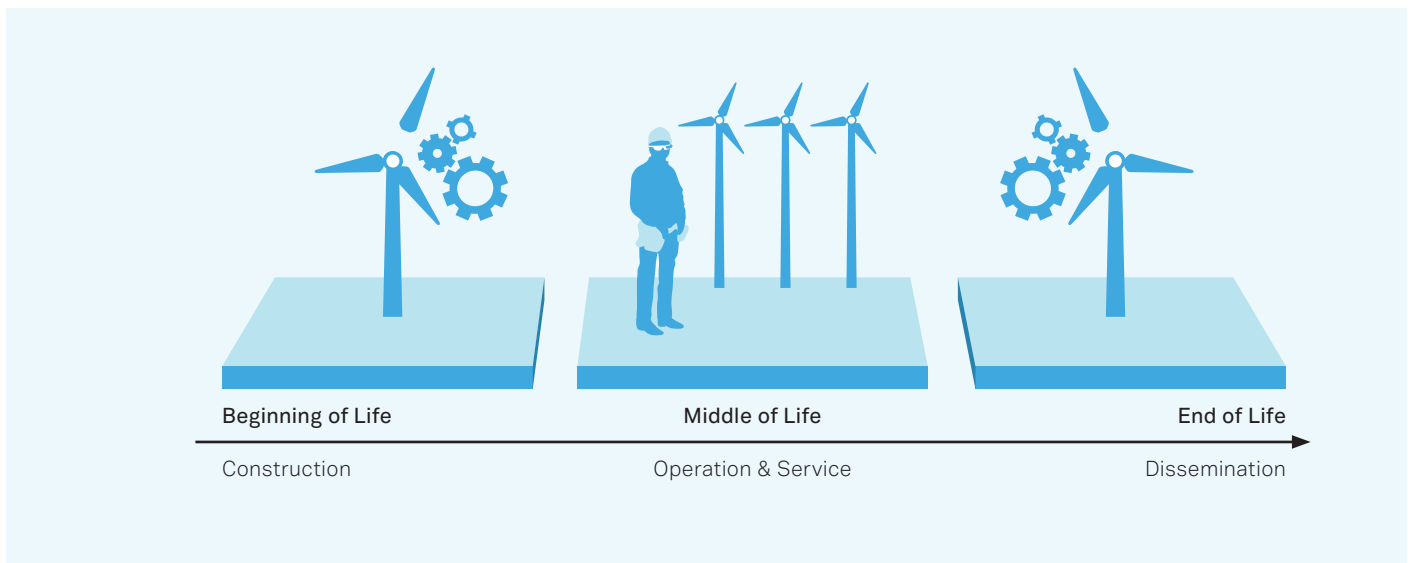
value-added services to the equipment operator and even be used to engineer better industrial equipment and hence drive the product business. Decision makers in the equipment manufacturing industry need to be informed about the opportunities that emerge with this new technology. Because of the servitization trend, the operations phase of industrial equipment becomes more important. This report is an attempt to examine the added value of CPSs for the operations phase of industrial equipment. Within this report we identify and discuss seven clusters of use scenarios enabled by CPSs.



# Exciting times for a traditional industry

The manufacturing industry is subject to fundamental structural changes. From a lifecycle perspective on capital goods and heavy equipment and machinery, production and sales of such goods barely account for 5 to 10% of their lifetime cost/value. Hence, the sales transaction of industrial equipment can be seen as the beginning of

a long-term customer relationship resulting in the opportunity for high margin revenue for the equipment manufacturer or service organization and allows profitable service business models during the operations phase of industrial equipment [12–15]. Figure 1 provides an overview of the product lifecycle of industrial equipment.



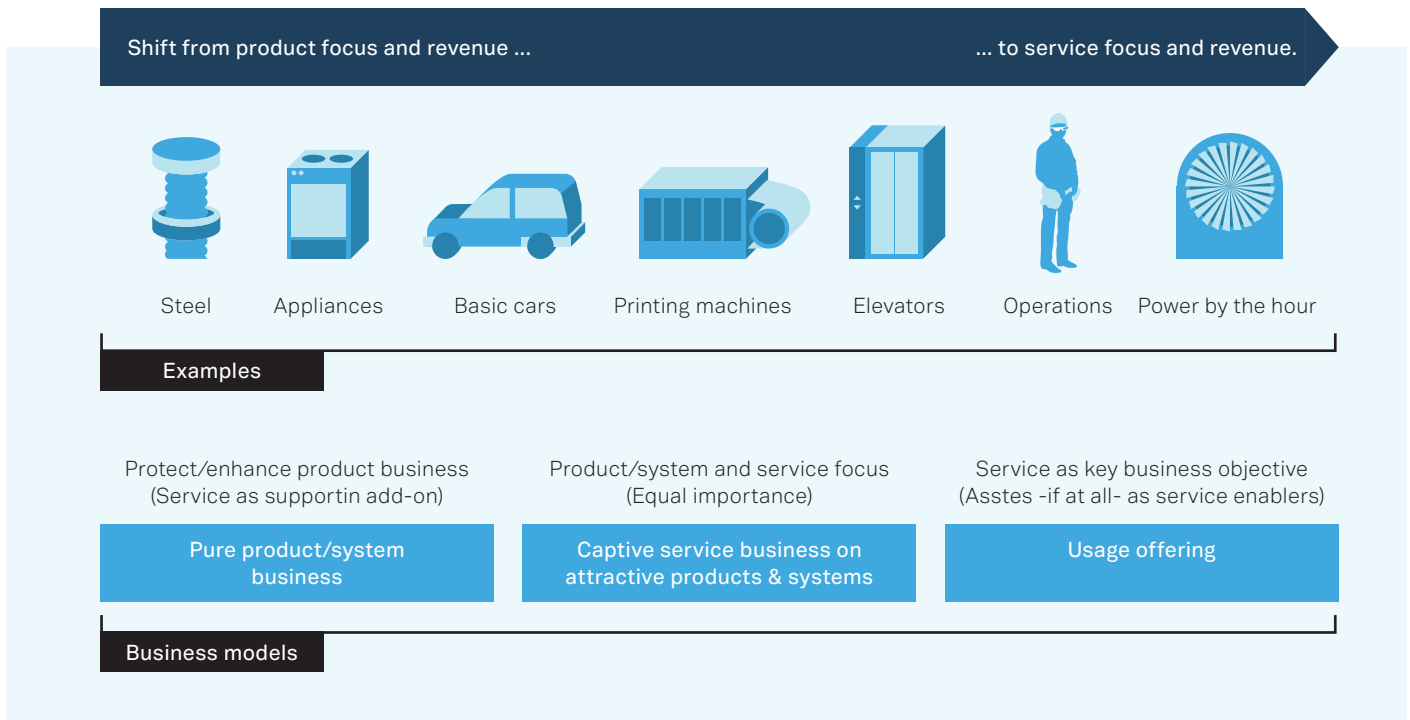
**FIGURE 1:** Product lifecycle of industrial equipment

Realizing this opportunity and facing shrinking margins in their core business, manufacturing firms of heavy equipment and capital goods started to expand aggressively their business: For some years now, they offer maintenance and repair services addressing technical support of equipment installed at the equipment opera-

tors' site [2–5]. Consequently, business models of equipment manufacturers increasingly aim at exploiting the operational stage of the goods by providing MRO services. In sum, the manufacturing industries changed significantly over the last years and will change even more in the future. The service business continuously gains in importance

for manufacturing firms [13]. Servitization as a major trend in manufacturing becomes omnipresent [6,13]. With digitalization, new interaction channels evolve and take the service business to a new level. In manufacturing, however, organizations often fail to exploit the financial benefits of extending their service business. One reason lies in the increasing competition and the race for service efficiency [16]. The installed base is getting equipped with sensors and connectivity. This trend of connected equipment and low-cost sensing capabilities in combination with advanced computing and analytical capabilities to generate meaningful insights and actionable information based on operational

data allows equipment manufacturers to innovate and realize new business models. Traditional manufacturing companies often no longer sell industrial equipment to their customers (i.e. equipment operators) and generate additional revenue with the MRO business. Instead, they offer increasingly their products as a service. Rolls Royce is the classic example, having shifted from “selling aircraft turbines” to “selling power by the hour”. Hence, constant revenue streams are generated by the performance of the equipment at the equipment operators’ site, and the operations phase is becoming more and more important.



**FIGURE 2:** Business models in manufacturing are shifting from product- to service-orientation

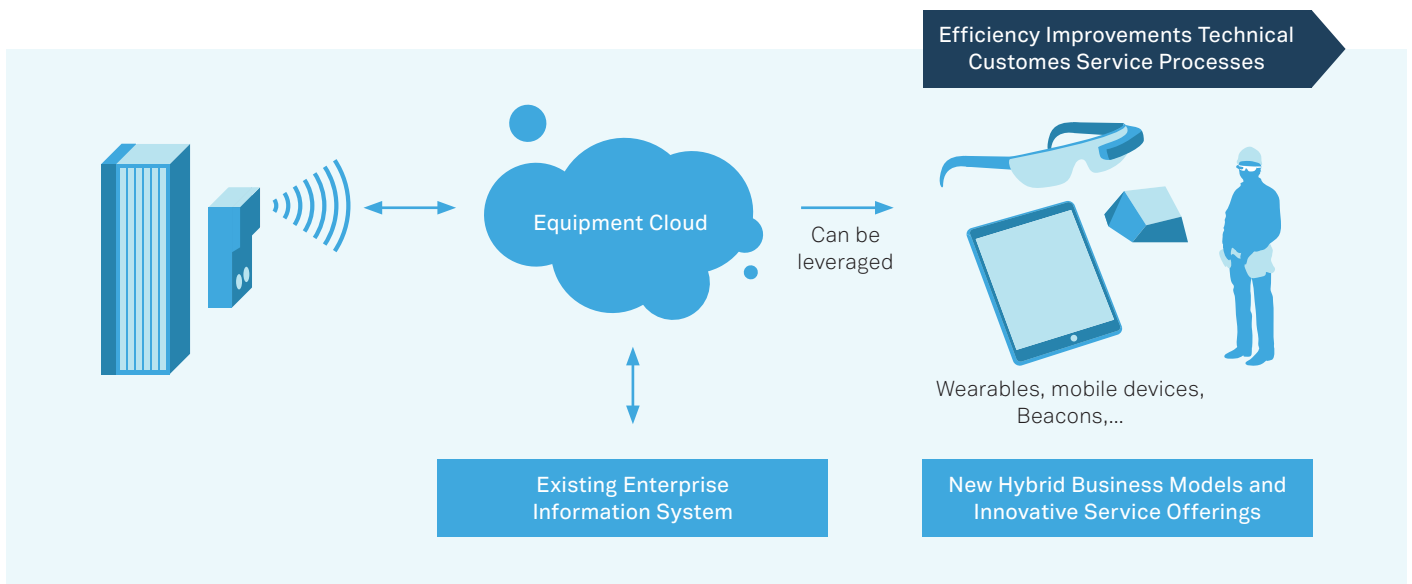
In the manufacturing industry, the physical and the digital world move closer together. Advanced technological capabilities allow monitoring the condition of industrial equipment in the field during the lifecycle. CPSs provide industrial equipment manufacturers new opportunities—in particular for the service business. The emerging technology creates new possibilities for complementing field service [15]. Hence, new opportunities for a smart

service business arise as remote real-time monitoring of industrial equipment becomes possible. In combination with historic data and advanced industry-specific analytical capabilities [17], new opportunities arise. In particular, the new technology provides increased internal efficiency for traditional service operations. However, additional benefits can be identified by taking a comprehensive perspective on the functional benefits of

CPSs for industrial service. New technology paves the way to generate additional value, fuels digital innovation [7,18], and creates new hybrid business models.

