Smart Factory – ICT Requirements

Project Paper

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(S)CRM	(Social) Customer Relationship Management
ERP	Enterprise Resource Planning
IaaS	Infrastructure as a Service
JSON	JavaScript Object Notation
MES	Manufacturing Execution System
SOA	Service-oriented Architecture
ICT	Information and communications technology
FOSS	Free and open-source software
PERA	Purdue Enterprise Reference Architecture
SCADA	Supervisory Control and Data Acquisition
OPC-UA	Open Platform Communication-Unified Architecture
CPSs	Cyber Physical Systems
PROFINET	Process Field Net
M2M	Machine-to-Machine
GIS	Geographical Information System
DRM	Digital Right Management
IP	Intellectual property (e.g. patents)
SW	Software
HW	Hardware
IT	Information Technology

Executive Summary

Though involving complexity and requiring innovation in various fields, smart factory is not a thing of the future. The seeds were already sown in the last decade and smarter factories are already evolving. It is just a matter of time before companies will be able to harvest its full potential.

For enterprises who want to move towards an Industry 4.0 compliant smart factory, the trigger needs to come from within the enterprise. Flexibility to change and efficient change management in the fields of information, communication and technology holds the key for a successful smart factory implementation. All of that is going to increase firm's competitiveness due to flexibility e.g. in terms of individualizing complex mass production and efficiencies in energy consumption and resources requirements.

Innovations and improvements are not only restricted to these areas, but also in the areas of hardware systems, human resource management, inter-enterprise collaboration and continuous innovation towards a completely autonomous environment. As more and more factories mature towards Industry 4.0, an umpteen number of requirements will evolve. These requirements will be met by researches ongoing in various fields incl. computer science and many others.

Accomplishing a smart factory is not a discrete process. Instead it is a continuous process wherein new concepts and innovation from various fields integrate together and enhance the factory to become smarter and smarter. Businesses not assimilating the need for a smart factory and continuing with the conventional processes will become obsolete in the future and enterprises which move along with the tide and adapt to the new industrial revolution will reap the benefits.

To conclude our seminar paper, we have identified three major dimensions of ICT requirements for smart factories. On the lowest level, there will be always the **hardware**, which is necessary for creating (even not-so-smart) factories. Indeed, the sensors play here the major role as they need to be resilient to the different factory environments as well as support different M2M communication protocols.

Secondly, the **middleware** should be able to process different data in different structures in order to transfer them to company's enterprise systems. This layer is certainly one of the most important ones because even though sensors and devices can gather data, it is the goal of middleware of "connect" these data with the enterprise platforms, e.g. by using service-oriented architecture (SOA) or web-services.

Lastly, it has always been the **software** applications which have decided if users are going to use either technology. Indeed, we cannot talk about expansion of smart factories if the complexity will extremely high or the interfaces (i.e. GUI) will not be user-friendly. Additionally, it will also depend on software to process and handle large volume and variety of data, and therefore one cannot omit topics such as *Big Data* or its privacy.

1. Introduction

In the following report, we are going to introduce our reader to the ICT requirements of a smart factory. Our seminar paper consists of six sections.

While in the first chapter, we are going to provide additionally an executive summary (ch. 1), in the second one we begin firstly with the explanation of this trend. This is done by touching many different aspects, including smart factory's history (ch. 2.1) and definition (ch. 2.3) up until finally ending the whole section with opportunities and challenges (ch. 2.6) of it.

After the introduction part, the paper continues with a description of requirements for the ICT architecture in a smart factory. Therefore, chapter three starts with the information landscape which includes different technologies and systems that are necessary for the today's modern factories. In fact, it is not only just about generation of information but also about how to process it (retrieval and transformation) and derive further value out of it, e.g. though machine learning and *Big Data* analysis. Such a landscape, therefore, must also include communication technologies (the middleware) which facilitate the exchange of information between different layers. That allows anybody to use and create web services and other business applications.

Then, in chapter four we focus more on the basic IT systems used in factories nowadays. Furthermore, we also provide the reader a concept of a service-oriented architecture (SOA) in the context of the smart factory. The last chapter of the section (ch. 4.3) describes two integration scenarios and offers a guidance for their implementation.

In the chapter five, we take a look on the current environment and state in the field by presenting two examples. One of them that shows Siemens factory using and further enhancing capability of smart technology and another one that has revolutionized production process due to being cheaper, faster and but also more accessible – the 3D printing. Additionally, we examine the future scope of research as for example smart factories can be easily become a target of state-sponsored hacking attacks, thus needing a protection by the government and other authorities.

2. Smart Factory - The goal of Industry 4.0

The term "Smart Factory" came up with the development of Industry 4.0. This chapter first describes the history of Industry 4.0 and in this context the development of the smart factory followed by a further description of terms such as *Internet of Things*, *Cyber Physical Systems* and their connection to smart factories and *Industry 4.0*. After that, the definitions of a smart factory are presented and explained in section 2.3, followed by the different characteristics which are shown in section 2.4. Subsequent chapter explains the technologies that are necessary to implement a smart factory and enable its rise to achieve all its goals. Lastly, the challenges and opportunities are described in chapter 2.6.

2.1 History of Industry 4.0

In context of Industry 4.0, researchers are also always talking about the 4th industrial revolution. Looking back into the history of the industrialization one can observe that there were three groundbreaking technologies that revolutionized the production processes, see Figure 1. The first industrial revolution began around 1750 with the invention of the water- and steam machine (Bauernhansl, 2014). With the use of electric energy, the mass production was implemented in the second industrial revolution. Famous examples are the use of assembly lines. The further development of phones and telegraphs led to the third industrial revolution about 100 years later (1970). The invention of the first computer made it possible to automate the mass production and further to individualize products. Today the widespread use of information- and communication technologies as well as the network of the complete production is said to be the next industrial revolution (Peßl and Ortner, 2013).

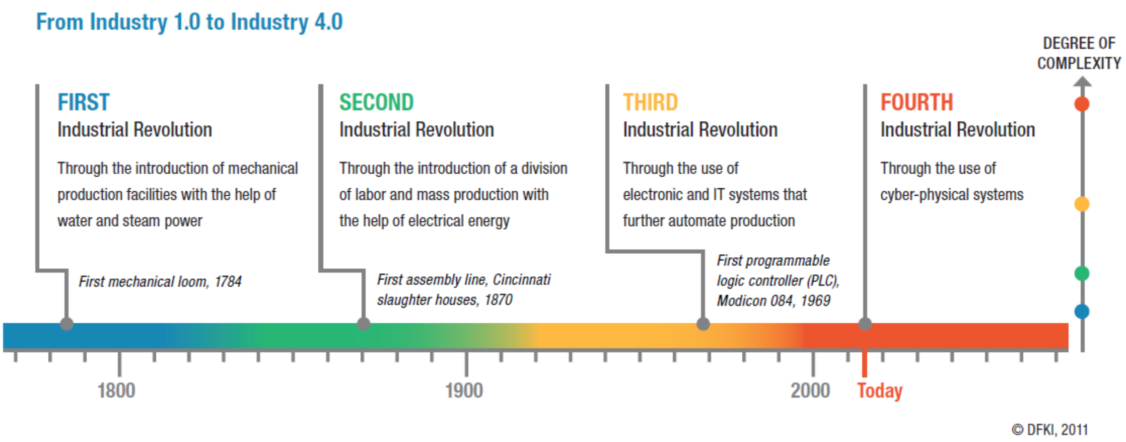

Figure 1 illustrates the transition from Industry 1.0 to Industry 4.0 (Roberts, 2015).

In April 2013 the national "Plattform Industrie 4.0" was founded at the industrial Hannover Fair. Since then, the level of awareness of the term "Industry 4.0" has risen enormously. The frequent use of it has the consequence that the meaning of the term blurs (Bauernhansl, 2014). The *platform* defines the fourth industrial revolution as:

"In der Industrie 4.0 verzahnt sich die Produktion mit modernster Informations- und Kommunikationstechnik. Treibende Kraft dieser Entwicklung ist die rasant

zunehmende Digitalisierung von Wirtschaft und Gesellschaft. Sie verändert nachhaltig die Art und Weise, wie zukünftig in Deutschland produziert und gearbeitet wird: Nach Dampfmaschine, Fließband, Elektronik und IT bestimmen nun intelligente Fabriken (sogenannte „Smart Factories") die vierte industrielle Revolution.

Technische Grundlage hierfür sind intelligente, digital vernetzte Systeme, mit deren Hilfe eine weitestgehend selbstorganisierte Produktion möglich wird: Menschen, Maschinen, Anlagen, Logistik und Produkte kommunizieren und kooperieren in der Industrie 4.0 direkt miteinander. Produktions- und Logistikprozesse zwischen Unternehmen im selben Produktionsprozess werden intelligent miteinander verzahnt, um die Produktion noch effizienter und flexibler zu gestalten." (Plattform Industrie 4.0, 2013)

The main focus of this definition is not the use of specific technologies but rather present the target state. As the name "Industry 4.0" already implies, the focus is on the production industry as it describes the different goals of the fourth industrial revolution and what will change by the implementation of smart factories.

Figure 2 shows, as well as the definition above, that the smart factory is one of the most important parts of Industry 4.0. Kagermann et al. (2013) note that Industry 4.0 should not be considered isolated, but in the context where it is used. Furthermore, this figure also shows the connection to the topics *Internet of Things* and *Cyber-physical systems*, which are going to be explained in the next section.

2.2 Internet-of-Things, Industry 4.0 and Cyber-Physical Systems

Figure 2 illustrates the connection of Industry 4.0 and the *Internet of Things* (IoT), services, data and people. This underlines the importance of separating the terms IoT and Industry 4.0.

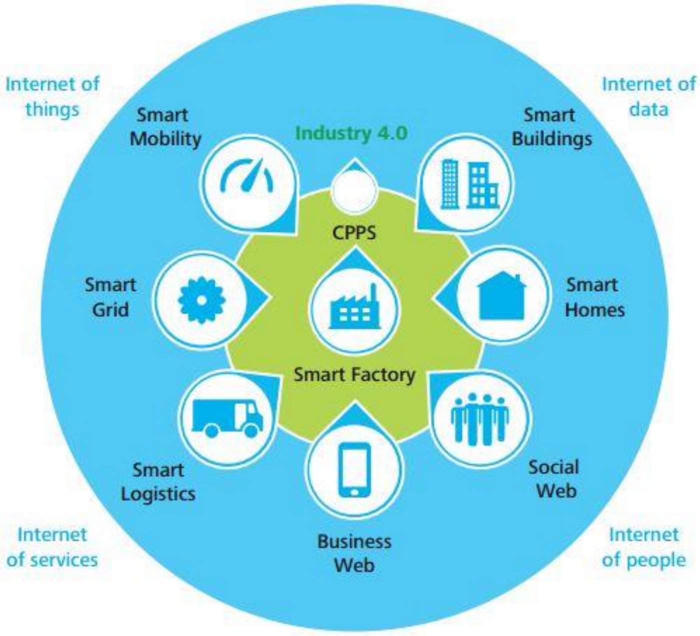

Figure 2 showcases the environment of Industry 4.0 (Source: Deloitte, 2015a).

