Thermal processing plants in the smart factory

by **Hartmut Steck-Winter, Günther Unger**

The smart factory changes the basis of production. The classical production hierarchy will be dissolved and replaced by self-organizing decentralized cyber-physical production systems. The production chain becomes a production network. Smart products actively support the production process. The workpiece knows what it is, where it is, what it is supposed to be and how it can be manufactured. This makes the production more flexible. Resource efficiency, smart services and big data become indispensable framework conditions. The future impact on thermal processing plants, planned and existing ones, will be significant. This article is an attempt to determine the status of thermal processing plants on the way to the factory of the future.

For years, everyone has been talking about Industry 4.0[1], or the smart factory. The smart factory is about no less than a flexible, highly efficient and self-organizing production that is superior on every level to today's production. There is heated discussion about which requirements, opportunities, and risks evolve from it for a company.

In this essay, an attempt is made to answer the following four questions:

- What is a smart factory?
- What are the key components of a smart factory?
- Is there a future for PLC and PCS in a smart factory?
- What specific requirements need to be considered for thermal processing plants?

This essay is a shortened and updated version of two essays published 2015 with the title "Thermal processing plants in the factory of the future" [1].

THE VISION OF THE SMART FACTORY

The vision of the **smart factory** stands for the advent of the internet of things and for omnipresent internet technologies within production as well as for the widespread digitalization of all business processes.

The smart factory brings about a paradigm shift in the field of production organization. It is self-organizing. Smart workpieces actively support self-organization. The principle is simple: Any workpiece to be produced knows its state, it knows, which operations still are to be carried out and which ones have already been carried out. Every device or plant knows its own functions, its workload, and each is able to pro-actively connect with its surroundings. Paired with suitable transportation logistics, this makes for an automatic organization of all production facilities.

The human component still determines the basic production plan, but any short-term changes cannot and should not be included beforehand. Thus, any fine-tuning is also done automatically among products and plant. If the products change, the production plans change too, and so do the settings of the plants. Production jobs in the smart factory are individualized, with small batch sizes, and they have, if possible, alternative processes (multi-channel).

KEY COMPONENTS OF THE SMART FACTORY

The smart factory is organized, controlled and monitored by very few key components. Essentially, these are the Cyber-Physical Production Systems, smart products and cloud computing (with big data), which communicate with each other via the internet of things.

Cyber-Physical Systems

Cyber-Physical Systems (CPS) are likely the most striking component of the smart factory. As can be seen in **Fig. 1**, a CPS is like a mechatronic system in its basic structure [2]. The same figure could also be produced by a machine with a decentralized set-up PLC and several CPUs.

A CPS contains embedded systems to carry out func-

1 Aside from "Industry 4.0", the concept is also referred to as "smart factory", "factory of the future" or "digital revolution". In countries such as the US, it is called "Industrial Internet" or, in more general terms, the "internet of things".

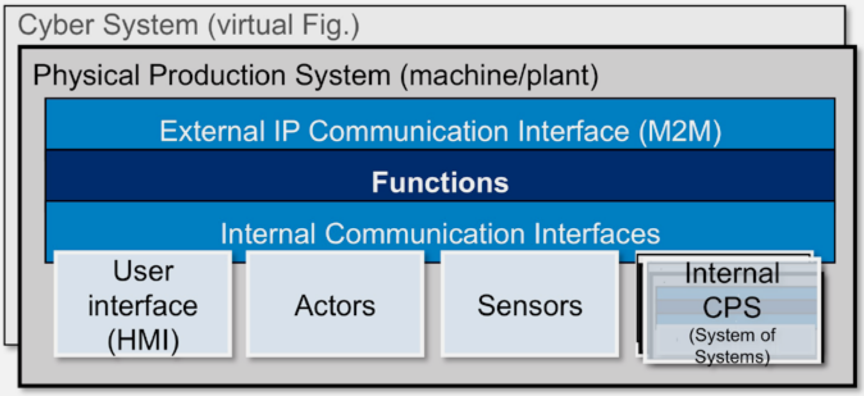

Fig. 1: Set-up of a Cyber-Physical-Production-System

tions, it communicates via interfaces with the sensors and actors, and it has a user interface as well as IP communication interfaces.