The manufacturing industry is about to redesign their business models: the considerably longer operations phase of industrial equipment compared to goods in the consumer business is becoming increasingly a major focus. In this phase, industrial goods are no longer located in the sovereign territory of the equipment manufacturer (i.e. shop floor) but instead provide value to equipment operators scattered throughout the field.

Figure 3 provides an overview on the new opportunities for the industrial service business. Equipment gets connected to the internet and operational data can be leveraged during the product lifecycle. Analyzing the data results in insights about the equipment status that drive efficiency improvements of the traditional MRO processes of the field service workforce. Besides those efficiency improvements, new hybrid business models and innovative service offerings emerge.



**FIGURE 3:** New opportunities for the industrial service business

Manufacturers, service organizations, and equipment operators face the challenge to exploit effectively the emerging technical capabilities of smart, connected industrial equipment. Managers habitually focus exclusively on particular application scenarios that grasp their attention. Hence, this report is an attempt to structure use scenarios for leveraging CPSs for the service business of organizations in the equipment manufacturing industry. We aim to generate an understanding of the different configurations and the characteristics of various scenarios. In the light of servitization in manufacturing, we pay special attention of

how CPSs support and enable new and existing service business models.

This report should help managers and practitioners to understand better the benefits and potential areas of use of smart, connected products and CPSs in an industrial context by providing categories of application scenarios. By providing an overview of use scenarios, this report strives to define the boundaries of the application of CPSs and inspire managers in manufacturing-related organizations to use innovative applications of the new technological capabilities.

# Fundamental terms and concepts

As a foundation for this work, the following section offers a shared understanding of various technical terms used in this report. First, this section provides a brief overview, the key characteristics and lifecycle stages of industrial equipment. Second, we provide an understanding of the concept of

CPSs in the context of industrial equipment. Third, we explore insights on the new capabilities that open up with the rise of CPSs. This section ends with presenting a fundamental understanding of the most relevant stakeholders during operations lifecycle stage of industrial equipment.








# What are key characteristics and lifecycle stages of industrial equipment?

In an industrial manufacturing context, we use the term industrial equipment to describe a specific category of industrial products that we are focusing on within this report. The term refers to industrial capital goods that are characterized as highly productive for value creation at the equipment operators' site. Examples for industrial equipment are all kinds of machinery for materials handling such as cranes or elevators, excavators, moving

equipment such as forklifts, trucks or construction equipment, engineering equipment or equipment for the production and transportation of oil and gas. Because of the rather long lifecycle of such equipment, a lifecycle perspective becomes relevant. The lifecycle of industrial equipment can be divided into three phases [19]. Table 1 provides an overview on commonly accepted lifecycle phases.

	Equipment lifecycle phase	Description	Involved stakeholder groups
	<b>Beginning of life (BOL)</b>	Conceptualization, definition, and realization of industrial equipment	Equipment manufacturer, supplier and co-innovation partner
	<b>Middle of life (MOL)</b>	Use, service, and maintenance of industrial equipment in the field at the equipment operators' site	Industrial equipment operator(s) and service organization(s)
	<b>End of life (EOL)</b>	Reuse of industrial equipment or individual components, refurbishing, disposal with or without incineration	Equipment manufacturer

**TABLE 1:** Lifecycle stages of industrial equipment [21]

First, equipment is planned, engineered, and manufactured in the “beginning of life” phase (BOL). This early lifecycle phase is often tightly interwoven with the operations phase. Operational data collected by sensors during equipment operation can help to engineer better equipment. Based on operational data, equipment can be re-engineered to avoid typical breakdowns in future series of the equipment. Second, after engineering and production of industrial equipment, the product marketing and installation phase and an after-sales phase start [20]. This phase is often named “middle of life” phase (MOL). Usually, all activities are focused on the effective exploitation of the equipment during this lifecycle phase. Third, the lifecycle of industrial equipment ends with the disposal phase, which is also referred to as “end of life” (EOL).

Traditionally, equipment manufacturers generate revenue by manufacturing and afterwards selling industrial equipment. With the trend of servitization, equipment manufacturers more and more monetize the operations phase of the industrial equipment by offering services such as MRO. As industrial capital goods are characterized by long lifecycles lasting over decades [20,21], the operations phase (middle of life) is the most important lifecycle phase of industrial equipment. During the operations phase, high requirements in terms of availability and reliability exist resulting in a special significance for the traditional MRO service business: Efficient and effective MRO services are crucial for smooth operations of the equipment. As industrial equipment is immovable in most cases, traditional MRO services have to be provisioned by a mobile workforce of field service technicians at the equipment operators’ site. The term “after-sales service” was coined describing the traditional MRO service business. This traditional service business model is characterized by high profit margins since equipment operators (i.e. customers) have to pay for the reactive service efforts of the service organization. In case of a breakdown,

spare parts are needed. Costs for the spare parts themselves and installation are directly charged to the equipment operator. Service organizations of equipment manufacturers can leverage dedicated expertise and knowledge about the industrial equipment. As a result, strong lock-in effects and high profit margins can be realized. 3rd party service organizations try to compete with the equipment manufacturers’ service organization. They make the market more competitive, resulting in declining profit margins in the market.

In this context, CPSs serve as a tempting tool for service organizations of equipment manufacturers wishing to gain a competitive advantage during the operations phase of industrial equipment.

Taking the example of performance contracting, instead of just selling their industrial equipment, manufactures become responsible for scrupulously careful equipment operation. Hence, along with a pivoted business model, service organizations of manufactures must rethink their service operations: operational service efficiency is getting more important since equipment operators no longer pay for individual service activities but for smooth operation instead. Equipment manufacturers’ service organizations think of ways to realize increased internal efficiencies for their MRO activities while offering new added-value services to equipment operators. In particular, huge potential exists in terms of mobile work force management and field service. Empowered by mobile work support (e.g. mobile devices and wearables) [31], accessing rich operational data becomes possible. Service activities can be scheduled depending on the current status of the equipment, and spare parts are distributed automatically.

Hence, CPSs serve as a tempting tool for gaining a competitive advantage during the operations phase of industrial equipment. Within this report, we focus on use scenarios of industrial equipment during the operations phase. We pay special attention to the service business.






# What are cyber-physical systems in an industrial context?

Cyber-physical systems can be defined as systems in which collaborating computational elements are controlling physical devices by exploiting data gathered from different sensors and other devices, which operate in the environment of the devices [22]. In an industrial context, the application of the CPSs concept is predominantly driven by initiatives like the “Industrial Internet” [23] and the Industry 4.0 initiative of the German government [24–27]. In their position paper, Acatech [28] defines CPSs as “systems with embedded software [...], which

- » directly record physical data using sensors and affect physical processes using actuators;
- » evaluate and save recorded data, and actively or reactively interact both with the physical and digital world;
- » are connected [...] via digital communication facilities (wireless and/or wired, local and/or global);
- » use globally available data and services;
- » have a series of dedicated, multimodal human-machine interfaces.”

In the industrial context of this report, we follow Mikusz [29] who understands CPSs as “smartified” industrial equipment.



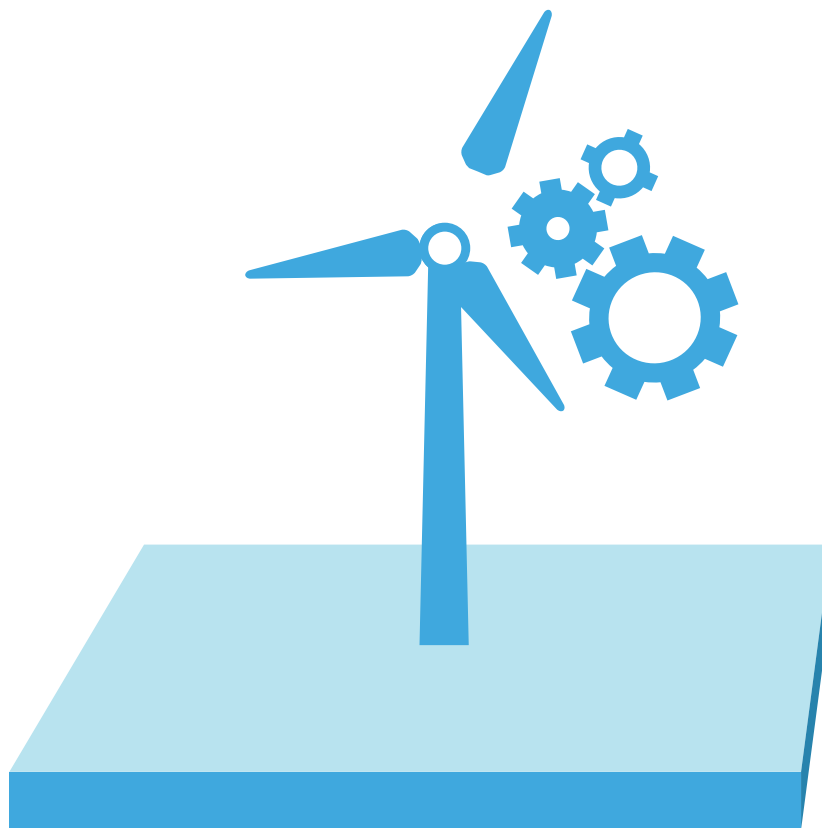
# What are capabilities provided by cyber-physical systems in the industrial equipment manufacturing industry?