Internet of Things

A first draft for a definition of IoT was that it is an extension of the world of information and communication technologies (ICT). Therefore, the connectivity anytime, anyplace for anyone is expanded to anything (Peña-López et al., 2005).

Hence, IoT are real objects that are connected to the internet so that they can communicate with each other, services and people (Atzori et al. 2010; Kargermann et al., 2013; Mukhopadhyay and Suryadevara, 2014). On the other hand, the *internet of services* describes web-based software components which can be orchestrated to complex and flexible solutions for the use in companies (Kargermann et al., 2013; VDI/VDE-Gesellschaft 2014).

Cyber-Physical Systems

In connection with Industry 4.0 and smart factories, the term *Cyber-Physical Systems* (CPSs) always comes up. As one can see in figure 2, CPSs are a very important factor for smart factories.

In simple terms, CPSs are the connection of physical objects, (physical) processes and information processing objects or (cyber) processes that influence each other (Lee et al., 2008; VDI/VDE-Gesellschaft 2014). This means that the “physical world” and the “information world” can be separated in “models”, “current status” and the “archive”, see Figure 3.

According to Broy and Geisberger (2012) CPSs are systems, like objects, buildings, processes and internet services that:

- recognize physical data with the help of sensors and influence physical processes with the help of actors,
- analyse and save data and furthermore interact on this basis actively or interactively with the physical or digital world,
- are connected with each other by means of digital, wireless, wired, local as well as global networks,
- use worldwide available data and services and lastly
- have a number of multimodal human-machine interfaces, that provide differentiated and dedicated possibilities for communication and controlling, for example speech and gestures (Geisberger and Broy 2012).

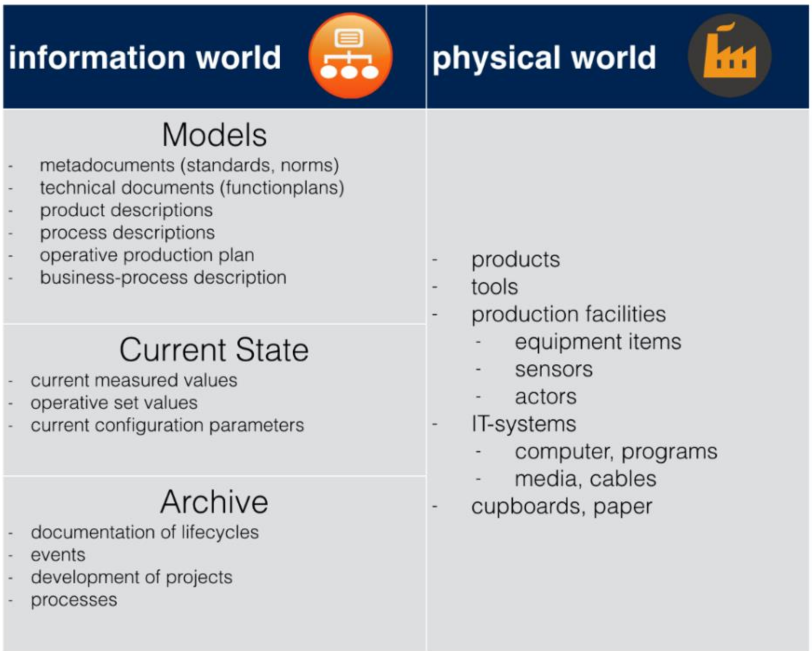

Figure 3 connection of the physical and information world (modelled after VDI/VDE-Statusreport Industrie 4.0; 2014)

To summarize, CPSs are physical objects or processes that have one or more units in the information world. According to Broy und Geisberger (2012) CPSs are furthermore able to recognize physical data from themselves or other CPSs with sensors and influence other physical processes with actors. They save and analyse data and interact on that basis with the physical and information world. They are also wireless as well as wired, local and global connected by digital networks so that they have access to all worldwide available data (e.g. information of the supplier or in the production network).

2.3 Defining Smart Factory

Looking for industrial as well as scientific definitions, we can observe that there are no common definitions for the term smart factory. Furthermore, there are a lot of terms that also have a synonymous meaning (Radziwon et al., 2014).

Yoon et al. (2012) developed a conceptual framework for their so called *ubiquitous factory* (u-Factory), seen as a synonym for a smart factory. The smart factory or a u-Factory therefore use ubiquitous and manufacturing technology to build a network between men, machine and systems. This ensures an autonomous and sustainable production with transparent information exchange (Yoon et al., 2012). Their concept of the u-Factory has not been realized yet as the technology that is necessary to realize it has to be further developed (Yoon et al., 2012).

Zuehlke (2010) sees the smart factory like a factory-of-things. This term sounds similarly to the *Internet of Things* too. As described in the section above it is about devices being able to communicate and act independently via an open network (Zuehlke, 2010). He describes a vision where the IoT-approach is adapted to a factory. This vision is developed by a collaborative initiative of academic researchers and industrial partners in Germany (SmartFactoryKL). In contrast to the abovementioned definition or view of Yoon et al. (2012), Zuehlke (2010) concentrates on the role and development of conventional manufacturing paradigms, like lean technologies. With the help of smart technologies those should be developed further, and therefore create a factory-of-things.

The *Institute of Industrial Manufacturing and Management* in Stuttgart (IFF) defines a smart factory as a factory that helps people and machines by executing their tasks. So-called calm-systems and context-aware applications are necessary to be run in the background (Lucke and Wieland, 2007).

The definition of Radziwon et al. (2014) describes the goals of the implementation of a smart factory and again the different characteristics of it. He sees smart factory as "*a manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could on the one hand be related to automation, understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in reduction of unnecessary labour and waste of resource. On the other hand, it could be seen in a perspective of collaboration between different industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization.*" (Radziwon et al. 2014, p. 1187).

As all these definitions describe certain characteristics of a smart factory, and hence this topic will be further explained in the next section.

2.4 Characteristics of Smart Factory

Figure 4 shows four main characteristics of Industry 4.0. The first one is a *vertical networking of smart production systems*. In this context it means that systems have to react rapidly to changes in the production and be able to organize themselves. This ensures that the production in a smart factory is customer-specific and individualized (Deloitte, 2015a). To realize this characteristic and a goal, smart sensor technologies and CPSs are necessary.

The second characteristic is the *horizontal integration via a new generation of global value chain networks*. Smart factories should have real-time optimized networks to ensure transparency and flexibility in context of the reaction to problems (Deloitte, 2015a). Furthermore, as part of smart factory the whole history of a product changes should be documented and accessible anytime and anywhere.

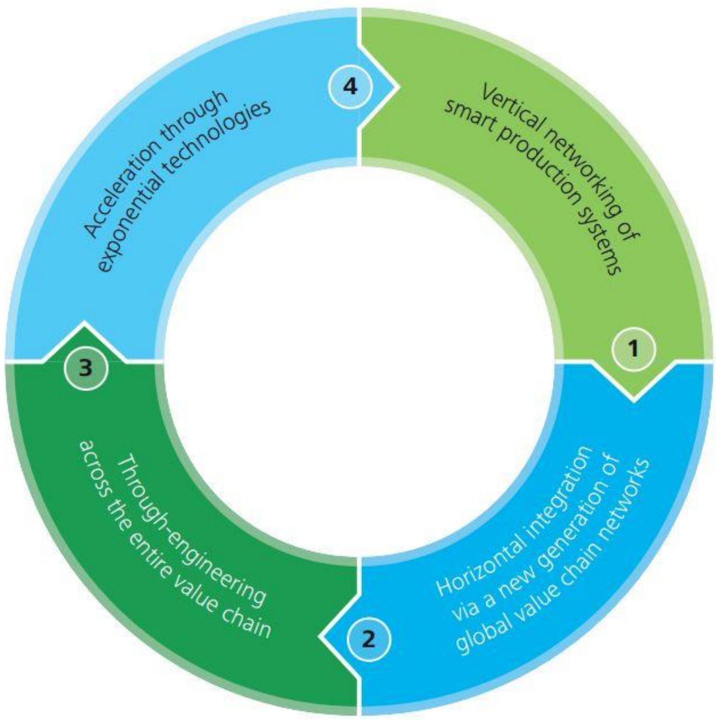

Figure 4 displays four characteristics of Industry 4.0 (Source: Deloitte, 2015a).

Through-engineering across the entire value chain is the third main characteristic of Industry 4.0. This is again based on the need of all data and information being available at every stage of production. In this case it should result in new and flexible product-lifecycles and processes (Deloitte, 2015a). The goal is also to have new synergies between the product development and production system.

The last characteristic *acceleration through exponential technologies* describes the "*(...) impact of exponential technologies as an accelerant or catalyst that allows individualized solutions, flexibility and cost savings in industrial processes*" (Deloitte, 2015a, p. 10). This requires the use of artificial intelligence, robotics and sensor technology. Indeed, the enabling technologies fulfil these characteristics and are shown and explained in the next section.

2.5 Enabling Technology

Figure 5 shows those technologies that are necessary for the implementation of a smart factory. Applications in a smart factory therefore consist of two parts. On the one hand, the so-called *calm systems* or in other words the hardware and on the other hand, the *context-aware applications* – the software. As one can see, *Calm systems* again consist of *Embedded Systems, Communication Technologies, Auto ID Technologies* and *Positioning Technologies.*

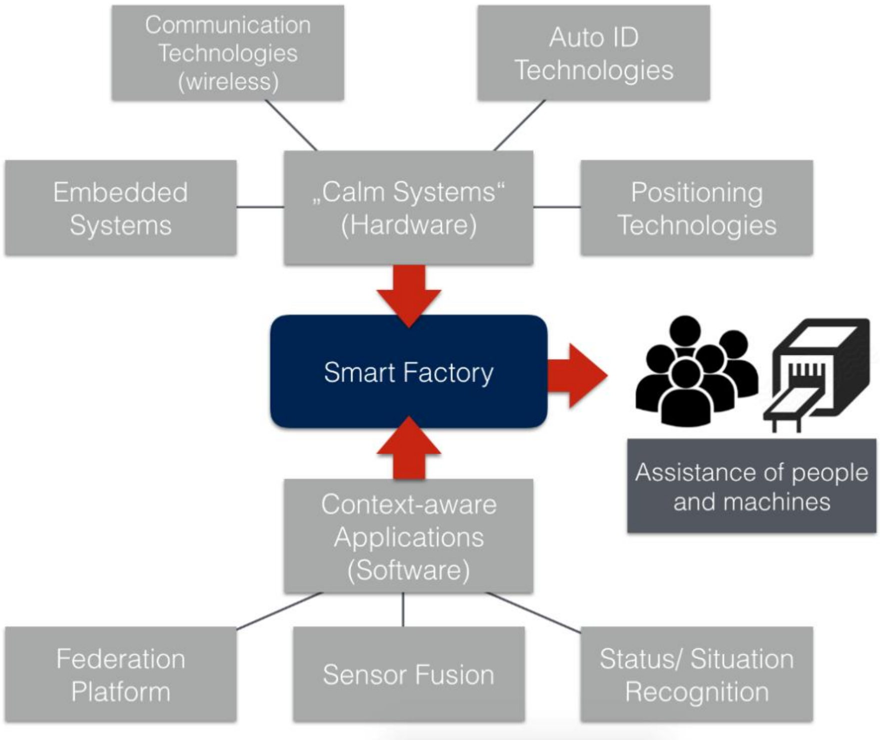

Figure 5 describes enabling technologies, from HW and SW side, of a Smart Factory (modelled after Lucke et al., 2008).