A system consisting of several CPSs that are connected, comprising a larger machine, is called Cyber-Physical-Production System (CPPS). Such a CPPS may, for instance, be a thermal processing plant.

The cyber system describes the systemic processes, the IT behaviour, and the physical properties of a production plant. Typical digitalized content may be kinematic data, technology data, temperature gradients, step sequences etc. Virtual and the physical worlds intertwine and complement each other.

Software agents

The heart of a CPS is its functions. The classic functions (measuring, operating, controlling, visualizing, reporting, evaluating etc.) are supplemented by "overarching" functions, the so-called software agents. A software agent is a programming method in artificial intelligence (AI) that has been known for years; it pursues predefined goals and is able to act autonomously within its own operational framework.

The agent communicates with other agents to find the optimal way to achieve its goals. It is able to use optimization methods to find adequate paths to goal achievement.

Machine-to-machine communication

Each CPS has its own unique IP address. It is also able to exchange and edit data by means of the internet protocol. CPSs communicate directly with other CPSs, quite often wirelessly. CPSs connect via plug and play through machine-to-machine communication (M2M), which is one of the main technical challenges. Producers of automation systems have not yet found a solution to the intercommunication challenges. It does not look like much is going to change about the M2M-interface issue anytime soon.

Human-machine-interface

The user interface of a CPS is usually referred to as human-machine-interface (HMI) and is adapted to those of smartphones or tablets. Voice command and gestures as well as information from the cyber system support the system. The virtual world will merge with the real one [2].

Smart products

This leads us to the other integral component of the smart factory – the smart products. First, we need to distinguish that a product may either be a workpiece in production or a machine component.

Smart machine components carry all the required information about their own production. Smart machine components have a cyber twin to record any notable events [2–4]. In other words: The smart workpiece is able to control its own production; the smart machine component has a digital memory.

Smart workpieces

A reliable piece of technology that has been in use for years is used as a data medium (ID tag) for smart workpieces: bar codes, data-matrix codes, or QR codes. Additionally, contactless, readable, and writeable RFID chips are used. In the smart factory, the position of a workpiece is always traceable. Instead of a workpiece, one could also trace the position of a transport container. Not only can the necessary production steps and parameters be specified this way, but using RFID chips, data can be stored on the workpiece. This has the advantage that a central backup of the workpiece data is no longer necessary.

However, it needs to be pointed out that RFID chips are not suitable for a trip through the furnace.

Smart machine components

With smart, valuable machine components, the focus lies on life-cycle management. For this, the component must be clearly identified with an ID tag and provided with a digital twin in the cloud.

Operational data, repairs etc. can thus be recorded. The digital twin provides documentation that enables the complete tracking of the component's life cycle. This means that the twin's function is the same as that of a "black box" in airplanes, recording all relevant parameters and releasing them for authorized access if necessary.

If, for instance, a machine component is disassembled for repair, it carries its identifier with it. Any actions taken can be recorded onto the digital twin in the cloud and a service technician is able to access them anywhere. This is another aspect that is becoming increasingly important when the component is being reused after maintenance in a different machine.

Cloud computing together with big data

The third distinguishing element of the smart factory is cloud computing together with big data. The two usually go hand in hand. It is not just within industry 4.0 that cloud computing has become one of the most important IT trends in recent years.

Cloud computing (Computer Locations Outside Usual Designs) includes the lease of IT infrastructure that has been dynamically tailored to the individual needs (processing capacity, memory or services) and that can be accessed worldwide through the internet. The range of services offered has virtually no limits. It also includes an entire range of IT services which a "regular user" would not usually be able to afford. One of the advantages is that resources that are needed on short notice do not lead to a cost-intensive expansion of the IT infrastructure for the tenant.

The smart factory will bring about unprecedented amounts of data. The quantities will downright explode. Of course, big data is not an end in itself. One of the goals is, for instance, to recognize hidden correlations in big data. It can be anticipated that through big data, there will be functions and services we are not yet even able to see. As already mentioned, one does not need to own a supercomputer for that.

EXCURSUS: THE FUTURE OF PLC AND LOCAL PCS

At this point, the question arises: "Is there a future for Programmable Logic Controllers (PLC) and Process Control Systems (PCS) in a smart factory?" Will they be replaced by CPS and the cloud?