Taking a consumer perspective, Heppelmann and Porter identify four different capability levels of digitalized products depending on the technical maturity. We argue that those capability levels also hold true for industrial CPSs. The four levels are named monitor, control, optimization, and automation [30]. First and most fundamental, monitoring capabilities generate visibility of the current status of individual equipment and are fundamental for realizing all kinds of use scenarios. By not only monitoring internal equipment conditions, but also collecting external data, highly relevant insights regarding equipment operation can be drawn. Monitoring capabilities provide the foundation for all kinds of use scenarios and allow organizations to sense the current status of their equipment in

the field — independent of the addressed lifecycle phase of the product. CPSs enable the collection of data through sensors and external data sources. Collected data can serve to continuously being aware of the condition of the equipment and lets the manufacturer or service organization anticipate breakdowns. Second, control capabilities build upon the monitoring capabilities. With control capabilities, it becomes possible to keep track not only of the current status of machines and equipment but also interfere actively in operations. Therefore, organizations must lay the technical foundations to realize a backchannel, allowing organizations not only to sense the current status of equipment but also to respond to unexpected events or equipment malfunctions.

This allows more advanced use scenarios such as controlling individual instances of the installed base from remote locations. Third, optimization capabilities exist. The combination of monitoring the data generated by CPSs and the ability to control equipment of the installed base allows optimizing equipment operation. In other words, the ability to send control commands to the equipment and leverage industry-specific statistical and analytical capabilities allows that equipment operations and service activities can be optimized. By performing preventive maintenance, the downtime of the product can be minimized and costs for expensive field service activities can be avoided. If personnel must be sent on-site for repairs, advanced information about the cause of the defect, the required parts, and how the repair has to be done can improve first-time fix rates. Optimizing equip-

ment and service operations presupposes a high degree of integration as well as advanced analytical capabilities to derive actionable insights from operational equipment data [17]. Forth, leveraging the aforementioned maturity models, equipment operations can achieve a new level of autonomy based on automation capabilities. Depending on the level of intelligence of the product, equipment in the field can even learn about its environment, self-diagnose their own service needs and adapt to the preferences of the equipment operator. The coordinated action of an autonomous product with other products or systems is also possible. As more and more products become connected, the value of this capability can grow exponentially. Depending on the implemented maturity of technological capabilities, different use scenarios can be implemented.



# What are relevant stakeholders in the product lifecycle of industrial equipment?

In the equipment lifecycle, the operations phase is the most important phase [20]. During equipment operations, various stakeholders offer services among the product-lifecycle and exploit the trend of servitization in manufacturing [4,6,13]. The different stakeholders all have different objectives. For investigating the business value of CPSs, it is important to understand and evaluate the perspective of the equipment operators and third party organizations that are relevant in many contexts (e.g. elevator industry, renewable ener-

gy, industrial solutions) instead of just taking the perspective of equipment manufacturers. The key stakeholders groups in the ecosystem are equipment manufacturers with their own service organizations, equipment operators, 3rd party service organizations that provide services for equipment of various manufacturers and white-label sensor and control unit manufacturers. Table 2 presents a fundamental overview on the most relevant stakeholder groups in the industrial equipment service ecosystem.



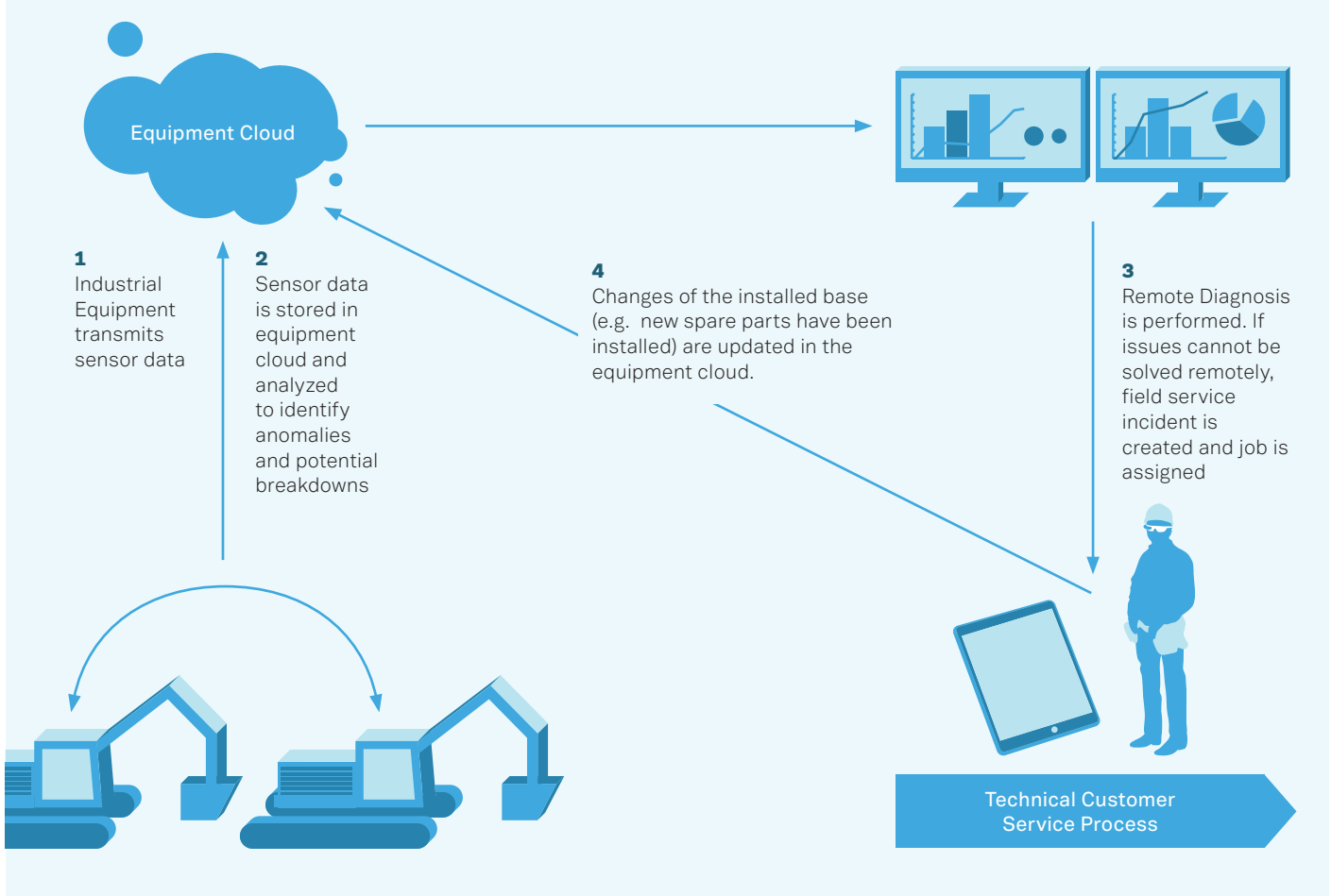
Stakeholder Organization	Description	Key Objectives and Opportunities	Key Challenges
<b>Equipment Manufacturer (OEM)</b>	<ul style="list-style-type: none"> <li>» Original Equipment Manufacturer (OEM) of smart, connected products</li> <li>» Offers MRO services to its clients</li> <li>» Seeks to leverage new technological capabilities to drive efficiency improvement for the MRO service business</li> </ul>	<ul style="list-style-type: none"> <li>» Strong market power by trying to enforce closed systems</li> <li>» Leveraging product knowledge to offer</li> </ul>	<ul style="list-style-type: none"> <li>» Keep pace with technological progress</li> <li>» Understand products as platforms (commodity) for value-adding services</li> </ul>
<b>Equipment Operator</b>	<ul style="list-style-type: none"> <li>» Operates equipment for own value creation</li> <li>» Examples: Airports, hotel chains: elevators and escalators Warehouse operators: materials handling equipment Wind farm operators: wind turbines</li> </ul>	<ul style="list-style-type: none"> <li>» Low TCO (buying price and service cost)</li> <li>» Elimination of asset breakdowns</li> <li>» Interoperability and connectivity</li> <li>» Interoperability, and standardization in terms of smart product components and interfaces</li> </ul>	<ul style="list-style-type: none"> <li>» Monitor and maintain products from various OEMs in a standardized and efficient way</li> </ul>
<b>3rd Party Service Organization</b>	<ul style="list-style-type: none"> <li>» Attacks the service business of the OEM by providing white-label MRO services at a competitive price</li> <li>» Can provide service for assets of different OEMs from one source (one-stop-shop)</li> </ul>	<ul style="list-style-type: none"> <li>» In-depth knowledge of equipment of several asset manufacturers</li> </ul>	<ul style="list-style-type: none"> <li>» Effectively leveraging proprietary service platforms of individual OEMs for their own service business</li> <li>» Providing superior service compared to OEMs in terms of quality and efficiency</li> </ul>

**TABLE 2:** Most relevant stakeholder groups in the industrial service ecosystem

Taking the traditional MRO business as a starting point for our analysis, service organizations of equipment manufacturers have strong knowledge about the industrial equipment they engineer as a key asset for providing service to equipment operators successfully. For example, in the elevator industry, industrial equipment is usually sold as a bundle with a service contract for the first year. Equipment manufacturers have the objective to connect industrial equipment in the field to

an equipment cloud. Sensor data is then stored and analyzed to identify anomalies and potential breakdowns of the equipment. In case of a potential service incident, remote diagnosis can be conducted and potential service visit of field service workforce is scheduled. Changes of the industrial equipment configuration are updated in the equipment cloud for future interaction with the industrial equipment. Figure 4 depicts this standard service scenario enabled by CPSs.