In the book *Embedded System Design - Embedded Systems Foundations of Cyber-Physical Systems* (2011) by Peter Marwedel describes his view on the next generation of ICT systems. He characterizes the future of ICT systems with terms like ubiquitous computing, which means that information are available anytime and anywhere as already mentioned in the sections above (Marwedel, 2010). Furthermore, he says that people will use their computing devices permanently day-to-day (so-called *pervasive computing*). Another term that comes up talking about that topic is “ambient intelligence”. This represents the communication technology in context of future buildings and smart homes. The last term that can be found in the literature is also “post-PC era”. This is the term for processors and software that are now used in much smaller systems (e.g. smartphones), and therefore in the future PCs will be “*(...) less dominant hardware platforms*” (Marwedel, 2010).

To achieve this grand vision of a new generation of ICT, Marwedel (2010) names two technologies. Firstly, embedded systems which include robots and control systems and secondly communication technologies that consist of networking, distributed applications and the quality of service.

Embedded systems are defined as systems that process information in their belonging products (Marwedel 2010). Furthermore, embedded systems should be integrated in physical processes, too. On the one hand, Lee (2006) sees the technical problems in managing time and on the other hand the concurrency in computational systems.

The definition of Lee (2006) illustrated the strong link between embedded systems and physical systems. Thinking of CPSs as defined in section 2.2, embedded systems are taking the information processing part (Marwedel 2010).

Embedded Systems together with Communication Technologies influence ubiquitous computing as mentioned in section 2.2.

The importance of embedded systems is illustrated by the fact that today there are more processors in embedded systems than in PCs and the number of processors in embedded systems is going to continue to increase (Marwedel 2010).

Calm systems also include automatic identification (Auto-ID) technologies. They are necessary to assign information or virtual data to real objects, like products. The most known Auto-ID technologies are *Electronic Product Codes*™ (EPC™) and radio frequency identification (RFID) technology. Another possibility is to use barcodes, which are still often used in industries, since they are the cheapest possibility (Lucke and Wieland 2007). Given that Auto-ID technologies increase the certainty of all information of a product, the historical as well as the current, it improves the production operations, too. It is also possible to add sensors to the RFID chips so that they can store information about the temperature and other information. Another advantage of RFID is that it works without contact and its non-line-of-sight nature (Lucke et al., 2008).

The fourth part of calm systems are positioning technologies. The information of the location of an object is very important in the manufacturing process. Therefore, different methods like scene analysis, triangulation and proximity are used to get these information (Lucke et al., 2008).

Context-aware application or software includes *federation platform*, *sensor fusion* and *status/situation recognition* (Lucke et al., 2008).

The idea behind the federation technology is that it should be possible for applications to have access to heterogeneous data. Looking at the whole supply-chain in a company, every organizational unit often has its own separate information system. The goal of federation technology is therefore to ensure "*(...) seamless handovers of the data between different organizational units when tools cross organizational boundaries*" (Bauer et al., 2004, p.18). Thus, data should be stored in context servers.

Another important point of context-aware application is the situation recognition. It ensures that the employee gets the right information at the right time. Therefore, the system has to recognize the situation of the user and know what information is needed and when.

The last part of the software is related to the federation platform. In contrast to other factories, the smart factory uses the sensor fusion technology. In order to achieve better measurements this technology combines data of different sensors. Even new forms of measurement can be created and applications be implemented, since all the information, including those of the sensors, are available via the federation platform (Lucke et al., 2008).

Combining all the parts of the calm-system and the context-aware applications the smart factory is now able to assist the employees of a factory, as well as the machines in an optimal way.

2.6 Smart Factory's Challenges and Opportunities

Before we proceed further with the description and explanation of smart factory's challenges and opportunities, we should say - contrary to our initial thinking - that there seems to be a bias among many scientists, who have usually concentrated themselves on the problems and issues of smart factory (and the whole Industry 4.0) and less on its benefits and opportunities for the businesses.

On the other hand, this could have also been expected as such a trend and subsequent transformation brings a tangible source of uncertainty for many industries, companies and other stakeholders, including governments. Therefore, a deep analysis is necessary. In addition, given a relatively new field of interests for both academic and outside world, the topic has not yet been rigorously researched. Hence, as we saw it throughout many journal articles and other sources, it is met with a rather scepticism.

To start with, when looking on challenges and opportunities one will be able to distinguish between two major points of view, as it has been outlined based on studies done by Deloitte (2015a), Strategy& (2015), Lucke et al. (2008), Zuehlke (2010) and many others.

The first one is the *management* perspective. To illustrate two examples, firstly corporations will be able to increase their competitiveness and flexibility due to the effective use of smart factory facilities and other technologies. This will further improve and strengthen their transnational configuration of value chain activities. Secondly, they will be also facing new challenges. For example, in adjusting their human talent and IT resources.

The other type is of course the *technical* point of view and here one can say that without reliable connectivity e.g. to the internet or energy resources, smart factories can only be partially functioning and be efficient. This goes hand in hand with the strong reliance on such a technology as it will further mean that in cases of hacking-attacks such a factory will stand still for several days, potentially losing thousands and millions of USDs.

On the other hand, *Internet of Things*, *Industry 4.0* and related terms create a whole new opportunity for the (open-source) software and hardware. By giving the rise to new companies (start-ups) that react quickly to such new emerging trends, they are able to bring a real innovation and have big impacts on employees' everyday lives in factories. As a result, they are able to challenge established players such as Microsoft, SAP or IBM even on their (non-)traditional markets.

In the following several sections, we present the reader both types of chances and risks, starting first with the management ones.

2.6.1 Management perspective

Increased competitiveness through efficiencies, flexibility and risk management

"*The fourth industrial revolution — characterised by the increasing digitization and interconnection of products, value chains and business models —*" has begun and it is already bringing tremendous changes to all stakeholders involved including firms, countries, labour force, unions and managers (Strategy&, 2015, p. 3).

Having a focus on companies, as we have already mentioned, this transformation will increase their global competitiveness, in addition to bringing higher revenues, providing better customer reach and having higher productivity in factories (Strategy&,

2015). In fact, such a digital and computerized evolution will have an impact on every major industry, from automotive and electronics to manufacturing. Independent of its size or country.

Therefore, acting quickly and taking the lead position in this evolution will give firms an edge in integrating and better managing horizontal and vertical value chain activities across different fields such as R&D, procurement, production, warehousing and logistics (Strategy&, 2015, p. 3, 17; see Figure 6 as well). In all those segments a smart factory, as an example of Industry 4.0, not only brings a better energy use and all kinds of production efficiencies (e.g. prediction of maintaining times) but it can also improve the bottom-line of the company when less resources are required and costs can be minimized.

Imagine a situation when a firm has successfully build such a smart factory. This opens it a new way "*to integrate [its] customers' needs and preferences into their development and production processes*" (Deloitte, 2015a, p. 1). Such individualised solutions are then going to take the manufacturing "*into a whole new era of customisation*", which "*will require (...) to switch from the 'push into the market' to (...) understanding of customers' needs and (...) [creating] industry-specific solutions - 'pull from the customer'*" (Deloitte, 2015a, p. 2). Furthermore, because of for example better (e.g. *Big Data*) analyses, it will "*enhance quality and avoid faults in the production process*" too (p. 3). All of that is going to lead to the better satisfaction of customer needs - the ultimate goal of every business.

Flexibility

With help of Industry 4.0, factories can become efficient and flexible resulting into the company which is being able to produce individualized products still on very large economies of scale (Steinmetz, 2014). Indeed, those companies, which will not able to meet such individualized demands will be diminished in the future. All of described points are also empirically confirmed in the recent studies of Deloitte among Swiss manufacturing companies, in addition to the report by Strategy& (Deloitte, 2015a, p. 9ff.; Strategy&, 2015).

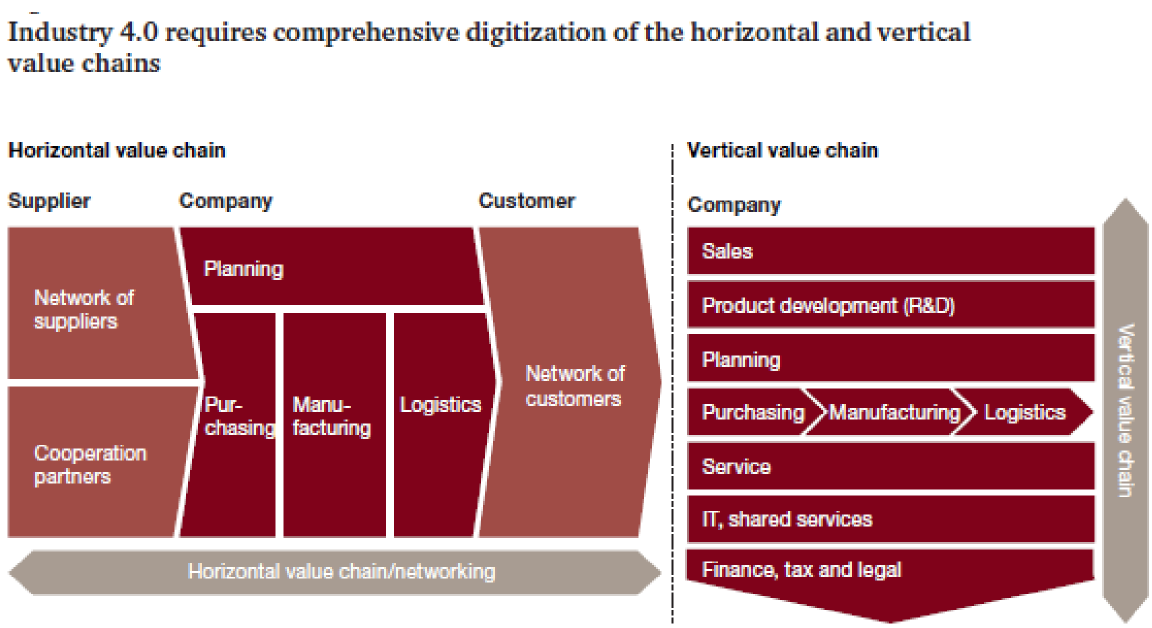

Figure 6 shows two different value chains and its respective activities (Strategy& 2015, p. 17).