Automation tasks usually follow a traditional hierarchy, as pictured on the left in **Fig. 2** [5]. On top of the automation pyramid is the management level (ERP and MES), followed by the process control level (PCS or SCADA) and the control level with PLC or IPC and other specialized automation systems. There is usually a mix of different automation systems on the control level, such as frequency converters or temperature controllers by various manufacturers. Underneath the automation systems, the network of the field level with its sensors and actors spreads through the machine or plant.

PLCs are the core of automation technology and they have a secure, stable operating system, enabling direct and real-time capable connection of input and output signals. Control software as well as Human-Machine-Interfaces (HMI) are coded for each plant individually.

Data processing and data logging, which do not need to have real-time capability, are often outsourced onto the process control level. Control and process control levels thus merge seamlessly. Quite often, the addition of data processing and logging to a classic PLC based on IPCs is practiced; this alternative has gained ground due to independence to real-time demands.

M2M-interfaces and HMI are optimally tailored to the automation structure. On a horizontal level, automation systems communicate with other automation systems that are also configured, parameterized or programmed for that specific application. Vertical communication usually takes places with the level directly above or underneath only.

CPS with software agents and cloud computing make the classic automation pyramid redundant. Hierarchic structures break away, as can be seen in Fig. 2 on the right, and turn into a comprehensive network [5]. Basically, every level can be replaced by interlaced, decentralized, self-organizing services. Hence, the pyramid becomes a network without hierarchy, with, where necessary, a direct communication channel from the field level to the cloud.

Within such a network, the input signal of a smart sensor on the field level could, for instance, be read and processed by any given CPS inside the network. Likewise, any CPS

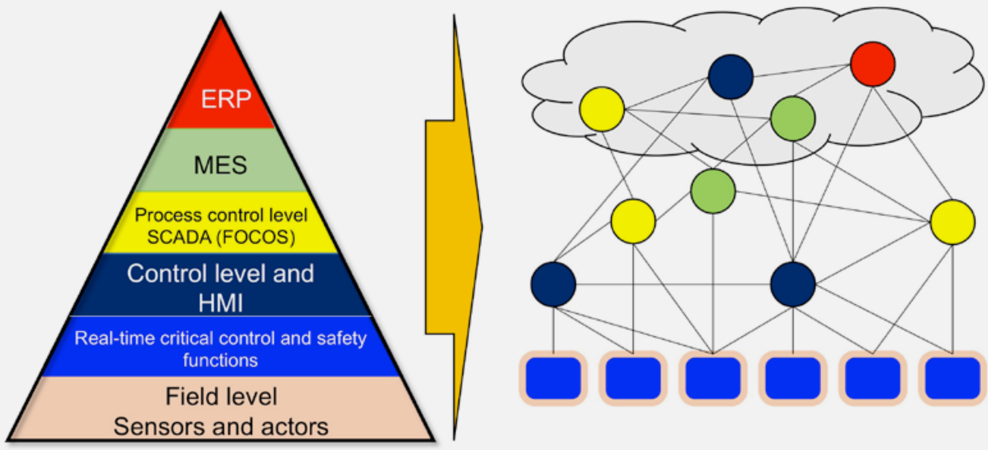

Fig. 2: From the automatization pyramid to network automation

could drive any given actor. In other words: A CPS function is basically location-independent. Software agents could be run on any automation component.

Failure safety and stability

For reasons of safety and stability, there will have to be some restrictions. Even with a CPS or CPPS fail safety handling requirements cannot be lower – quite the contrary. This means that proven failure tolerance principles, such as redundancy or fail safe, will still have to be considered in the future [6]. Traditional safety technology however, like an emergency stop button, can be replaced with sensors that are able to recognize hazardous situations. In such cases, tablet-computers (without emergency stop buttons) can be used for operation.

Due to the relatively long service life of thermal processing plants, especially compared to IT, stability and longevity of the automation system are everything. It should continue to be possible to operate an automation system over a very long time without forced changes, such as updates, from the outside. It is especially the contrast between a stable PLC operating system and a constantly changing IT operating system that speaks in favour of PLC operating systems.

Is there a future for PLC and local PCS?

The question of whether there is a future for classic PLC and local PCS in a smart factory is therefore well justified. The answer for both is a clear yes! The good old PLC and PCS are not dead, they can both exist as a CPS within a CPPS. With regards the status quo, it is certainly not looking like PLC and local PCS in a smart factory setting are going to lose their prominent position anytime soon.