How Cyber-physical systems can help to overcome the service paradox



**FIGURE 4:** CPSs enable efficient and effective MRO service processes

Besides the service organizations of the equipment manufacturer, 3rd party service organizations exist. In the succeeding years, equipment operators are able to choose and engage a competitor or other organizations for service operations. Such organizations often act as full-service providers covering a broad spectrum of services for numerous industrial capital goods. As they have a pooled service workforce, such service organizations can exploit economies of scale and increase operational efficiencies. Once a service technician visits the equipment operator's site, various services are provided at the same time resulting in lower costs relative to the generated revenue. With CPSs as well as equipment clouds for industrial being in place, 3rd party service organizations might struggle

to have access to operational equipment data (i.e. the equipment cloud), depending on the actual configuration of the ecosystem and the CPSs design. Equipment manufacturers must decide on an adequate IT architecture enabling their "smartified" industrial equipment and CPSs. In sum, CPSs shift the balance of power in the stakeholder ecosystem. Equipment manufacturers as privileged operators of the equipment cloud obtain more influence and have to decide provide 3rd party service organizations access to industrial equipment data as well as control capabilities. For digitalizing industrial equipment, basically two approaches are possible - a closed system and an open system approach [30].

By following a closed system approach, the whole system, including sensors, connectivity, analytical capabilities, as well as interfaces for accessing the data, are proprietary. The best preconditions are set in case of a dominating market position of the manufacturing organization. With the right preconditions and effective implementation strategy (closed system requires higher initial investment), a closed system might result in a competitive advantage for the manufacturing organization. Following this approach allows a company to control and optimize the design of all parts (physical and non-physical) of the system relative to one another. Hence, the organization keeps control over technology and data as well as future system developments. Producers of system components are either restricted from accessing a closed system or they are required to license the right to integrate their products into it. For instance, analytical capabilities could be provided by an external IT service provider that is specialized in analyzing industrial data in a dedicated branch. Closed systems might become a de facto industry standard. This would result in enabling the organization that introduces

and uses the standard to capture the maximum value. In the other case however, the organization would have to replace their closed architecture with an industry state-of-the-art architecture resulting in high changing costs.

In contrast to this, an open system enables end equipment operators to assemble and customize dedicated parts of the solution. Equipment manufacturers, 3rd party service organization, or even competitors are invited to interface with the system and contribute to changes depending on their needs. Parts of the CPSs might originate from different organizations (e.g. industrial equipment can be produced by the manufacturer, equipped with a sensor network, and connectivity from a special 3rd party entity). Standardized APIs and well-documented interfaces enable key clients, lead users, or software companies to develop system interfaces and applications to optimize operating and servicing the equipment more efficiently. In total, the open systems approach can foster innovation and system development as multiple organizational entities are able to contribute.

### Insights from the elevator industry - Standardization vs. flexibility and the stakeholder ecosystem

In manufacturing, many sub-industries are characterized by a closely interlinked product and service business. The following example from the elevator industry shows impressively the implications and absorptive powers between the different stakeholders and the impact of CPSs on the service stakeholder ecosystem. It furthermore serves as an example that there are not only technical challenges to overcome as several players act along the product lifecycle.

Equipment manufacturers in the elevator industry traditionally sell industrial equipment to equipment operators. Today, these manufacturers often do not engineer the entire equipment by themselves.

Like in the automotive industry, they often purchase dedicated modules such as control units or the motors from subcontractors or suppliers. With the rise of CPSs, not only the traditional parts of elevators but also technologically more advanced modules such as sensors or connectivity are often bought from dedicated 3rd party. This leads to higher complexity in the engineering and manufacturing processes of industrial goods. In combination with IT capabilities, manufacturers of elevators are enabled to store all the equipment- and sensor data generated by “smartified” elevators in a single place. As the sensor data is considered as being highly valuable, manufacturers aim to

connect every instance of the installed base in the field to a central cloud-based information system (i.e. equipment cloud). They furthermore undertake strong efforts to design the control units and product-interfaces of their industrial equipment as proprietary systems. The reason for this behavior lies in the service business:

Equipment manufacturing organizations aim at generating advantages in servicing their own equipment and forcing out competitors with regard to the traditional MRO service business. With proprietary closed systems, competing service organizations might have difficulties in reading out error codes of the control unit of an elevator. Hence, even if only the interplay between different equipment manufacturers and their respective service organizations is considered, high lock-in effects emerge.

Besides the service organizations of elevator manufacturers, 3rd party service players also want to take their slice of the cake. In the elevator industry, such 3rd party service players are often organizations that provide a large variety of services such as security services, cleaning services, and facility services as a full-service provider. In addition to this competitive environment, equipment operators have additional stakes in the game. Particularly large equipment operators such as airports, hotel chains, or worldwide operating corporations usually use equipment from a number of different manufacturers resulting in a heterogeneous installed base. Nonetheless, for the management of tall buildings, usually integrated facility management systems are used aiming to connect and

integrate the different types of equipment. Examples for equipment that is connected to central building control system are air conditioning, lighting, elevators, and escalators. This enables operators to control centrally and monitor their heterogeneous installed base. Hence, it is a major objective of equipment operators to operate and maintain equipment of different manufacturers in a highly standardized and efficient way. Therefore, a high degree of interoperability and standardization in terms of components and data interfaces of the industrial equipment is necessary.

As we have seen, the objectives of equipment operators are in contrast to the design efforts of equipment manufacturers that pursue a rather proprietary and closed approach for providing connectivity to the industrial equipment. This leads to situations, in which equipment operators even decline to buy industrial equipment comprising proprietary interfaces of control units and bus systems. Instead, for many large equipment operators such as hotel chains or airports, it is best-practice to equip the installed base with control units and connectivity from independent sensor automation systems providers. This leads to facilitated connectivity of the central building control systems that monitor and control all kinds of building services independent of the equipment manufacturer and its proprietary bus system. All in all, this example shows that there are not only technical challenges to overcome for effective service operations.



# Seven service application scenario clusters of cyber-physical systems for industrial equipment operations and industrial service

In the following section, we go into detail regarding the application scenario clusters enabled by CPSs in the industrial service business. Focusing on the operations lifecycle phase, we identified a set of 45 service scenarios grouped in seven clusters. For each cluster, a description as well as an illustrative use scenario is given. Table 3 provides an overview of the identified categories of application scenarios.



Application Scenario Cluster	Description
<b>I</b> Engineer better equipment by leveraging operational performance data	Data from the industrial equipment of the current installed base can be used for engineering future version of the equipment.
<b>II</b> Optimization of equipment operations	Operation of the equipment can be optimized based on historic operational data. Breakdowns can be prevented. Based on historic usage patterns operations can be optimized.
<b>III</b> Control and manage equipment remotely	With the ability of CPSs to receive control information, dedicated functionality of the equipment can be controlled manually via remote service centers. A reset of CPSs can be conducted to eliminate faults remotely.
<b>IV</b> Predict and trigger service activities	Continuous data collection based on CPSs might be used to trigger and predict remote and field service activities. For example, routine maintenance activities can take place based on usage or wear of the equipment measured by sensors in the industrial equipment.
<b>V</b> Remote diagnosis and replace field service activities	In many cases, some maintenance and even repair can be accomplished remotely. Comprehensive service centers are set up, and experienced staff diagnose and solve problems remotely. Experienced service agents can be utilized more effectively since travel is not necessary. Initial diagnosis is accomplished remotely, and field service is sent out only if the problem cannot be solved remotely.
<b>VI</b> Empower and optimize field service	Industrial CPSs can be used to optimize and enhance efficiency of existing service processes and particularly field service activities. Based on CPSs, field service activities can be performed faster, and service quality could be increased. Field service technicians can be supported by remote experts to solve problems faster and more effectively.
<b>VII</b> Information and data-driven services	Data as well as insights obtained from CPSs can be used to realize unexpected data-driven service offerings. For instance, operational equipment data can be sold to other stakeholders via standardized interfaces.

**TABLE 3:** CPSs application scenario cluster for the industrial service business

## I Engineer better equipment by leveraging operational performance data

Operational data collected during equipment operation in the field can help to generate valuable insights about weaknesses of currently used industrial equipment. These insights can be used to engineer better equipment within the paradigm of product lifecycle management (PLM). This might result in using more sustainable materials or re-

duced energy consumption during the production process, as well as equipment operation. Hence future generations of equipment captivate due to increased durability less vulnerabilities for failures and breakdowns. Table 4 presents exemplary use scenarios that show how operational data can be used to engineer better industrial equipment.

Concrete Use Scenario Example	Description
Energy consumption during operation	Data collected by CPSs can be analyzed ex-post to identify weaknesses of equipment in operation. For instance, equipment operations can be analyzed with respect to energy consumption. Statistical analysis of historic sensor data can be used to optimize equipment design regarding energy consumption during operation.
Use operational sensor data to engineer better equipment	Sensor data of industrial equipment in-use can be analyzed and leverage to engineer better equipment.

**TABLE 4:** Exemplary use scenarios to engineer better equipment by leveraging operational performance data

### Insights from the heavy equipment manufacturing industry – Minimizing the impact of extreme weather condition on equipment performance

#### Use scenario example: Use operational sensor data to engineer better equipment

Heavy equipment is often exposed to extreme conditions in terms of temperature and humidity. Smooth operations must be ensured in both tropical climates and under arctic temperatures. Such extreme conditions result in high equipment requirements as well as short and expensive maintenance intervals. Equipment such as excavators

must work reliably in gold mines in South Africa as well as in northern Siberia. Nonetheless, the extreme conditions often lead to unexpected breakdowns and expensive interruptions in equipment operations.

With CPSs, equipment manufacturers are able to identify coherences between internal and external conditions causing breakdowns of the equipment. For instance, a manufacturer of hoisting equipment is able to identify a considerably higher number of breakdowns in specific locations due to extreme weather conditions by analyzing service logs of the installed base. Components, which are susceptible to wear and tear with high maintenance requirements can be reengineered to reduce necessary service activities and promise higher equipment uptimes to the equipment operators.

Leveraging sensor data to engineer better assets is easy to implement since no real-time capabilities for data analytics is needed. No connectivity of the equipment is needed as data can be analyzed at any point of time. Relevant data can even be collected manually via diagnostic tools of field service workforce. Although the ease of implementation of this use scenario, analyzing operational data of equipment to engineer better equipment results in substantial savings in terms of service for future product lines.