Also, previously, where there was a risk of producing too much or too low, smart factories will now be able to predict what quantity of products will be needed, and thus utilize their resources in a better way. This, due to the huge amount of external and internal data that they collect and process. Make-to-order becomes make-to-stock permanently. And even though, one could argue that ERP and MES can do already just that, one should not forget the fact that they are greatly depending on user's input – be it at the begging of production process or at the end. With smart factories, we are talking about their autonomous thinking capabilities.

Managing human talent resources

In the chapter above, we have presented how companies can benefit from the smart factories. Nonetheless, there are also a number of challenges, one of which is described in the Gartner study "*Service Providers Are Waging War Against U.S. Talent Shortage with Unconventional Methods*" (Gartner, 2015).

To quote additionally, "*by 2020, there will be 1.4 million computer specialist job openings, according to the U.S. Department of Labor. But projections show universities are not likely to produce enough qualified graduates to fill even about 30% of these jobs*" (Rosenbaum, 2015). And this is a very relevant issue for companies not just in the USA but also worldwide, see for example Figure 7.

Take for example Germany where – according to *2015 Talent Shortage Survey* by the ManpowerGroup – 46% of all employers surveyed had difficulties filling their jobs (ManpowerGroup, 2015). More than that, Germany needs - according to various statistics - over 90 000 candidates in the technical fields such as engineering, biotech etc. every single year alone (Dierig, 2014). Especially now in the computer science and software engineering there is currently a huge shortage in every developed nation.

Going back to our topic of smart factories, namely its success - at least in the first stage at the beginning - relies very much on developing sensors and building the networks where a combination of IT and hardware engineering skills are required. However, as it can be seen, companies are already (and this will only increase in the coming years) facing tremendous difficulties in finding the right talent for enabling such a "*digital transformation to Industry 4.0*" (Deloitte, 2015a, p. 3). Not only the competition will increase but also such talented people will be able to command high salary with many additional benefits which companies will need to accept and adopt to.

To summarize, in order to enable the quick rise of smart factories (and partially also the whole field of Industry 4.0), it is essential that corporations, governments, universities and the whole society recognizes the need for having skilful people at the right time, and thus adopt themselves to the new requirements of the fast-moving, globalized world.

Even though, in this chapter we narrowed our focus on two major points which come to us from the non-technical view, we also need to mention that there are many others. Zuehlke (2010) mentions for example the fact the production and the whole supply chain becomes increasingly global and more complex. Thus, not only a factory but also highly skilled managers, who are able to adapt quickly to the customers' needs and new technological environments, are absolutely necessary for firm's competition and long-term survival.

2.6.2 Technological perspective

Given overall scepticism of researchers, there seem to be - from the technological point of view - even more risks associated with the Smart Factory. For one, there is the whole field of security, which in the today's modern world of (state-sponsored) hacking-attacks makes managers extremely cautious when deciding to construct such a "smart" facility. This, combined with the notion of even bigger reliance on technology, makes smart factories also more vulnerable, expensive and harder to create and build.

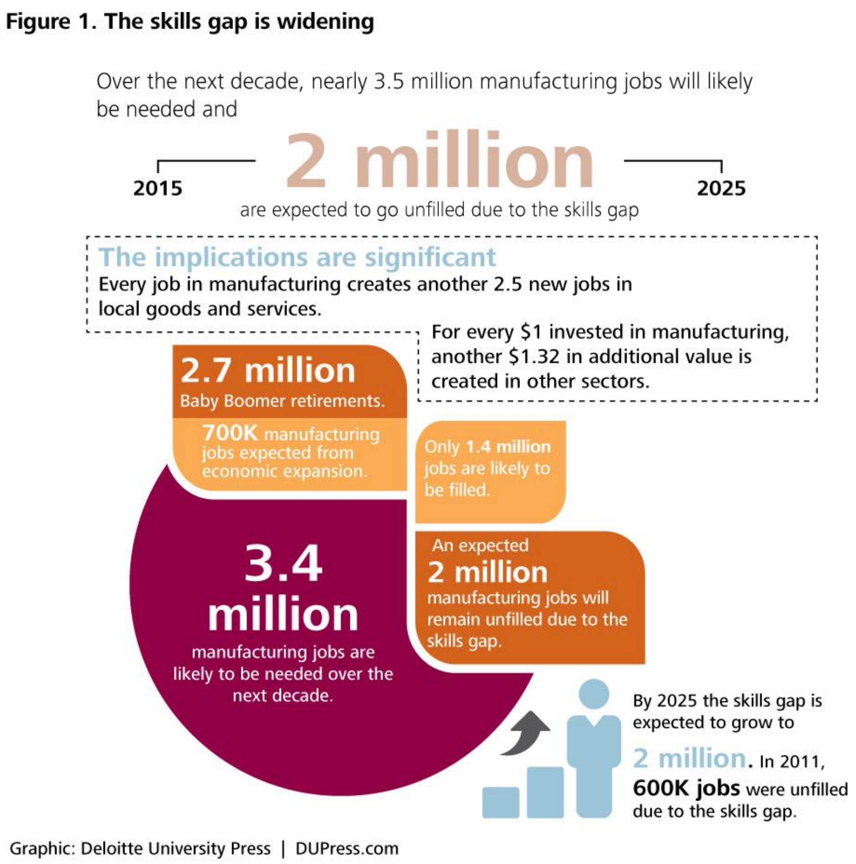

Figure 7 shows infographic by Giffi et al. (Deloitte, 2015b)

Speaking about reliance on the technology, in order to overcome potential blackouts such a facility needs to have several independent sources of not only the internet (i.e. fibre cables) but also the energy (in addition to many others). This, however, in some locations can be very problematic due to high expenses, micro-politics or other factors. Moreover, designing firm's IT architecture while taking into account the current IT landscape can present a great IT challenge which is also a resource (mainly financially and timely) intensive task.

The *smart factory* challenges many other requirements which both software and hardware must now provide or address too. For example, in the software area some of the very important topics of the last decade were *SoLoMo*[1], *cloud computing*[2] and last but not the least the *open-source movement*[3]. All of these have profoundly impacted

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[1] Social, Local, Mobile – meaning that for example without responsive (mobile) website to the administration portal of the factory, a manager may find it very hard to adjust settings from his smartphone during his vacancy.

[2] For example, consistency and fault tolerance across different databases in many geographical locations at the same time must be ensured in the case of system failures.

[3] Building a smart factory "locked" in SAP, ORACLE or any other provider can be viewed as a problematic due to financial expenses, general uncertainty, (costly) extensibility for new features and in some countries like China presenting a security risk to the nation. Therefore, *FOSS* technologies present an alternative for the aforementioned cases.

software development processes too (see more about *open-source* in articles by Lerner and Triole, 2000; Colazo and Fang, 2009; Lakhani and von Hippel, 2003; Brown and Booch, 2002).

Specifically, after Mr. Snowden's release of NSA's secret information in the summer of 2013, security embedded in the hardware as opposed to have it on the software level has become an increasingly important topic in the research community. Indeed, for example, Intel already provides DRM at the CPU level (i.e. in chips) making it very hard for hackers to crack the protection of PC games, videos or other content protected in that way (*adc*, 2015). Furthermore, Snowden's revelations have also changed how the security is perceived. Nowadays, this has become a mandatory part of each (new) software application (incl. on the web) as opposed to have it as just "nice to have" paying feature.

While these issues may all be true and very relevant, they are less specific and given our focus on smart factories also very general. Therefore, we would now like to talk about articles by Lucke et al. (2008) and Bauer et al. (2004), who have identified several smart factory specific requirements to overcome these challenges.

2.6.2.1 Practical Requirements

The first issue they talk about is how objects (e.g. machines etc.) will be *identified* in a factory. They write that this challenge creates a need for "*suitable identification methods, tags, sensors, sensor readers and communication facilities (...) to be found and chosen, specific to their tasks in a rough industrial environment*" (Lucke et al., 2008, p. 2). Whereas for smaller devices an identification tag may be well suitable (as they can be transported by other machinery), for larger objects a small sensor with limited processing power and storage may be necessary (Bauer, 2004). Once, this aspect of smart factory is solved then the next one is no less important.

Their second issue raises the question of the *location*: Given that we can identify our objects, how are we going to know where are they located in the factory? In the car industry this is solved by systems such as GPS (of the USA), GLONASS (Russia) or Galileo (EU) where it is pretty much irrelevant if the car is 25cm or 50cm off the right track. But in large factories such as in the aviation industry it can be quite a big challenge to find 5cm x 5cm x 5cm object with a precision of several meters (Galilio, 2015). Therefore, not only location services need to be very precise (accuracy of 15cm suggested by Bauer'04 can be ideal) but also be very scalable and work under any conditions (which can be inside of the factory, e.g. high heat, dusty environment etc.).

This brings us again to the more general requirement such as having appropriate networks for transferring information. Here, for example, Wi-Fi may be – in the context of huge industrial factory – very unreliable as it is prone to interferences from other devices using the 2.4 GHz band. Radio-frequency identification (RFID), “old-school” barcodes, newly developed *Machine-to-Machine* protocols or Bluetooth may be more useful for such situations (Rowe, 2014). Once the obstacle of the transfer of information is accordingly addressed, then authors suggest to look on another category of issues, namely what they call under the umbrella term *Gathering Dynamic Information*. To reiterate, this requires to again know an exact position of any object in the factory.

Therefore, Lucke’s et al. (2008) and Bauer’s et al. (2004) third focus is on *Updating Management Systems*. This essentially means the location as well as many other information from devices including sensors must be securely transferred and stored in (preferably) in one *management system*. Not only such enterprise applications need to be resilient to the system failures (losing data is not acceptable under any conditions) but also be able to provide fast (with the goal of real-time and low latency), accurate and high-quality information to its stakeholders – mainly the managers.