Real-time capability, safety and security, and, of course, simple and individual programmability of the application are the main touchstones for automation technology. These features will continue to be needed. However, for the PLC to remain the core of a CPS, its functionality will have to be expanded. Aside from the interfaces, it is essential that the virtual mapping of the machine as well as its capability for self-organization that will have to be enhanced.

What will definitely change is that fixed operation terminals will be replaced by mobile tablets with smart user interfaces. This shift is already underway.

Will the local PCS be replaced by the cloud? Local PCS reach their limits of use where hitherto unknown event patterns and relations need to be revealed from large quantities of unstructured data, typically with cloud-based pattern recognition or data mining programs, and also when data has to be evaluated across several processes and plants.

However, the question of "cloud or PCS?" is not an either/or, but a "both the one and the other". Data mining or text and figure analysis are better suited for a cloud, but it makes no sense to relocate relatively simple trend analyses or error statistics into the cloud.

Fig. 3: Multi-purpose chamber furnace plant

SMART THERMAL PROCESSING PLANTS

Finally, we must ask what impact a smart factory and its key components have on thermal processing plants and their services. Are thermal processing plants smart enough?

As shown in **Fig. 3**, thermal processing plants use technology common for plants and machines, which will continue to be the foundation of their automation technology.

Hence, we must focus primarily on features specific to thermal processing plants. These include the capability to self-organize, small batch sizes, track and trace, and M2M-communication as well as HMI.

Self-organization and simulation of heat treatment

The cyber system of a thermal processing plant together with the software agent of the smart factory who is responsible for production organization must negotiate optimal plant utilization with minimal reposition losses. The order of heat treatments is optimized in the cyber system. As soon as production starts, it takes place under optimized conditions.

This is no longer a visionary. Already today it is possible for a thermal processing plant to communicate the treatment cycle and changeover times to a master computer so that it can determine the optimal production order.

Maybe thermal processing plants are even way ahead when it comes to virtual possibilities. Simulation programs have been state of the art in heat treatment for years; they are, for instance used for carbon diffusion calculations or annealing temperature calculations when tempering fastening components.

Production flexibility

At first glance, the inherent inflexibility of large continuous plants seems at odds with product variant flexibility up to batch size 1 (one piece flow). However, the question is in how far this requirement affects heat treatment. The customized variant diversity rather takes place in areas visible to the end customer. For cost reasons, platform strategies with large quantities of the same components are predominant in production.

It is old news, and experience shows that classic continuous thermal processing plants are far from being on their last legs. In the efficiency-optimized smart factory, the opposite is true.

Lot and recipe change

However, this does not mean that production flexibility is not an issue in continuous thermal processing plants. For a lot change[2] (different workpiece, but same heat treatment parameters), a lot separation gap is required to avoid mixing of parts. Depending on the transport system and the changeover times, tot separation gaps can vary. The gaps are tracked and controlled electronically, just like the workpieces in a thermal processing plant.

Recipe changes[3] usually include long changeover times, meaning that the flexibility is restricted. Any recipe change requires pre-calculated production gaps (for lot separation), where, for instance, the temperature is changed. While lot size 1 is still possible, it is not economical due to the unused production capacity.

The changeover of the heat treatment parameters in continuous plants is carried out automatically and depends on the electronic lot tracking. This requires a virtual image of the significant parameters, such as temperature gradients, zone assignments, assignments of place of error, etc. (cf. paragraph on cyber systems). These automatic lot and recipe changes have been state of the art for a long time.

Tracing of workpieces ("Track & Trace")

Material transport containers with machine-readable information carriers cannot withstand the high temperatures inside a thermal processing plant. Therefore, those workpieces that undergo heat treatment must either be loaded directly onto the furnace transport system or onto special heat-resistant transport racks. The workpieces are thus separated from their information carriers. After heat treatment, the workpieces are loaded back onto transport containers with machine-readable information carriers that are better suited for further transport logistics.

Inside the heat treatment plant, the material flows (which are usually compiled in lots) are traced electronically. Even in a smart factory, this cannot be avoided! However, electronic lot tracing has proven successful over the last decades and need not be questioned.