## II Optimization of equipment operation

The operations phase could be identified as the lifecycle phase that benefits the most from the emerging technological capabilities. At the same time, the highest requirements of CPSs can be found during equipment operations. In particular, the temporal aspect of data and insights become relevant. For instance, real-time capabilities are getting important when field service activities are supported by CPSs. Gathered data and insights cannot be leveraged only in the context of field service but can also be used for optimizing industrial equipment operations. Furthermore, the

gathered data can serve to better understand the usage of the equipment in the field. If it is fully understood how the industrial equipment is used, it can improve the design and after-sale service of the equipment, resulting in adapted equipment design.

However, in many cases, historic operational data needs to be available to conduct statistical analyses and identify potential for optimization. Table 5 presents an overview of exemplary use scenarios addressing the optimization of equipment operations.

Concrete Use Scenario Example	Description
Optimize equipment operations based on external data	Using external data coming from other systems or equipment to optimize operation of dedicated equipment based on external conditions. For instance, building technology such as lighting, heating, or air conditioning at an airport might be optimized depending on flight schedule and/or people flows. Elevator operations in large buildings might shutdown safely when an earthquake is approaching. On-going operations of an off-shore wind park might be depended on comprehensive real-time weather data. Rail freight traffic might be optimized based on supply and demand of the electricity grid.
Adapt equipment performance based on people profile	Using historic performance data of employees to adjust equipment performance and output quantity in the equipment operator's on value creation or production process.
Send information to equipment operators for better equipment operations	Parameters and information can be sent to the equipment operators' machines and to the machines in the value chain. This allows manual equipment control, optimizing equipment operations based on historic data, and generating insights from other equipment operators as well as updating the equipment firmware.
Sustainable reduction of energy costs based on operational sensor data	Operational sensor data is used to identify inefficiencies in terms of capacity utilization or equipment operation. This might help to fulfil regulatory requirements to reduce operational energy costs.

**TABLE 5:** Exemplary use scenarios to optimize equipment operation

### Grid optimization in the electric supply industry

#### Use scenario example: Optimize equipment operations based on external data

Generating electrical power is quite a challenging task: Distribution system operators need to balance the amount of energy that is generated and consumed within their part of the electric grid in real-time in order to provide a constant voltage and thus service quality to their customers. In the past, electricity was generated steadily by nucle-

ar power plants or coal-fired power plants. Power production was completely geared towards statistically calculated load profiles describing expected energy consumption based on historic data with the goal to keep the balance between the production and the demand side.

With the rise of renewable power generation and the liberalization of the energy markets, the challenging task of optimizing the system as a whole became more relevant. Particularly on the production side, more movement came into the game. Renewable energy creation such as solar plants and on- and off-shore wind parks brought more uncertainty in the grid. Energy production based on renewable energy sources can barely be predicted and planned. Hydroelectric power plants (i.e., pumped-storage power plants) or gas-fired power plants are continuously on standby to potentially absorb peaks in energy demand. Gas and water plants are used for this job because of their ability to quickly start and stop power production. However, operating such plants is expensive resulting in strong incentives to minimize their usage. In a nutshell, the technical capabilities to balance

load peaks are available. But how are the individual components of the system integrated with each other to optimize the system as a whole?

Equipping both sides, producers and consumers of electrical power, with monitoring and control capabilities is a first step toward to monitor energy generation and consumption and to control the energy generation of gas- and water plants to absorb peaks enables self-regulating electricity grid and autonomous feedback-loops. Besides just controlling additional power generation in times of power shortage, it is also possible to limit the amount of power produced by wind parks. With sensor technology, historic data, advanced analytical capabilities, and prediction models, the uncertainty becomes more manageable, and the operation of the entire power grid can be optimized.

### III

## Control and manage equipment remotely

Since industrial equipment is not only equipped with sensors and unilateral connectivity but also with the ability to receive information, controlling and managing individual functionality of equipment in the field from remote locations become possible. Hence, an equipment manufacturer or a service organization can provide added value to the equipment operator and user of the equipment by manual control, activating or deactivating dedicated functionality. This allows interesting use scenarios such as the upgrade/downgrade of

equipment functionality or changing the operation mode of industrial equipment depending on dedicated events or situations. Such scenarios can be harnessed to generate additional revenue by leveraging the control capabilities of CPS-enabled industrial equipment. Completely new service offerings become possible besides just leveraging CPSs to increase internal efficiencies. Table 6 provides an overview of exemplary use scenarios to control and manage individual equipment configurations or functionality remotely.

Concrete Use Scenario Example	Description
Up-or downgrade functionality via software update	In the age of CPS, the physical part of the industrial equipment is increasingly degraded to just act as a platform for providing added value through services. For instance, a washing machine as a physical product is utilized to provide and run washing programs for the customer. In the future, maybe all customers (premium and economy) might initially buy a quite similar physical product platform. Depending on the customer's needs, the customer's individual situation, and payment reserves, modular functionality can be added or removed via software updates. Hence, product configuration and features of a product become more dynamic and move based on changing customer needs.
Lock/close equipment operations based on sensor data or external influences	Operations of industrial equipment can be refused based on sensor data or external influences for safety or other reasons. For instance, it is conceivable that individual stops of an elevator are closed on behalf of the client (e.g. for special events / special operation mode) as a dedicated functionality/service offering. Moreover, closing stops might be relevant in cases that door closing mechanism is not working correctly at a particular stop. Passengers are notified in advance that dedicated stops cannot be reached with this particular elevator. However, equipment operation for accessing other floors is not affected.

**TABLE 6:** Exemplary use scenarios to control and manage individual equipment configurations or functionality remotely

### Warranty management for industrial cranes in the logistics industry

#### Use scenario example: Lock/close equipment operations based on sensor data or external influences

As many other kinds of industrial equipment, hoists and industrial cranes are characterized by high requirements in terms of availability and reliability. Particularly in logistical hubs such as harbors or airports, trouble-free working equipment is essential. Strict legal requirements and safety regulations exist for operators of such equipment. Often, different requirements apply depending on the country the equipment is operated in. In the crane business, meeting safety requirements are also highly relevant for maintenance contracts. To detect violations, sensors get installed in the equipment to continuously measure equipment operations. In case of exceeding certain threshold values, safety alerts can be sent to mobile devices

of operators as a service. If those thresholds are exceeded on a regular basis, operator training can be planned to ensure smooth operation without costly downtimes in the future. In case of compliance violation, service and maintenance are often getting more expensive for operators as contracts often contain special clauses. In such a scenario, operational data can be used by equipment manufacturers and service organizations to identify misuse and justify higher service costs to guarantee safe equipment operation. Based on actual usage data, maintenance activities can furthermore be optimized resulting in minimized downtimes and maximized safety.

## IV

### Predict and trigger service activities

When servicing industrial equipment, it can be distinguished between three service strategies: (1) corrective, (2) preventive, and (3) predictive service [32]. Whereas (1) corrective service has to be performed after a breakdown, preventive and predictive maintenance apply before the actual breakdown happens. In the case of (2) preventive maintenance service, we can distinguish between three strategies depending on the respective trigger. First, in the case of (2a) time-based predictive service, service is triggered by a certain date or point in time. Depending on dedicated equipment maintenance schedules, maintenance is triggered based on historic empirical values [33]. In this case, maintenance intervals are rarely optimized; maintenance activities are not triggered efficiently [34]. Second, (2b) usage-based service describes service activities that are triggered based on the (simple) usage intensity of equipment. No additional or more detailed data about the equipment is used. Third, in some cases, the condition of the equipment can serve as a trigger for maintenance. In the case of (2c) condition-based service, the condition of the equipment is measured by wear and condition of dedicated equipment parts. However, no forecasting is carried out. The most sophisticated service strategy is (3) predictive service. Following

this strategy, condition-based monitoring is extended by taking into account forecasts and predictions based on historic data. Bloch and Geitner [35] found that the largest amount of equipment failures can be predicted based on dedicated symptoms or precursors long before they occur. With their p-f curve, they give an example of this concept. Now, with CPSs, it becomes possible to sense these symptoms of equipment in the field in an automated way. This draws service organizations and equipment operators one step closer to the dream of zero unplanned downtime. Continuous data collection, based on CPSs, might be used to trigger and predict service activities. Based on historic data, forecasts are generated about potential breakdowns. Predictive service is carried out before the breakdown happens and only for equipment that is threatened by potential breakdowns. Compared to other service strategies outlined above, predictive maintenance is considered as the most efficient service strategy [32–34]. Efficiency increases are not only possible by conducting the service activities efficiently, but also by scheduling them in an efficient and effective way. Table 7 provides an overview of exemplary use scenarios to predict and trigger service activities.



Concrete Use Scenario Example	Description
Use rotation sound sensor for predictive maintenance	99% of all machine failures are preceded by certain signs, conditions, or indications that a failure is going to occur. In many cases, first signs can be noticed weeks or even months before a failure or breakdown. P-f curves describe the relationship of equipment performance depending on the time. For instance, anomalies can be identified, based on ultra sound long before they can be recognized by human touch (thermography and vibration) or trained ears. In case of rotating equipment, such as wind turbines in onshore/offshore wind parks, rotation and vibration sensors based on ultra sound as part of CPSs can be used to identify potential failures or breakdowns. Based on industry specific algorithms and historic data, predictive maintenance can be scheduled before the actual breakdown happens, resulting in minimized equipment downtimes.
General predictive maintenance	Based on CPSs technology, maintenance of smart industrial equipment can be performed before actual breakdowns happen. Comparing sensor data of individual equipment instances with the sensor data of the entire installed base as well as the service history can result in insights about potential breakdowns. In difficult cases, an initial diagnosis can be performed from remote service centers by leveraging control capabilities of CPSs. In case that the problem is identified and cannot be resolved remotely, field service technicians get notified via mobile work support systems and a field visit is scheduled. Field technicians can then fix problems or exchange parts before the actual breakdown happens. This results in unnecessary maintenance visits, minimized equipment downtimes, optimized equipment utilization.