Such applications will in fact handle large volume and variety of data. Per Lucke et al. (2008) each device may need to transfer its status data up to every 30 seconds, which is about 2880 transfers of information per day. Therefore, terms such as cloud computing or *Big Data* cannot be omitted from a designing process of the firm’s IT landscape (architecture). For example, a company having a smart factory will most probably not have its core business (and strength) in the maintaining and building energy-efficient datacentres akin to those build by Google, Amazon, Microsoft and others. Therefore, it will rely on other providers not only to store the data safely but also to maintain those datacentres too.

Today most of the SME and all large companies use some sort of *business intelligence* environment to conduct different analysis and create reports. The main purpose of these applications is about *integrating all other (heterogeneous) systems* such as resource planning (ERP), financial ones or even (S)CRM. In fact, only if these are highly integrated, a true benefit of analysing different information from many sources can be seen and have a measurable effect on the business decisions and activities. Additionally, in the case of system failures, which can happen in the production process anytime, for example the integrated monitoring systems can help to identify and analyse root causes of problems and take pre-defined actions if necessary.

Having and building such enterprise applications is, however, only one part of the puzzle. To make all that information available to users, Lucke et al. (2008) also talk about supporting a *wide range of queries*. In fact, it cannot be enough to support just the classical SQL statements. Nowadays, the support of spatial (used in the GIS) queries or graph-based ones is needed too. In the recent years, the NOSQL type of databases have risen dramatically, and thus there should be no reason not to have them incorporated as well (Leavitt, 2010). Yet, from the technological point of view this is technically very challenging and several different databases will need to be used for querying structurally different data. In addition, building such a complex (*business intelligence*) systems require a very high level of expertise in the field and the use of right (and thus usually expensive) tools as well.

Even when deciding to build one, companies usually face new kinds of problems such as inconsistent data formats (e.g. text based JSON vs. proprietary Microsoft Excel's XLSX format) or inadequate quality of their own data. Moreover, not to talk about problems with finding right technical, in-house, talent described in the previous chapters. On the other hand, if and once accomplished, making queries in such unified system makes it easier to gain an insight into e.g. the customer needs or together with the *machine* and *deep learning* predicting when facilities need their maintenance.

As a summary, we present a table of both technological and managerial challenges and opportunities which show several areas that authors usually talk about in the references to the *smart factory*.

Type	Challenges	Opportunities
Management	• Competition for scare human (incl. IT) talent • Limited resources (physical, financial etc.) • Risk management	• Flexibility & Efficiency & Individualization of production • Shorter product development • Increased world-wide competitiveness
Technological	• Complexity • Security & Privacy • Permanent reliance on technology • Scalability and stability	• Opening of new markets & businesses (e.g. by developing better sensors or use of IP) • Advancing the state of the IT technology (new SW & HW)

Table 1 displays a summary of challenges and opportunities.

3. ICT Architecture in Smart Factory

The major focus areas that are involved in the transition of conventional factories to smart factories are information, communication and technology. The existing factories already comprise a huge number of innovations in these focus areas. But, the envision of the fourth industrial revolution (Industry 4.0) provides a compelling reason and proves that these systems need to be more autonomous, interoperable, intelligent and smart to handle the diversity and dynamism existing in the manufacturing arena. This had made the researchers and scientific groups to revisit the overseen gaps in existing factory systems and in turn had triggered numerous new requirements and enhancements in these three focus areas.

Every area is loaded with a set of independent requirements to realize the vision of a smart factory. The requirement in one focus area has eventually necessitated the need for additional requirements in the other two focus areas. Practically, these three focus areas are inter-mingled and need to be addressed separately in some cases and together in some other cases to arrive at an efficient solution.

The requirements in these areas are also dependent and vary based on the different functional units of an enterprise. According to the Purdue Enterprise Reference Architecture (PERA), an enterprise can be visualized as a stack of 5 layers, each having its own functionality and which are bi-directionally dependent on other layers (Li & Williams, 2000; see Figure 8). The information, communication and technology have an interlinked architecture which spans across all these layers.

Business logistics systems	**Level 4**
Manufacturing and operations systems	**Level 3**
Control Systems	**Level 2**
Intelligent devices	**Level 1**
Physical Process	**Level 0**

Figure 8 shows *Purdue Reference Model*.

3.1 Information Landscape

The information landscape across the layers of an enterprise can be broadly visualized and categorized as Information *source/generation, collection, storage, retrieval, transformation, analysis, control* and *visualization*. Although this landscape is also valid for conventional factories, the scope of each of these categories needs to be scaled up and be made intelligent to convert these factories to smart ones. An additional system is required to act as an enabler of smart factory to provide this intelligence, also called the *information learning* system. Figure 9 shows the different systems of a smart factory and their position in the information landscape of the enterprise. The figure also shows the position of the information system in PERA Layers (*Lx*-where ‘x’ stands for layer number).

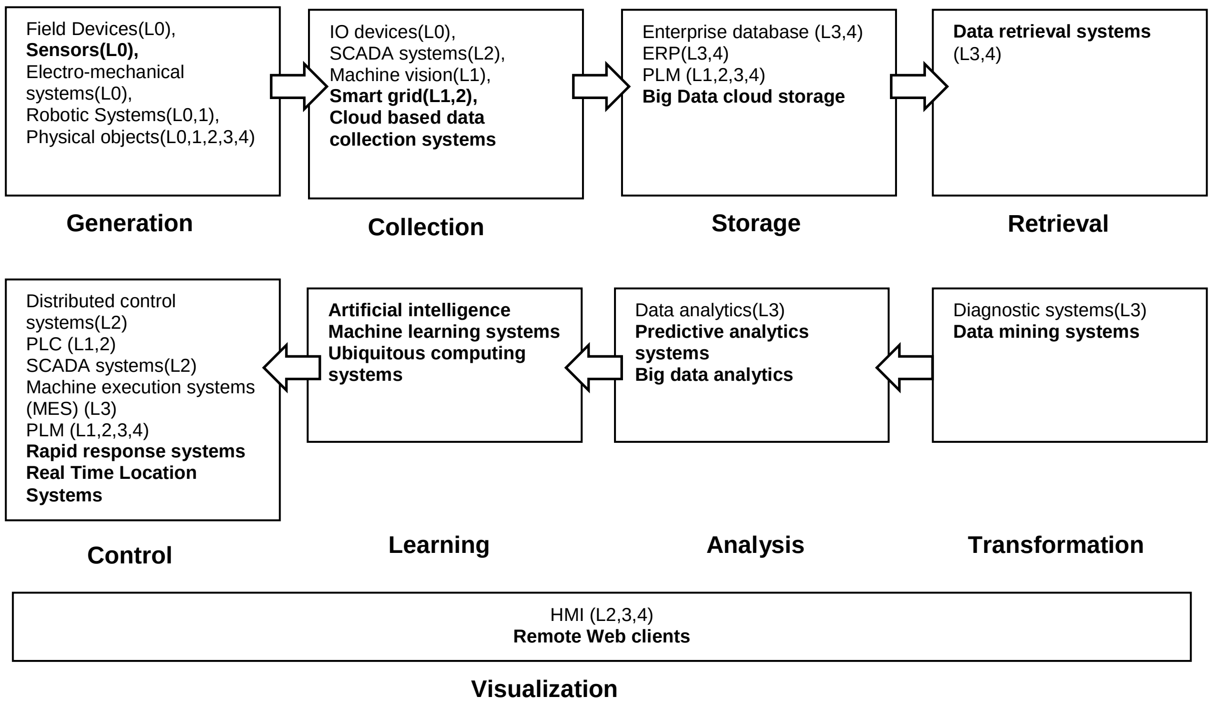

Figure 9 gives an overview of information landscape in a smart factory.

There is an inherent need for innovating and enhancing many of the systems in this information landscape to adhere to the requirements of a smart factory. The key components such as sensors, cloud-based data collection systems, data mining and retrieval systems and real-time location systems need to have innovative value additions. Other innovative systems, which are being used in multiple other sectors, need to be incorporated and integrated to smart factories as well. Some of these important systems are *smart grid*, *Big Data cloud storage*, *predictive analytics* with *machine learning* capabilities, *artificial intelligence* and *rapid response* systems. Even though these systems prevail for use in other scientific fields, they are not yet mature enough to handle factories. Scientific research is ongoing to enhance and adapt the capabilities of these systems to make them deployable for use and to harness their potential for making the factories intelligent and efficient.

Smart factories need to accommodate the information arising out of both passive and active digital foot prints. Both physical objects and humans behave like sensors. Physical objects have a stern passive digital foot print, while humans have both passive and active digital footprints (Thatcher, 2013). When all physical objects of a factory become part of the cyber system, the information flow created by passive digital footprints will become enormous. This information is a boon and a bane in its own sense. The enormous amount of information can be analysed by incorporating Big Data analytics and the resultant data can be used to predict factory behaviour and take pre-active and reactive measures which are a boon. But the analytics itself needs a cumbersome effort to derive at useful information which might include advanced pattern matching, history comparison and data integrity checks.

3.2 Challenges in Information Management

One of the main challenges in a smart factory is to handle the huge volume, variety and velocity of information that is flowing through the enterprise. Huge volumes of information with high velocity need to be handled by scaling up existing systems and using new technologies like Big Data and cloud systems. The huge variety of data needs to be managed by developing new interoperability solutions and standardizing the same. This would allow a smooth flow of information without interfering with the integrity and consistency of the data across the smart factory.

The technological entrants like Big Data and cloud computing into the factory environment forces updating of existing tools and technologies used. For example, *Oracle Big Data SQL* extends *Oracle SQL* to *Hadoop* and other NoSQL databases to handle unified queries for Big Data Management Systems (Oracle, 2015; see also 2.6.2.1). The updating and scaling up of technologies and such a transition should be optimally carried out by factories based on the key requirements to avoid overwhelming costs. According to Moore's law the information-technology driven changes happen as a speedy pace nearly doubling every 18 months (Schaller, 1997). These changes in turn drive the exponential growth of microchips, bandwidth and computing power which ultimately requires the factory to keep upgrading. Indirectly, the growing information content within factories tends to drive the technological requirements within the factory floor. Though these facts portray the complexity of data management, there is a high potential that can be carved out of this complexity. The value that is generated out of this complex activity is huge and changes the trend in factories by foreseeing situations so that the control mechanisms can do prescriptive analytics and take decisions for scenarios that are yet to occur, see Figure 10.

In the Figure 10, it can be seen that the value component increases with difficulty. To dilute the difficulties of handling huge information, there are so many technological solutions in existence. *Hadoop* and *Oracle Big Data SQL* are a couple of those software technologies which can handle such information with ease. Of course, they come with a cost. But the return on investment (ROI) is rapid and business benefits are huge, see Figure 11.