If the workpieces are also marked with an "engraved" Data Matrix Code, then, paired with the heat treatment proof documentation, every single workpiece can be traced long after it has left the factory.

Heat treatment proof reports

Product liability and certifications require a quantified documentation of all significant process parameters. Even though workpieces do not necessarily show their heat treatment clearly, it is required to comply with the treatment rules and to completely document their compliance. In heat treatment, the term "heat treatment proof report" was established. It generates large amounts of data which can no longer efficiently be saved, processed or evaluated in the PLC. Therefore, they are outsourced to superior PCS, such as FOCOS 4.0. It is also possible to save the aggregated data to the cloud.

In the near future, the focus will be on utilizing these data further, for example to analyze relations with other events.

Human-machine-interface

For an interactive communication between human and machine (HMI), an entire range of systems are available today (**Fig. 4**). Supplementary mobile operating devices are state of the art. Tablets in particular are virtually made for this service.

Information on tablets have already been available for a few years in the case of new Aichelin plants. The augmented operator has long been possible in some areas. For example, the "virtual product memory" of important sensors such as thermocouples and oxygen probes, in particular their calibration data and offsets, can be transmitted to tablets via a WLAN connection. This means that all necessary information and aids are available to maintenance directly at the installation site.

Additionally, circuit diagrams, operating instructions or spare parts lists can also be retrieved, since they are rarely available at the plant.

SMART SERVICES FOR THERMAL PROCESSING PLANTS

Product and traditional service, supported by digital services, intelligent assistance systems and semantic technologies, are combined into smart services. Many experts agree

2 A production lot is a certain amount of identical parts that are manufactured together.

3 The entire set of parameters (target values) for the heat treatment of a specific workpiece is called recipe. Typical recipe parameters are charging requirements, temperature setpoints, cycle times, and C-level setpoints.

Fig. 4: Traditional operating system with visualization

that data will be just as important as the physical product and the traditional services. They offer tremendous potential and numerous possibilities for new smart services. All that needs to be done is to make use of the opportunities at hand and to gain experience. Data analysis will sooner or later become a new discipline in the service field.

Digital service portals

Soon, leading service providers will their already partially digitized services, in particular condition monitoring, spare parts requirements planning and maintenance planning, integrate into a service portal. Digital list of components are the foundation. They contain in a hierarchical structure all (important) assemblies and components. For every single assembly and component there is a specific maintenance strategy, a plan for spare parts requirements, and a service plan.

Digitalized planning of spare parts requirements in the spare parts store

The spare parts store of the service portal (**Fig. 5**) offers the plant operator all the information on spare parts directly to their cockpit. Zoom functions and filters display the assemblies and their components. Spare parts requirements are calculated automatically, always considering any default probabilities and the number of identical components. Current availability, prices, and order status of the spare parts available with just one click. Thanks to highly efficient logistics, spare parts selected in the store reach the customer very quickly. Traditional spare parts logistics and online services form a symbiotic relationship.

Service portals are already a lot more functional than spare parts lists on paper or electronic spare parts catalogs. Digital assistants support customers with their spare parts planning and enable them to draw on the full potential of an efficient spare parts management system.

In the not too distant future, factors such as service life, default probability as well as past experiences are going to be considered when forecasting spare parts requirements. Because the plants are directly connected to the digital wear and tear status detection system, the digital assistant calculates the spare parts demand automatically and puts together specific orders in the spare parts store precisely when they are needed. The service portal thus becomes another actor within the smart factory. "Machines plan their spare parts requirements themselves" will then no longer be a utopian dream.

Digitalized wear and tear status detection

The next, almost inevitable step is a comprehensive digitalization of wear and tear status detection. The wear and tear status detection of important and valuable components in the smart factory is data-driven! This detection is not limited to condition monitoring sensors only.

Almost effortless wear and tear status detection as a by-product of the inputs to an advanced automation systems is the driver of this vision. It is a question of which inputs the wear condition of components and their influencing factors can be continuously recorded and evaluated.

Some of the goals are to make the wear and tear status detection less dependent on inspections, to provide constant current status information, and in this way to pave the path for preventive maintenance.

Preventive maintenance

Condition-based maintenance has one major drawback. It is restricted to the few components for which wear and tear status changes can at all be inspected or detected by help of condition monitoring sensors. This works for very few components only [8]. In contrast, preventive maintenance paired with digital status detection is able to include almost every preventively maintained component.