**TABLE 7:** Exemplary use scenarios to predict and trigger service activities

**A dream comes true: First-time fix-rate = 100% in the elevator industry**

**Use scenario example: Predictive maintenance**

Elevators are expected to provide reliable service in various fields of application. In large facilities such as airports, large corporations, hotel chains, or skyscrapers, often a dedicated facility management division is responsible for smooth operation of the entire building. As maintaining the facility is not considered as being the core business of such organizational entities, dedicated facility service companies are responsible for smooth operations. In case of minor defects, they are able to solve the problem. In case of significant breakdowns that require specific knowledge about the equipment, service organizations with expert knowledge in the elevator industry are engaged as sub-contractors. Hence, multiple stakeholders are involved in the service business of the elevator industry. This

ecosystem causes several media disruptions for the service business resulting in the following situation: Although field technicians in service organizations get a digital service assignment, based on the work-order management to fix a breakdown, they often do not know the dedicated causes of a breakdown or even what exactly is broken. Instead, they just get a notification that an elevator is not operating correctly and the location of the broken elevator.

In the described circumstance, imagine a 50-story-building in the middle of Shanghai being operated by a facility management firm that can barely pay the security service that is also responsible for facility management. No facility manager is responsible for the building. In case of problems

with elevators, security just calls the service organization without even localizing the problem. The service technicians now have to spend a huge amount of time in identifying the problem in the large building. After problem identification, they might have to drop in a second time since spare parts have to be ordered to fix the problem. This leads to high service inefficiencies. In today's market, costs for such inefficient service business are directly passed on the equipment operators (i.e. the building owner).

Now imagine the same incident in a world with CPSs: Based on historic data and optional remote

diagnosis capabilities, the reason for the breakdown can be identified remotely in advance. Based on the diagnosis, field service technicians get specific instructions, including descriptions of which specific activities must be performed at the equipment operators' site. With smart spare parts management, parts that need to be exchanged might be ordered in advance and delivered directly to the equipment operator and be available when the service technician arrives. Saving five minutes on a field service task would result in significant efficiency and profitability increases for service organizations in the elevator industry.

## **V** **Remote diagnosis and replace field service activities**

Smartness and connectivity of industrial equipment can be leveraged to replace activities that previously were accomplished by field service technicians. Remote diagnosis is the most obvious use scenario in this context. In many cases, maintenance or even repair can be accomplished remotely. Comprehensive service centers are set up, and experienced staff diagnose or even solve problems remotely. Experienced service agents can be utilized more effectively as travel is no longer necessary. Initial diagnosis is accomplished remotely. Field service is sent out only if the problem cannot be solved remotely. As industrial equipment is be-

coming more and more complex and the software as the "smart" component of CPSs is becoming increasingly important, there must be an efficient way to maintain and service this part of the industrial equipment. Hence, remote diagnosis and the opportunity to replace field service visits for servicing the digital parts of the equipment increases in value. There is no sense in visiting the customer's site to do just a software reset as this activity can be done remotely. Table 8 provides an overview of exemplary use scenarios to perform remote diagnosis and replace field service activities.

Concrete Use Scenario Example	Description
Remote (software) reset of equipment	In many cases in the equipment manufacturing industry, service technicians are sent out to the installed base to fix problems. Often, the cause of equipment downtimes can be identified (or even resolved) remotely. In the future, some routine checks can be performed automatically, distant-tested, and centrally documented. By the generation of the maintenance contract and checklist, the already successfully passed remote-checks will be chopped off as “already carried out and passed successfully”. The service-technician can use the new available time in his daily business, e.g. selling spare parts, writing reports, or repairing. If a remote-check was not successful, the remote-service-technician/-agent has to check and implement a measure if necessary.
Check error-free operation of dedicated equipment components or perform error diagnosis remotely	With CPS, it becomes possible to investigate the error cause of equipment breakdowns remotely based on an in-depth analysis of sensor data. As the mobile workforce is highly expensive, diagnosis activities can be performed from remote locations instead of sending service technicians to the equipment. After in-depth remote diagnosis, dedicated field service experts get informed about the exact equipment condition and can solve the problem on-site in a highly focused and efficient manner.

**TABLE 8:** Exemplary use scenarios to perform remote diagnosis and replace field service activities

### Check safety circuit automatically in the elevator industry

#### Use scenario example: Check error-free operation of dedicated equipment components or perform error diagnosis remotely

Imagine elevators and escalators carrying people in buildings. Rigorous safety requirements need to be implemented to prevent breakdowns and failure. To ensure safety, elevators need to be equipped with a safety circuit ensuring smooth operation.

The safety circuit of an elevator comprises a series chain of contacts that are connected between at least one safety relay, an electric power supply, and a monitoring device. The monitoring device continuously checks voltage and current in the series chain. A signal from the safety relay is transmitted to the control unit of the elevator. Then, the voltage across the safety relay is measured. If all the contacts of the series chain are closed, the voltage across the safety relay is constant.

Traditionally, the safety circuit is checked by field service technicians as part of routine maintenance visits every couple of months. The service technician checks the voltage with a portable measuring instrument. With cyber-physical industrial equipment, such routine checks have no longer to be conducted by field service technicians at each visit.

With sensors and connectivity installed in the elevator, routine tasks such as checking the safety circuit, emergency battery or calls can be accomplished autonomously. Service technicians could be notified in case of a defect to fix the problem or exchange broken parts of the system.

## VI Empower and optimize field service

For the majority of services performed with industrial equipment, service technicians have to be physically at the customer site to service the industrial equipment or install spare parts. Capabilities of industrial CPSs can be used to optimize and enhance efficiency of existing service processes and particularly physical field service activities. Leveraging monitoring and control capabilities of CPSs enables that field service activities can be performed faster and service quality can be increased. Field service technicians can be supported and empowered by CPSs data and collaborate with remote experts in a variety of ways to solve problems faster and service equipment more effectively. With adequate mobile support, service technicians get faster access to relevant information collected by sensors in the field. Analytical capabilities help to generate valuable insights for the field and remote service technicians. To realize such scenarios of this cluster, several preconditions need to be met. First, field service pro-

cesses need to show a high level of standardization and maturity. This allows effective leverage of mobile work support systems (e.g. mobile or wearable devices) for field activities. Second, sensor data and operational insights from CPSs need to be integrated and combined with additional data from other enterprise information systems such as CRM or HR systems, mobile workforce management systems, spare parts management, and procurement. Combining different sources of information yields in a unified service memory with all relevant information for effective service provisioning. Integrating the relevant information systems, however, is a challenge to overcome and results in high initial investments. However, effectively leveraging CPSs to support field service is rewarded by high improvements in field service efficiency. Table 9 provides an overview of exemplary use scenarios to empower and optimize field service.

Concrete Use Scenario Example	Description
Recognition of same faults (recommendations of "related faults")	Based on comprehensive logging of data related to historic service activities as well as sensor data, service technicians are able to access a comprehensive database of related maintenance activities in the past. The service technician gets a list with related or similar faults. If the technician has to fix the problem, it is possible to check whether similar problems have occurred in other instances. Furthermore, the technician could learn from experienced colleagues dealing with the same problems by learning from their experiences in the past. This leads to an increased first time fix rate as well as lower fixing time. Smart spare parts management could also be involved. This gives equipment operators the impression of a fast, structured, and systematic elimination of faults.
Replace diagnosis tools and provide information to service technicians in advance	Cable-based or wireless diagnosis tools are used by service technicians in many industries for reading error codes from the equipment. Depending on different standards, or different models of the industrial equipment, a large variety of diagnostic tools exists. This variety results in huge efforts to enable smooth operation of these devices for the mobile workforce of service technicians. Having the ability to continuously monitor and store error codes in an equipment cloud, such data can be used to conduct such diagnoses automatically and/or from remote locations. Service technicians in the field would just get actionable instruction based on the analyzed error codes and hence focus on resolving issues and replacing equipment components. Particularly taking into account an aging workforce, an increased pressure on the labor market and an increasing percentage of non-experts within their workforce, it becomes necessary that service technicians get supported by mobile technology.

**TABLE 9:** Exemplary use scenarios to empower and optimize field service

## Leveraging CPSs to empower technical customer service in the materials handling & logistics industry

**Use scenario example: Recognition of same faults (recommendations of “related faults”)**

In large warehouses across many industries, time is money, and downtimes of materials handling equipment such as warehouse equipment and forklift trucks are expensive and can have negative impacts on supply chains. Warehouse operators often lease materials handling equipment such as forklift trucks to avoid vendor lock-ins in terms of the equipment itself but also with respect to maintenance services. Furthermore, warehouse operators need to be able to react quickly in terms of capacity utilization. In the past, equipment breakdowns resulted in downtimes and massive delays in delivery as operators needed to contact the service organization manually. With CPS, the equipment itself can notify service technicians about (potential) breakdowns and trigger service incidents. Service incidents are assigned to dedicated service technicians that are responsible to fix the problem. In most cases, the problem itself is not obvious — even for highly experienced technicians. Service technicians usually use mobile diagnostic tools to connect to the equipment at the operator’s site to read error codes. However,

due to the variety of equipment, different diagnosis tools become necessary as various communications standards are used for different types of equipment. This variety results in huge efforts to enable smooth operation of the industrial equipment. In addition, many months or even years of experience and implicit knowledge are needed to comprehensively understand the error codes and derive concrete service actions.

Thanks to CPSs, service technicians in the field also have the opportunity to access the insights generated from automatic analysis in advance of approaching the equipment. This allows concise and understandable service descriptions for field service technicians to be prepared better for their assignments. Having access to error codes from remote allows field service technicians schedule their assignments more efficiently. Error diagnosis can be automated or performed by remote staff. Identifying similar historic problems and related service can indicate promising solutions and make work for field service technicians much easier.

## VII Information and data-driven services

Industrial CPSs are primarily seen as tools to improve operational efficiency of existing (service) business models such as MRO activities. Besides those traditional use scenarios that address already existing engineering and operations processes, the new technical capabilities can also serve as a tool for enabling new business models and unexpected revenue opportunities.

In today's competitive and dynamic markets, data as well as insights obtained from CPSs can be used as a tool to realize unexpected information and data-driven service opportunities. In such scenarios, traditional manufacturing organizations can become data providers for service organizations or

the industrial equipment data to customers (operator organizations). For instance, in case that the equipment manufacturer is the owner of the data, data can be sold to other stakeholders via standardized interfaces that this data can be leveraged for the service business. Besides just selling data (or aggregated insights), they might think about using operational data for providing added-value services besides the traditional MRO service business. Completely new service offerings become possible besides just leveraging CPSs to increase internal efficiencies. Table 10 provides an overview of exemplary use scenarios for information and data-driven services models.