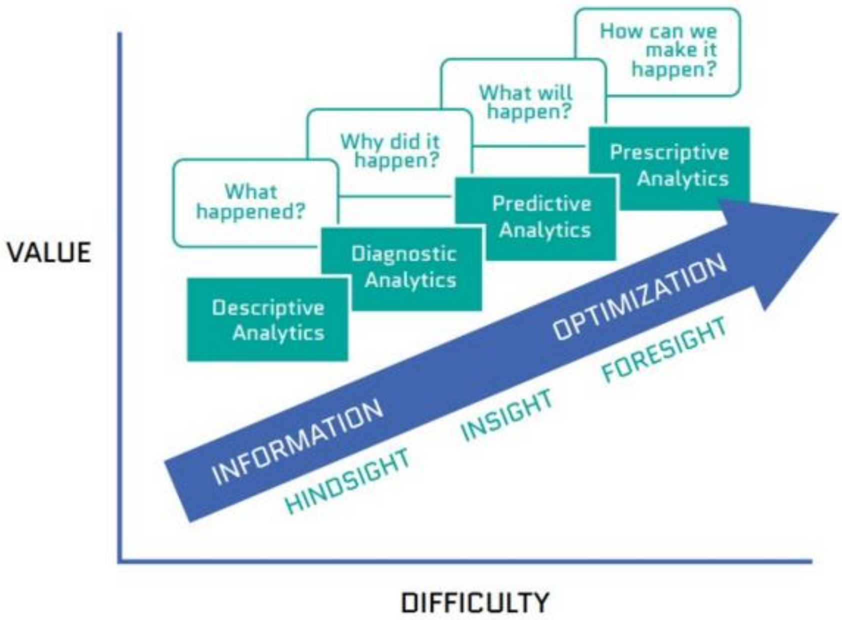

Figure 10 displays evolution of information management (on scale of value vs difficulty) Source: National Big Data Congress 2014.

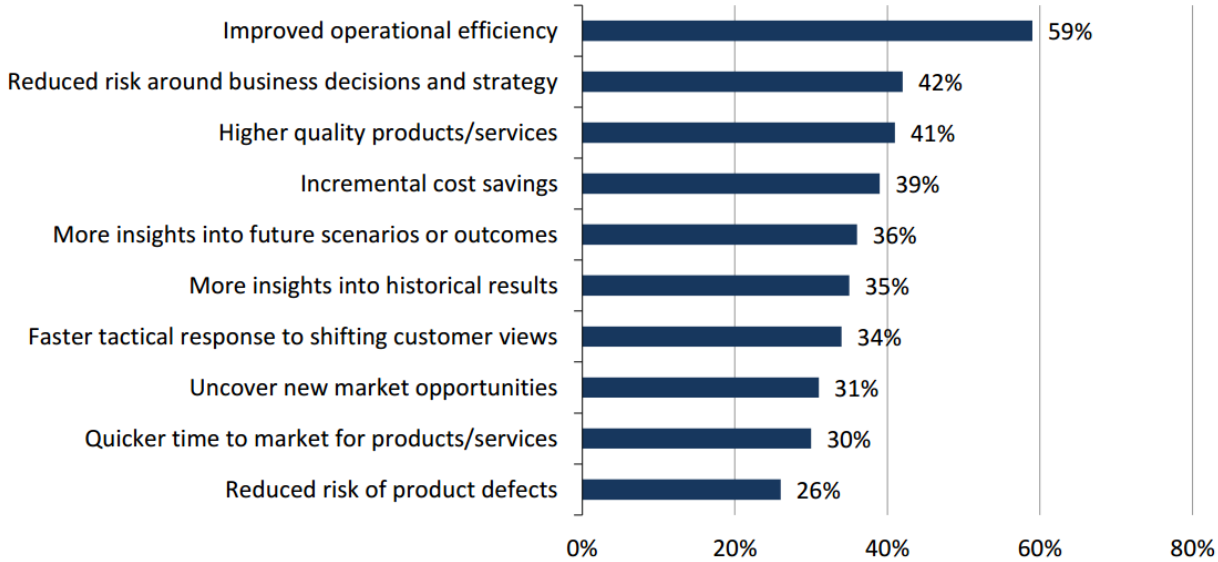

Figure 11 shows business benefits from investment on data analytics, business intelligence and Big Data (Source: Enterprise Strategy Group, 2014).

The fourth industrial revolution, the reason behind the concept of smart factory, necessitates ubiquitous information. This paves way to the concepts like *Internet of Things*, *Factory of things*, *Internet of everything* and *cyber-physical systems*. These concepts put forward additional challenges in the area of information security. They open up new avenues for data theft, industrial espionage and attacks by hackers (Deloitte, 2015a). These additional requirements imposed on the information landscape (related to volume, velocity, security) cannot be accomplished only from within, instead it also requires ramping up of communication methods and technological prowess.

3.3 Communication Methodologies

In an ideal smart factory, each and every object within the factory is ubiquitously made available in a common cyber platform either indirectly or virtually (in case of physical objects like raw materials). This creates a series of interaction between associated objects thereof coercing appropriate communication methodologies. Not only there is a need for a communication platform arising out of it, but also a need for middleware components to motivate and facilitate interoperability between distinct interacting partners. Within smart factory, the factory of the future, CPSs will enable the communication between humans, machines and products alike. As they are able to acquire and process data, they can self-control certain tasks and interact with humans via interfaces and services, see Figure 12 (Brettel et al., 2014). The complexity of communication especially happens in the middle layers of PERA, see Figure 13 (Günthner & ten Hompen, 2010).

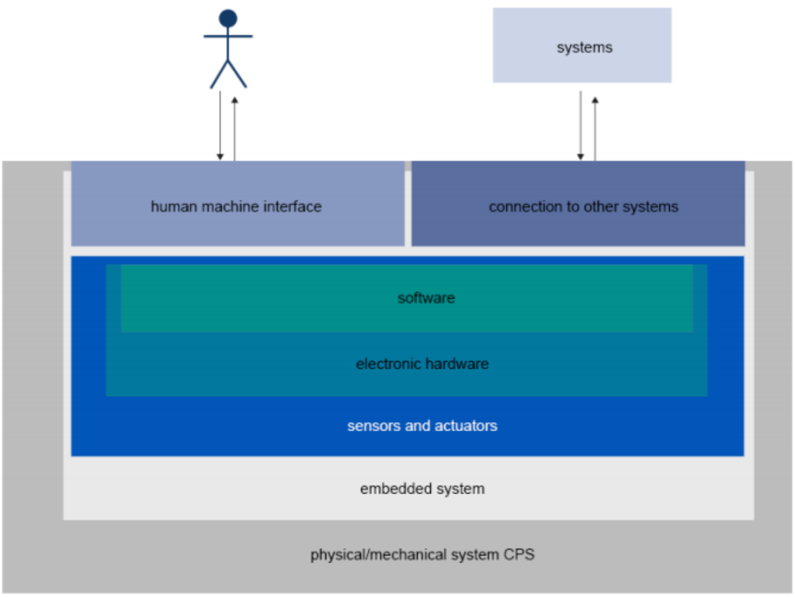

Figure 12 captures the interaction between humans and machines via CPSs (Broy, 2011).

The interoperability in communication will be required by devices doing the same functionality (multi-vendor field devices) and also between functionally distinct devices (PLM & ERP, PLCs and HMIs). Thus, the communication requires syntactic, semantic and cross-domain interoperable solutions. These to provide interoperability in communication spans a wide spectrum and requiring the inclusions of new protocols, software technologies, standards and digital communication concepts. The overall communication within a smart factory can be visualized in three planes and is shown in Figure 14.

The *devices and intelligent systems* is the lower plane which forms the basic units of a smart factory. *Web services and business applications* form the upper plane and the intermediate plane is the *control plane* which acts as a middle layer (middleware) for communication between the other two planes. The control plane actuates and controls the systems in the lower plane based on directions from the business applications in the upper plane. It also consolidates and transmits information from the devices to the server which can be used for analytics. The degree of heterogeneity within each plane and between the planes is huge. To ensure a smooth and consistent flow of data within the smart factory, proper communication methodologies and protocols should be adhered to by different components comprising the smart factory environment. Table 2 provides a list of such protocols that are currently being used only for process automation domain. This list can give a preliminary idea about the scale to which communication methodologies need to be handled in a smart factory.

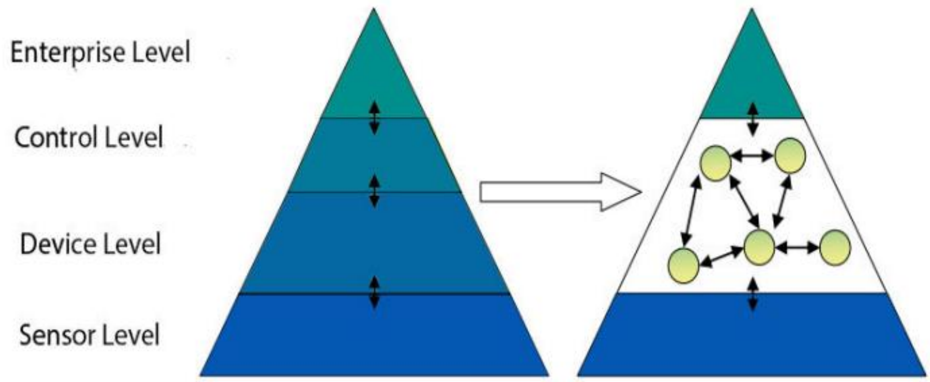

Figure 13 shows the classical automation pyramid with enhanced communication (Günthner & ten Hompen, 2010).

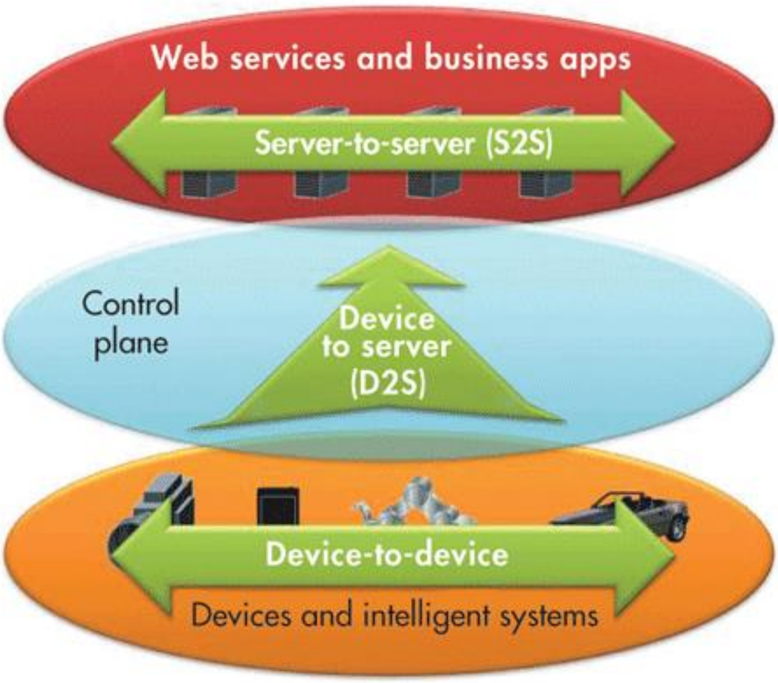

Figure 14 describes communication planes in a smart factory.