It will still be a while until comprehensive implementation of preventive maintenance is possible in thermal processing plants. This is due to furnace-specific components the service life of which has hardly been researched so far, because their operating conditions vary so considerably, which make systematic recording very difficult. The challenge is a good reason to start researching now.

Digital twin: Cockpit for the Life Cycle Management of components

The digital twin stands for the "C" in the CPS of a smart component. The physical component is one twin, its cyber object the other. Connecting a digital twin with its physi-

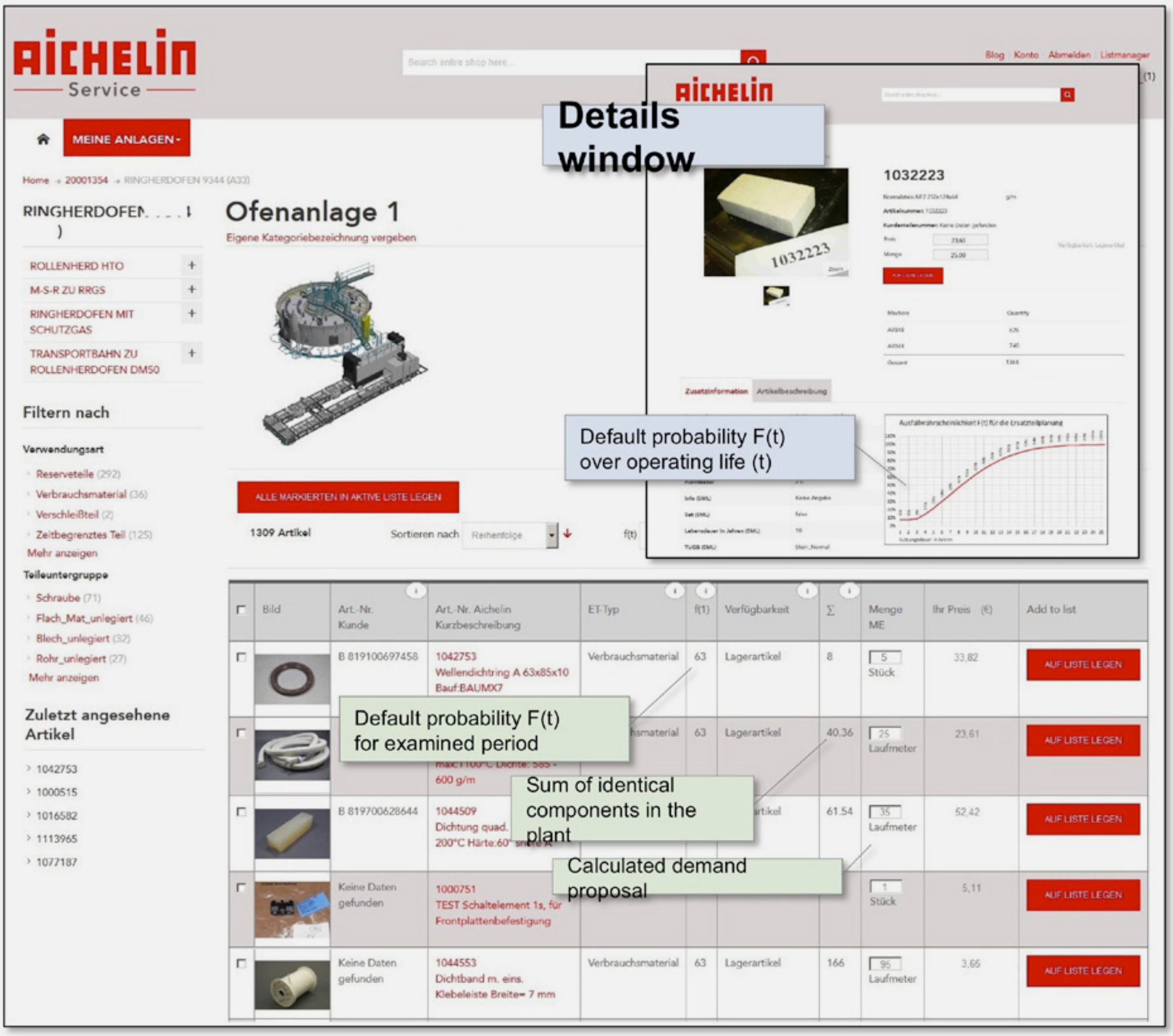

Fig. 5: Spare parts planning at the Service Portal

cal twin can be quite simple: A data matrix code on the component is, for instance, sufficient to establish a connection between the real and the virtual world. This link is not necessary for demountable components.