Concrete Use Scenario Example	Description
Equipment operators pay only for equipment usage and required performance	New service operation model. Instead of selling the industrial equipment, the actual usage of the equipment is sold. Service organization is in charge of the smooth operation of their entire installed base. Performance is contractually settled via service level agreements (SLA).
Sell sensor data to operators / equipment owners	Sensor data can be sold to operators allowing them to monitoring their installed base. Data can be provided through a standardized interface/API. In this scenario standardized real-time access is provided.
Sell sensor data to 3rd party service providers	In some service markets (e.g. in the mining equipment industry or elevator industry) 3rd party service organizations exist. With smart equipment and CPS, the challenge of how to empower the workforce of 3rd party service organizations arises as operational data is usually owned by the equipment manufacturer. Data of equipment operation is collected continuously. This data could be sold to 3rd party service organizations servicing the equipment. Data can be provided via a standardized interface or API to generate service notifications for the mobile workforce of the 3rd party service providers.

**TABLE 10:** Exemplary use scenarios for information and data-driven services models

**Value-adding information- and data-driven services in the manufacturing industry****Use scenario example: Sell sensor data to operators / equipment owners**

In manufacturing, traditionally a goods-dominant logic was present: in the past, manufacturing organizations mainly aimed at selling their industrial equipment. With servitization in manufacturing, services play an increasingly important role. Recently, equipment manufacturers started to establish a continuous (long-term) relationship with their customers in order to strengthen their market position. Value-added services during the product lifecycle help to foster this close relationship. Currently, the most obvious services are traditional MRO services provisioned by field service technicians. However, the market for traditional MRO services is getting more and more competitive since 3rd party service organizations also push into the market. As 3rd party service organizations offer a wide range of services, economies of scale take effect resulting in a higher service efficiency compared to highly specialized service organizations belonging to the equipment manufacturers.

With the extensive rise of CPSs in the equipment manufacturing industry, the service business is pivoting. Disruptive services solely based on data obtained from equipment in the field become possible. Equipment manufacturers are now able to offer value-adding services based on informa-

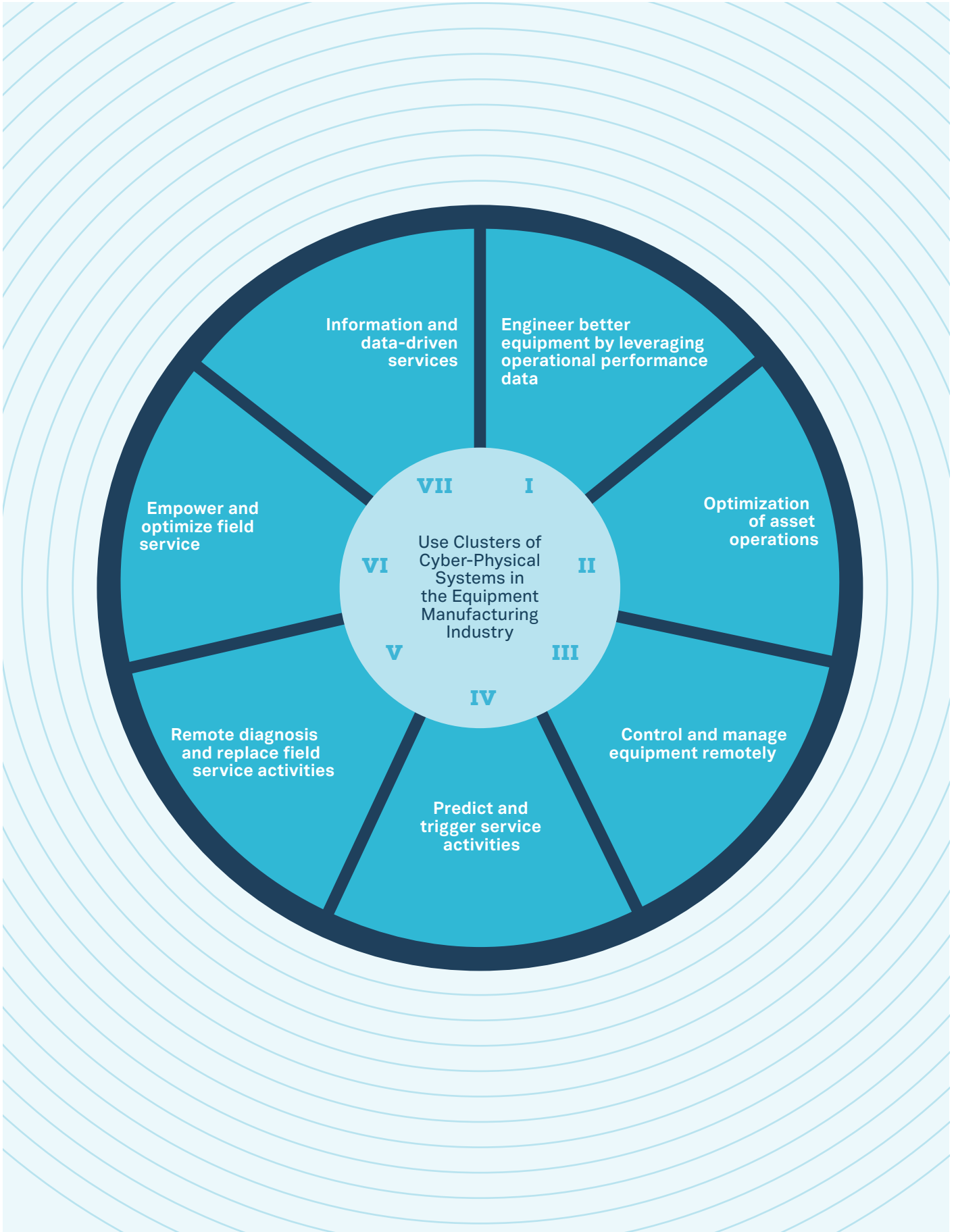
tion and data about the installed base in the field. For instance, an elevator manufacturer that has implemented sensor technology in the field can offer operational equipment data via a standardized interface to the equipment operator. Based on the standardized interface, equipment operators such as airports or hotel chains can integrate the data within their facility management system. Error-free operation can be tracked and uptimes can be tracked transparently. By also implementing control capabilities, the facility management system of the equipment operator can send instructions to the elevators to enhance equipment operations. Business model building blocks such as “Digital Freemium” describe selling physical products and attaching digital services to the actual product [36]. Value-adding services can be offered free of charge or for a fee. Independently of whether a service fee is charged or not, offering such services creates a lock-in effect for the service business: Service organizations of manufacturing organizations not only utilize the equipment itself but also the digital services attached to it. This leads to a stronger relationship between equipment operator and equipment manufacturer due to lock-in effects for the product and service business.

# Conclusion

Opportunities that emerge with CPSs are currently a wide-open playing field for enterprises. This playing field is young, heterogeneous, and full of uncertainty. The increasing demand of equipment operators to exploit connectivity and operational equipment data often poses some threats but also tremendous opportunities to existing manufacturing firms and other stakeholders in the industrial equipment service ecosystem. In particular, with the trend of servitization in manufacturing, CPSs might serve as a catalyst in terms of service business models: Performance contracting, guaranteeing a certain availability of equipment and other service-oriented business models are on the rise. This shift is driven and accelerated by harnessing the new technical capabilities, as more and more services are becoming digital [36].

Digitalization, ubiquitous computing, and CPSs have been heralded primarily as a way to improve internal operational efficiency during equipment production. In today's business environment, characterized by complex ecosystems and hybrid value creation, organizations should also harness the new technological capabilities as a tool for finding growth in unexpected opportunities. This report shows that CPSs can be leveraged in many different ways and create a lot of economic potential. Despite leveraging CPSs solely in the manufacturing process of industrial goods, we identify seven clusters of use scenarios to unlock the potential of implementing CPSs in equipment in the field (installed base) and thus address the operations phase in the lifecycle of industrial equipment. The seven identified application scenario clusters of CPSs among the industrial equipment lifecycle are summarized in Figure 5.





**FIGURE 5:** Seven use clusters of cyber-physical systems in the equipment manufacturing industry

Focusing on the lifecycle phase of equipment operations, we demonstrate that CPSs and digitalized industrial equipment unlock unforeseen added-value for operating and servicing industrial equipment in seven distinct areas. CPSs allow to (I) engineer better equipment based on operational equipment data of current equipment in operation. Furthermore, (II) equipment operations can be optimized by leveraging control capabilities in combination with external and internal sensor data. Industrial equipment can be (III) controlled and managed remotely. Use scenarios in this cluster are particularly interesting when it comes to inaccurate behavior of the equipment in the field. The new technological capabilities are also highly relevant for the service business: CPSs can be used to (IV) predict and trigger service activities, conduct (V) remote diagnosis for equipment in the field and hence replace many field service activities. At the same time, CPSs can (VI) empower the technical customer service staff in the field by providing relevant insights and increase field service efficiency. Last but not least, CPSs enable service organizations and manufacturers to offer equipment operators (VII) new information- and data-driven services that would not be possible without CPSs. Combining the newly gained capabilities of CPSs with other disruptive technological capabilities such as miniaturization and mobile, cloud technology or even 3D-printing for the spare part business results in breakthroughs and a transformation of existing business models and further unforeseen potential.

Right now, however, the development and implementation of CPSs in the field is still in its infancy – technical challenges and hurdles have to be overcome. An adequate architecture has to be identified to exploit effectively huge amounts of operational equipment data and the new opportunities. This holds particularly true for connectivity and security. Moreover, adding sensors and connectivity to an existing installed base is quite challenging, as industrial equipment is characterized by long life cycles and insufficient standards in terms of technology and system design [20]. Consequently, retrofitting and smartifying industrial

equipment that is already installed at the equipment operator's facilities would result in high investment costs. Managers must pave the way for different kinds of use scenarios depending on the characteristics of their industry.