AS-i – Actuator-sensor interface	BSAP – Bristol Standard Asynchronous Protocol	CC-Link Industrial Networks
Common Industrial Protocol (CIP)	Controller Area Network	ControlNet
DeviceNet	DF-1	DirectNet
EtherCAT	Ethernet Global Data (EGD)	EtherNet/IP
Ethernet Powerlink	FINS	FOUNDATION fieldbus – H1 & HSE
HART Protocol	HostLink Protocol	Interbus
MACRO Fieldbus	MECHATROLINK	MelsecNet,
Modbus PEMEX	Modbus Plus	Modbus RTU or ASCII or TCP
OSGP	Optomux	PieP
Profibus.	PROFINET IO	RAPIEnet
Honeywell SDS	SERCOS III	SERCOS interface
SSCNET	GE SRTP	Sinec H1
SynqNet	TTEthernet	MPI

Table 2 lists process automation protocols (Source: Consolidated from Galloway & Hanck, 2013).

Although at the first glance, handling the vast variety of protocols seems to be cumbersome, there are already well developed architectures like *Open Platform Communication-Unified Architecture* (of the OPC Foundation[4]) and standards like *MTConnect* (of the MTConnect Institute[5]) which are destined to solve these pitfalls. As more and more factories move towards Industry 4.0, many vendors are going and have already started adapting their devices to support such common platform architectures and standards. As the domain matures towards Industry 4.0 requirements, the peaks of these mountainous problems will be captured with ease. With exponential growth of processing power and miniaturization of electronic components along with a rapid growth in technology, these hurdles will be transformed to realizable and visible business benefits.

3.4 Technology Landscape

Technology plays a major role in overcoming challenges posed by information and communication complexities. IoT, one of the major goals of Industry 4.0, relies on different concepts in information and communication technology.

To visualize the role of technology, one can think about how IoT can be realized. The core concept of IoT specifies that all objects need to be directly or virtually connectable through internet. To create this Cyber-Physical bond, there need to be technologies like remote sensors, GPS dots, network technologies, software technologies for real-time location systems and of course a massive and reliable internet infrastructure (see also 2.6.2.1). These are achieved by deploying a specific technology for each purpose. Industrial Ethernet like *Profinet* for networking, Big Data and cloud computing technologies to handle the vast amount of data, IPv6 like protocols to assign unique IPs to all physical objects (since IPv4 is not enough), high bandwidth transmission devices, active routers and repeaters to ensure reliability, GPS mapping systems and various types of sensor technologies (touch, light, proximity, etc.).

Environments of IoT create invisible requirements related to performance, security, data integrity and other non-functional requirements. Security is an important one and is achieved by technologies oriented towards providing security for information and during communication to avoid industrial espionage.

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[4] OPC Foundation. 19 Dec. 2015. www.opcfoundation.org

[5] MTConnect Institute. 19 Dec. 15. http://www.mtconnect.org

4. IT Systems in Smart Factory

Even though CPSs in smart factories are able to operate and communicate decentralized on their own, IT systems are still essential. First and foremost, they are necessary for the design and compliance of the company's business processes across all involved manufacturing systems of the factory. Moreover, the least "smart" factories are and will be built from the ground up, also as an upgrade to existing ones. Therefore, IT systems are substantial for the integration and communication between old machinery, which is not upgradeable, and new smart cyber-physical systems.

The adoption of IT systems and especially *Enterprise Resource Planning* systems (ERP) is still unabated. According to a Gartner projection, in 2017 the world-wide sales of ERP-Systems will exceed 34 billion US-Dollars (Statista, 2015). Generally, these systems offer broad support for all business processes along the value chain of a company. Amongst various other functions and tasks they include inventory control, scheduling and capacity-planning, order processing, commissioning and billing (Kletti & Deisenroth, 2012).

Companies in the field of manufacturing are typically using a *Manufacturing System* (MES) in addition to the ERP system. The MES in its original form lies beneath the ERP-System, see

Figure 15 displays classic automation pyramidFigure 15, and is capable of operating and controlling all connected production systems in real-time. On the one hand, the scope of services and the numerous tasks of MESs make these systems versatile. On the other hand, the increasing ramification of subsystems and machinery tend to generate a multitudinous complexity.

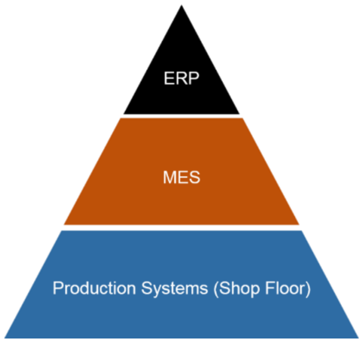

Figure 15 displays classic automation pyramid.

4.1 Manufacturing Execution Systems (MES)

The complexity described in the last section is enhanced due to the lack of an international standardization for MES. Since 1990, there were efforts for standardization guidelines by numerous different organizations but none has established itself as a leading standard. Nevertheless, the prevailing guidelines world-wide are the following three:

- The *Manufacturing Enterprise Solution Association* (MESA) assigned MES a very central role for producing companies. They defined the MESA model which contains eleven main categories enumerated to function groups for MES (MESA, 2015).
- A comprehensive approach to define and describe MES was undertaken by the ISA (*International Society of Automation*). Entitled ISA-95 they published their guideline into five parts. These include terminology, interfaces between MES and ERP systems, and production processes and data processing within the MES. Part four and five are still in development (ISA, 2015).
- In Germany, the *Verein Deutscher Ingenieure* (VDI) released the guideline 5600 based on the work of MESA and ISA. Their guideline serves the purpose of a guide for MES projects and as a basis for comparison of different solutions. They name eight areas of responsibility for a MES: detailed planning and fine-tuning, resource-, material-, personnel management, data collection, performance analysis, quality- and information-management (VDI, 2015).

4.2 Service-oriented Architecture (SOA)

The lack of a uniform standardization continues in the integration and collaboration of ERP systems, MES and CPSs. As mentioned in chapter 2.6.1, Industry 4.0 provides a seamless vertical and horizontal integration. In other words, the data stream along the production line (horizontal) is equally ensured as the stream from a machine to top management (vertical). Depending on the manufacturer of the implemented MES and its underlying standardization, these systems today are already partially capable of performing this level of integration. However, in order to achieve the central idea of Industry 4.0, further decentralization and greater consistency and transparency throughout all directions is essential (Netskill AG, 2013; Forstner & Dümmler, 2014).

Thus, there is a demand for modular systems based on the model of a service-oriented architecture (SOA) which can be flexibly extended. The ERP system provides the architecture with the company-wide task and service models that is necessary for this kind of collaborative infrastructure. The initial definition of these services must be done semantically and then refined down to the production unit. A service can be a simple intelligent sensor, a part of a modular machine or even a whole production system. When identifying these services, it is crucial to determine the ideal level of fragmentation. Thereby, their reusability can be enhanced and hence save development cost and time. To ensure a transparent data stream among services themselves but also towards IT systems it is vital to establish a standardized interface like OPC-UA, which was introduced in chapter 3.3. This kind of SOA would provide a flexible and fast interconnection of services and IT systems even throughout the company boundaries. Implemented properly across the entire company, it can replace the classic automation pyramid and the enhanced version (see Figure 13) with a giant network of loosely coupled services and IT systems represented in Figure 16 (Bauernhansl et al., 2014; Zuehlke, 2010; Forstner & Dümmler, 2014; Netskill AG, 2013).

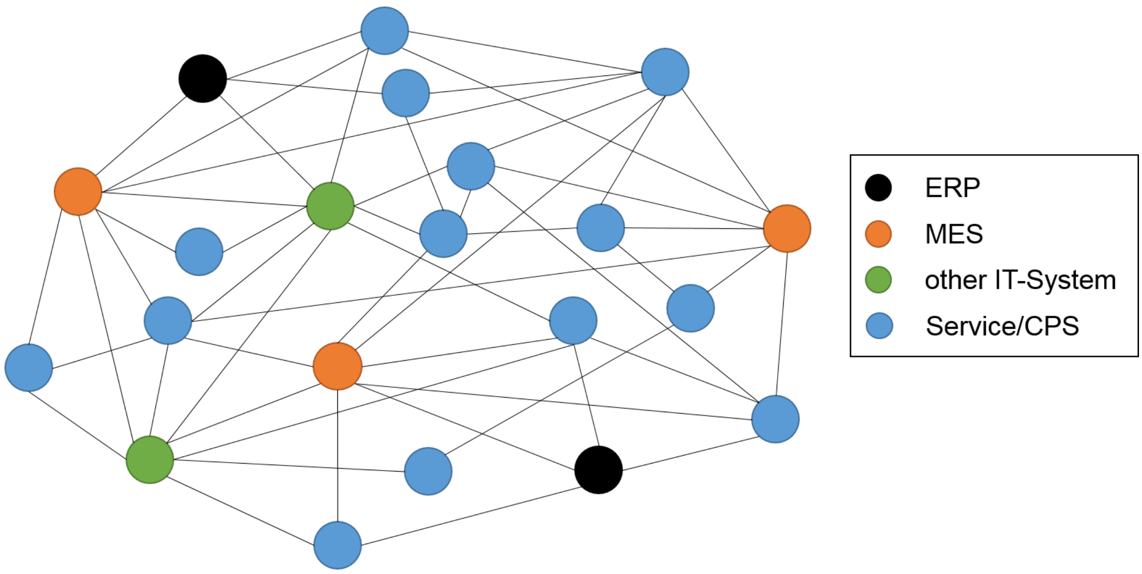

Figure 16 illustrates network of IT-Systems and Services (based on Forstner & Dümmler 2014).

4.3 ERP and MES in the Smart Factory

Nowadays, this optimal scenario with a network of IT systems and services, like described above, is not a standard yet. Accordingly, the extent to which IT systems might be abstracted and modelled as service highly depends on the manufacturer of the systems. A step in the right direction would be to transform the existing IT landscape, which is characterized by the classic automation pyramid where MESs are heavyweight standalone systems, with their own data management. Smart CPSs ensure that of some functionality provided by the original IT system can be relocated to the machine itself, for instance the computation of operating numbers.