The digital twin is the platform that provides information on the past, current and forecast status of a component, and it enables life-cycle management on component levels.

Top issue: Safety and security

Aside from operating safety, which provides for safety of production systems for humans as well as for the environment, security from IT-attacks has been gaining tremendous importance in the smart factory due to the internet of things.

To guarantee safety and security, plants, products, data, and know-how must have reliable protection from unauthorized access and misuse [3]. Manufacturers and operators need the guarantee that their know-how, their intellectual property, and their data are protected. It is therefore not sufficient, to add safety and security functions later, when security incidents have already occurred. This topic needs to be considered from the very beginning [6].

Security of data, information, and communication are crucial factors for success. Operators will only grant access to their factories via the internet if they can rely on dependable and resilient security solutions.

CONCLUSION

Industry 4.0 and the smart factory stand for the advent of the internet and the internet technologies within production as well as for a widespread digitalization of all business processes. The drivers of this innovation are two technical developments running parallel to one another: The internet of things and the internet of services and data. Industry 4.0 is so much more than just a reprint of the failed Computer Integrated Manufacturing (CIM) from the 1980ies.

The smart factory brings about a shift in how we understand industrial organization. The hierarchical organization is replaced by a cross-locational network. Plants, transportation, products, digitalized tools and humans communicate with each other through the internet.

A smart factory is about no less than flexible, highly efficient and self-organizing production that is superior on every level to today's production. Cyber-Physical Systems are a key element, consisting of automation systems, sensors, and actors as well as of non-hierarchical communication structures.

The smart workpiece controls the manufacturing process. Self-organization, autonomy, small lot sizes, high flexibility, and transparency (track and trace) are the objectives.

Operator and service are supported by digital services, intelligent assistance systems, and semantic technologies, along with cloud computing and big data.

There is a lot to do, but many things have already gotten off the ground. The rights steps must be taken now. Today, we are developing or supplying plants with a service life up until 2035 and longer. Retrofits must be developed for old sites. In these cases, it will be crucial not to aim for universal solutions, but to take careful steps to implement what is useful now.

The possibility that industry 4.0 might not be able to meet all expectations cannot be dismissed entirely. Touchstones will be the ability to self-organize and especially IT security.

LITERATURE

[1] Steck-Winter, H.; Unger, G.: Thermoprozessanlagen in der Fabrik der Zukunft – Teil 1 und Teil 2. gwi – gaswärme international 64 (2015), no. 02, pp. 39-44, and 64 (2015), no. 03, pp. 73-81

[2] Lucke, D.; Görzig, D.; Kacir, M.; Volkmann, J.; Haist, C.; Sachsenmaier, M.; Rentschler, H.: Strukturstudie "Industrie 4.0 für Baden-Württemberg, Fraunhofer- Institut für Produktionstechnik und Automatisierung IPA, Stuttgart 2014

[3] Plattform Industrie 4.0: http://www.plattform-i40.de/

[4] Spath, D.; Ganschar, O.; Gerlach, S.; Hämmerle, M.; Krause, T.; Schlund, S.: Produktionsarbeit der Zukunft – Industrie 4.0; Fraunhofer-Institut für Arbeitswirtschaft und Organisation, Stuttgart 2013

[5] VDI: Cyber-Physical Systems: Chancen und Nutzen aus Sicht der Automation, 2013

[6] Steck-Winter, H.: Sichere Thermoprozessanlagen 2.0. gwi – gaswärme international 61 (2012), no. 05, pp. 74-80

[7] Steck-Winter, H.; Stoelting, C.: Ersatzteilbedarfsplanung für Thermoprozessanlagen. gwi – gaswärme international 65 (2016), no. 03, pp. 55-65

[8] Steck-Winter, H.: Vorausschauende Instandhaltung von Thermoprozessanlagen. gwi – gaswärme international 60 (2011), no. 03, pp. 141-152

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