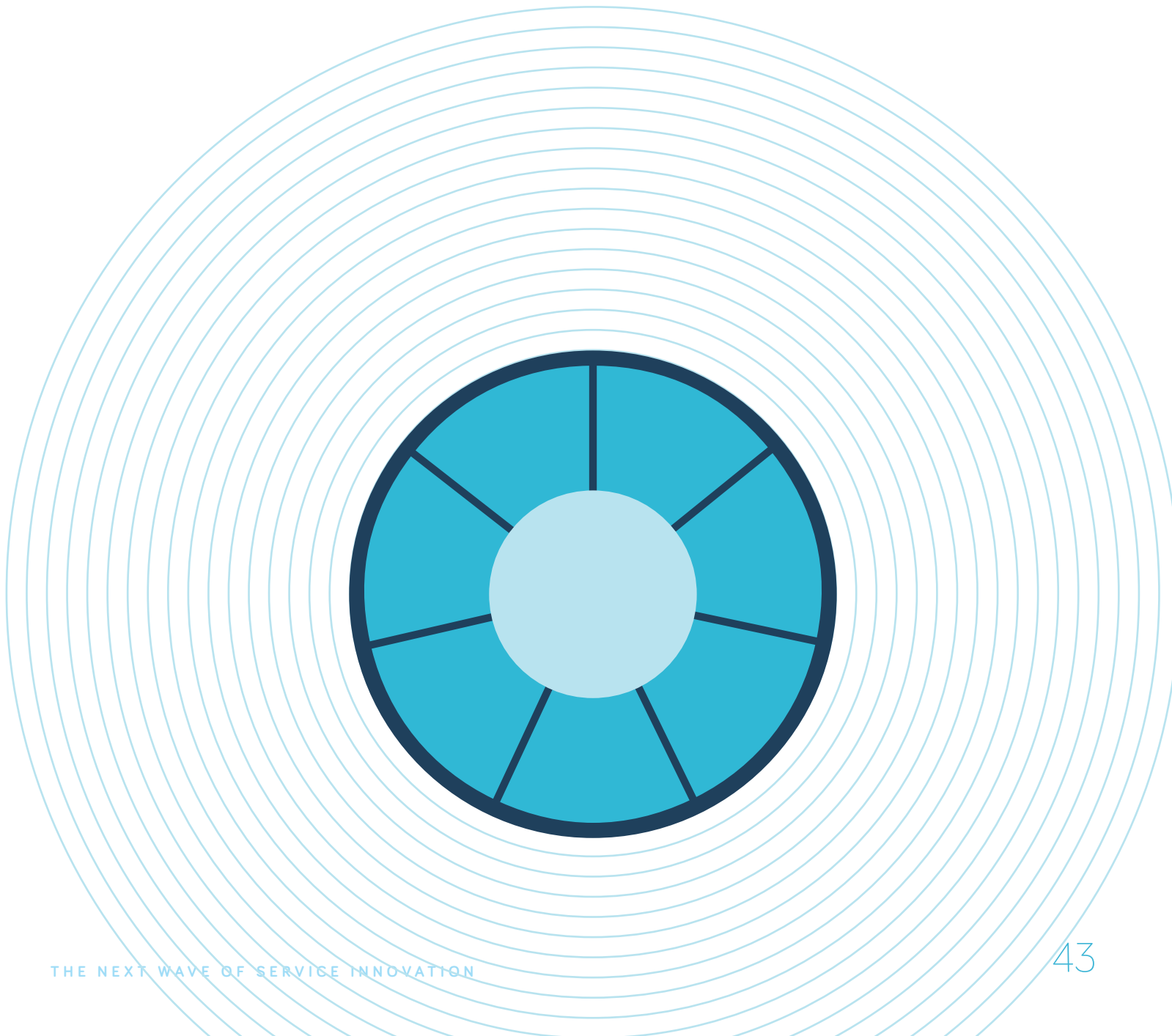
Practitioners should focus on realizing quick wins and use scenarios that can be easily implemented in the first place. Automating highly standardized repetitive routine activities or checks of the mobile workforce based on condition monitoring technology without advanced analytical capabilities result in low implementation efforts. Sophisticated mobile workforce support such as comprehensive predictive maintenance scenarios, recognition of same faults or remote assistance with complex analytical capabilities should be implemented at a later time. Nonetheless, practitioners should keep in mind the full set of CPSs capabilities to make the right decision in terms of IT architecture and CPSs strategy.

Furthermore, technological advances are often seen as a threat to human workers. Especially with the vast opportunities of replacing field service activities by using CPSs capabilities and remote diagnoses, field service technicians as well as works council are getting nervous about the functional affordances of this new technology, as the job of field service technicians can be partly supported and replaced by automation and digitalization of equipment. However, engineers with special expertise in both digital and mechanical components of the machines are needed to ensure an effective and reliable CPSs design among the long operations phase in the industrial equipment lifecycle. Furthermore, application of CPSs in manufacturing results in a shift of the workforce: the amount of activities that can be performed from remote locations results in a higher share of remote service technician and reduction of the size of the mobile workforce in the field. CPSs thus drastically change how machines and industrial equipment is serviced.

Organizations that are interested in becoming leaders in the service ecosystem need to develop capabilities at an organizational, technical and individual level to effectively monitor operational machinery data, transform the data into information and insights and derive adequate actions. Based on CPSs, advanced analytical capabilities, well-defined and data-driven processes are relevant to manage industrial equipment in a more efficient and effective way and hence stay competitive.

Although we believe, that this report serves as a sound starting point and an overview on use scenarios, it is important to keep on track with future trends and emerging opportunities enabled by

CPSs. Equipment manufacturers must identify adequate business models for their service- and product business leveraging CPSs and operational data. This requires companies to rethink traditional ways of doing business and to question well-established business models to create added-value for their customers. Servitization and maintaining service-oriented relationships with their customers (i.e. equipment operators) become even more important. For that reason, manufacturing organizations must ensure that their strategy of how to implement CPSs is in line with the future service operation models and expected internal efficiency increases and additionally generated revenue.



# Appendix

## **METHODOLOGY**

### **How we collected data for this report**

This report strives to provide an in-depth understanding of how CPSs impact the service business for industrial equipment. To gain vibrant insights and a high validity of results [38], we followed a multiple case study approach and lean on multiple data sources and methods. The work at hand arises from semi-structured expert interviews and focus group research involving 11 organizations. Cases were selected based on theoretical sampling to obtain a representative perspective on the equipment manufacturing and service business. We paid attention diversity in terms of the size of the participating organizations (turnover as well as employees) and industry focus to gain a rich understanding of clusters of potential use scenarios. Furthermore, we focused on three distinct stakeholder groups, namely equipment manufacturers service organizations, equipment operators and selected the cases accordingly. Another criterion for the selection of cases was that case organi-

zations are about to exploit CPSs for their service business based on sensors and connectivity in their industrial equipment.

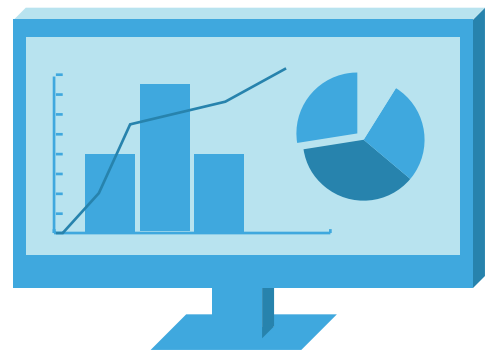
Initially, focus group workshops were conducted to get a foundational understanding. Participants were characterized by a high diversity, ranging from managerial, technical, and operative employees from different business areas to cover a broad range of application contexts. In addition, open-ended semi-structured expert interviews were conducted lasting between ~50 and ~110 minutes. In later phases of our analysis, we used scenario cards to evaluate use scenarios in a highly standardized way. Comments made by the subject matter experts were recorded and entered in our scenario library immediately after the expert sessions. Table 11 presents an example for the scenario profile cards that we used to discuss concrete use scenarios with experts.

<b>ID</b>	<b>43</b>
<b>Title</b>	Leverage rotation sound sensor for predictive maintenance
<b>Abstract</b>	<p>Bloch and Geitner (1983) have noted that 99% of all machine failures are preceded by certain signs, conditions, or indications that a failure was going to occur. In many cases, first signs can be noticed already weeks or even months before a failure or breakdown. P-f curves describe the relationship of equipment performance depending on the time.</p> <p>For instance, anomalies can be identified, based on ultra sound long before they can be recognized by human touch (thermography and vibration) or trained ears. In case of rotating assets/equipment such as wind turbines in onshore/offshore wind parks, based on the p-f curve, rotation and vibration sensors based on ultra sound as part of CPSs can be used to identify potential failures or breakdowns. Based on industry specific algorithms and historic data, predictive maintenance can be scheduled before the actual breakdown happens, resulting in equipment downtimes can be minimized.</p>

**TABLE 11:** Example of scenario profile card

In addition, to the data collection methods addressed above, internal documents, presentations, and process documentations were screened to identify additional use scenarios. In total, we identified 45 use scenarios of CPSs in the context of industrial services.

In addition, to the data collection methods addressed above, internal documents, presentations and process documentations were screened. Table 12 presents an overview of case organizations classified among the stakeholder groups we used in this report. For the evaluation of the results, two confirmatory focus group workshops were conducted. Participants of the confirmatory focus group workshops were not involved in the initial data collection [39].



Stakeholder group	Case organization	Industry	Employees	Turnover	Interview and application scenario evaluation partner, [# of interviews]	Focus group workshops
Service Organization	SO1	General facility services	>500.000	>10 Bio €	Head of facility operations, [1]	-
	SO2	Equipment-specific MRO service organization	>2,000	>500mn €	Branch manager and director service operations efficiency, Director, international technical services, [2]	-
	SO3	Equipment-specific MRO service organization	>2,000	>500mn €	Service development and processes, [1]	-
	SO4	Equipment-specific MRO service organization	>2,000	>500mn €	Vice-President service support, Head of technical (service) department, [2]	-
	SO5	Equipment-specific MRO service organization	>10,000	>1bn €	Head of service, [1]	-
Equipment Manufacturer	EM1	Equipment manufacturing industry	>150.000	>40 Bio €	-	2 workshops, 30 participants
	EM2	Industrial materials handling	>10.000	>2000 Bio €	-	1 workshop, 4 participants
	EM3	Industrial materials handling	>8000	>1500 Mio €	Service innovation manager, CIO, [2]	2 workshop, 3 participants
Equipment Operator	EO1	Public transportation	>6000	>1100 Mio €	Head of operations, [1]	1 workshop, 3 participants
	EO2	Public transportation	>1500	> 900 Mio €	-	1 workshop, 4 participants
	EO3	Services	>60000	n.a.	Head of facility management and shared services, [1]	-

**TABLE 12:** Profile of case study participants

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