As a consequence, there are two scenarios possible, which are displayed in Figure 17. One would be a global ERP-System with an entirely integrated MES module that acts as an expansion. This approach is pursued inter alia by SAP which offer three modules to extend their SAP ERP system:

- SAP ME (Manufacturing Execution) - This module enhances the SAP MII module extensive functionality for production- and quality-management.

- SAP MII (Manufacturing Integration and Intelligence) - This module extracts data from diverse sources (e.g. CPSs or basic machinery), processes it and provides various options for monitoring, controlling and managing those sources.
- SAP PCo (Plant Connectivity) - This module acts as an adapter and ensures that the previous modules are capable of real-time communication to the diverse data sources, which is assured by the use of OPC-UA.

(Sources: SAP, 2015; Netskill AG, 2013)

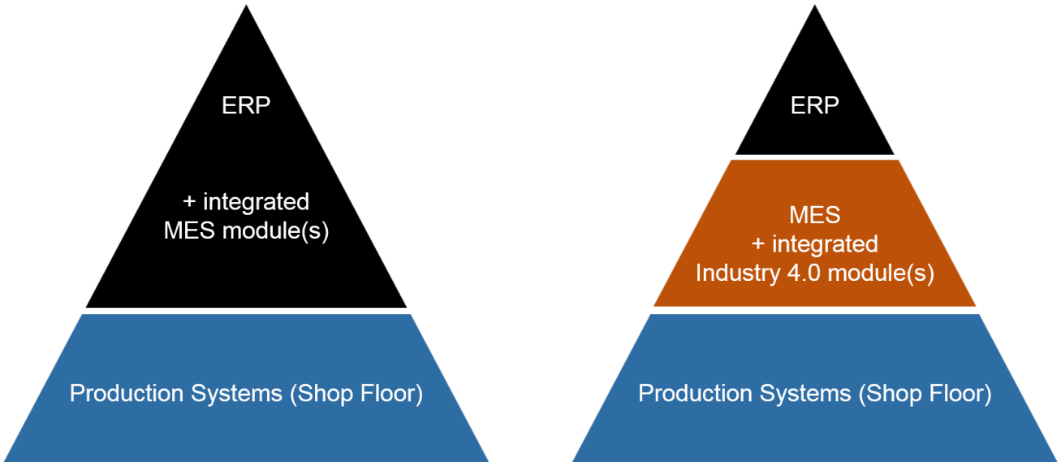

Figure 17 shows two categories of MES implementation (based on Netskill AG, 2013).

Other manufacturers, like MPDV, persist on their existing autonomous MESs and develop concepts to enhance these systems to be able to fulfil the requirements of Industry 4.0. MPDV has hence created an interface called UMCM (Universal Machine Connectivity for MES) which secures a standardized data exchange on the basis of OPC-UA, XML and other similar transport layers (Kletti, 2013).

Due to the fact that Industry 4.0 and smart factories in particular are in their infancy stages, further research and practical experience from existing factories is necessary. Nevertheless, the companies behind Manufacturing Execution Systems and other IT systems in general already provide interim solutions and concepts. Whichever solution is suitable for a company does largely depend on their IT architecture and strategy. Companies, who think about integrating smart systems into their factory, have to ponder and might consider waiting until a global standard has been established, although it is uncertain, as with MESs, if it will ever happen.

5. Smart ICT Factory: Where it stands today

As we have explained before, the world's manufacturing industry and business through the centuries has been envisioned by certain waves of structural changings. It started from the first revolution of mechanical facilities until the upcoming inter-connectivity of manufacturing and supply chain operations. Germany, as the European industry powerhouse, is in its transitional phase. The mission itself is to incorporate the emerging technology such as Internet of Things (IoT), Big Data, Wireless Sensor Network, Cloud Computing, and 3D Printing with the existing manufacturing technology (Netland, T., 2015). Since the vision of Industry 4.0 has been released, German manufacturers and several enterprises have taken their initial approach. Enterprises are developing their innovations and shifting their business activities to Industry 4.0 (Roland Berger, 2014). This means the Industry 4.0 is quite closer than we might think.

As the new age of production has been foreseen, many people think that Industry 4.0 has been already implemented and became the replacement of today's manufacturing. However, Industry 4.0 is only in its beginning of introduction. Although the fundamentals of smart technologies have been implemented by several manufacturers, the existing factory environment is still primarily based on the technologies from Industry 3.0. Accordingly, not all the automated machines and information technology are still integrated. In Industry 3.0, the information technology only becomes the tool of planning, controlling, and monitor all the automated technologies such as numerically controlled machines (CNC) and automated material handling robots. This is in the contrast with the vision and the future of a smart factory. In Industry 4.0, the intelligent machines are expected to adapt with the tasks by performing the self-autonomous and dynamic communications throughout the production process. Because of their complex and complicated architectures, smart factories have not been the mainstream choice for manufacturers yet.

The main challenges are tightly associated with the implementation of cyber-physical systems including affordability, network integration and the interoperability of engineering systems. It definitely takes time and well considerations because most of companies have invested and nurtured the stable, centralized, and well controlled automated machines for a long time. Leaping into smart factory decision of deliberating expensive investments can be the extreme choice. Companies need to change their internal structures, organization and culture of manufacturing. Despite of the limitation of implementation, some enterprises have already innovated and embedded smart technologies in their production infrastructures. Some advanced tools, shipping containers, machines, and conveyor systems in factories are already equipped with sensors and communication systems that share and analyze thousands of pieces of information in every second. Therefore, by over the next ten years of

2026, with the highly intensified researches and appropriately allocated times, smart factory is expected to be fully awaken.

5.1 Smart Integration Technologies in Siemens Factory

Figure 18 shows inside of a Siemens manufacturing plant (Source: Industry Week, 2015).

Siemens is already starting to implement the fundamentals of smart factory by planting the smart technologies and aspects of IoT within its factory in Amberg, Germany (see Figure 18). Siemens Electronic Works facility in Amberg is a high-tech plant with 108,000-square-foot. It consists of smart machines which coordinate the production and global distribution of company's Simatic control devices and a custom, built-to-order process. The production itself involves more than 1.6 billion components for over 50,000 annual product variations, for which Siemens sources about 10,000 materials from 250 suppliers to produce 950 different products (Industry Week, 2015). The endless variables and impossibly complex supply-chain needs far exceeded capabilities of a traditional factory.

Organizing such a material flow, sequencing its processes and scheduling 1,100 employees are totally beyond the capabilities of any single technology or any single tool. Moreover, Siemens has implemented the integration of three specific critical manufacturing technologies. Those are product lifecycle management (PLM), MES and industrial automation (Industry Week, 2015). By using these systems, successful manufacturers can focus on important aspects in their factory floor such as shortening their innovation cycles, getting transparency into their operations, raising individual productivity through knowledge sharing across their organizations and minimizing risk (Industry Week, 2015). Therefore, the challenge itself is how to gather all the smart technologies within the manufacturing and make it as a whole integrated part.

5.2 Collaborative Robots

Towards the Industry 4.0, the robots and human are already encouraged to work in a collaborative way. The robots are created more human-like and without any fencing. The security constraints have been demolished. The robots for helping workers on the factory floors are designed to meet the requirements of smart and cage free robots.

Figure 19 illustrates Kuka's Collaborative Robots (Source: Kuka Roboter GmbH, 2015).

KUKA's lightweight robot, the *LBR Iiwa* (for intelligent industrial work assistant) was introduced at Hannover Messe 2013 in Germany, see Figure 19. It was developed under a technology transfer agreement with the *German Aerospace Center* (DLR) and was originally designed for use in outer space (Robotics Industries Association, 2013). The current model is a 7-axis arm, weighing 23 kg, with a "light touch" for sophisticated assembly tasks (Robotics Industries Association, 2013). KUKA is going to presenting innovative solutions that have one key characteristic in common. They are all designed to meet the requirements of Industry 4.0 and bring flexibility in the utilization of production capacity, logistics, and the sustainable use of resources. KUKA achieves this by merging the IT world and conventional high-tech industry solutions into complete *Cyber-Physical Production Systems* (CPPS) (Kuka Roboter GmbH, 2015).

5.3 Additive Manufacturing

The spearhead of fourth evolutional industry can be seen from the emerged additive manufacturing which is widely known as the *3D printing*. 3D printing basically works by using material such as plastics, ceramics, and metal. It builds up the objects layer by layer by following the computer's digital instructions such Computer Aid Design (CAD) (Live Science, 2013). Additive manufacturing, in the fourth stage of industrial revolution, is believed as the suitable solution for *smart factory* environments. Since the *smart factory* delivers a kind of complicated and complex process, 3D printing can cover production process in the manner of cheaper, faster, more flexible way. The complex digital blueprints can be built directly, parting layer by layer within the automatic procedures. That means the complicated shapes can be produced more easily and with a lot less material waste.

Figure 20 presents High-Pressure Turbine Blade as the result of 3D printing (GE Reports, 2013)

Several new 3D printing machines have been released into the market. Additive manufacturing penetration is not only restricted in the circles of leading companies, but also in start-up world (General Electric, 2013). One of leading companies, General Electric (GE), for example, had encouraged small start-ups from all over the world to engage in 3D printing's *Open Innovation*. The event is called "Maker" (General Electric, 2013). Moreover, GE has already applied the additive manufacturing within these 20 past years and currently is using more than three hundred 3D printing machines. Hence, by 2020, GE predicts that the company shall produce 100,000 different parts by using the technology of additive manufacturing. Although additive manufacturing has been the newest breakthrough in factory innovation, it is not closer enough to replace all conventional mass products yet.

6. Future Scope of Smart Factory's Research

When IT and physical world converge, there is the importance of acknowledging the threats and challenges for every leap of innovations. The assessment is getting to know what the possible threats and challenges are. It is not only for the precautions before deciding to move on with smart factory but also for the scope of future smart factory's research itself.

6.1 Collaborative work between professional and machines

Industry 4.0 is transforming the labor's jobs and skills. It changes the role of human-worker from the center of decision-making and controlling in the traditional manufacturing into the engagement of collaborative work between human and machines (Forschungsunion, Acatech, 2013). In the physical-cyber convergence, machines are embedded with the intelligence to work autonomously without being fully controlled by the workforces. It needs the trained workforce integrated in smart factory processes and their capabilities to adapt with the autonomous machines. On the other hand, smart factory's innovations need to demonstrate the more interoperable and smarter machines to gain the ideal of 'human-machines-interaction'. Hence, the challenging part is how to collaborate between humans and machines for getting the maximum possible outcomes of smart factory implementation.

6.2 Regulatory Framework

The significant problems arising through the interconnected things is data protection and security (Forschungsunion, Acatech, 2013). Once the companies decide to implement the smart factory, it means that the companies agree to step on the higher dynamic network. Gathered data from the autonomous machines shall not be only available within the boundaries of companies, but also to other interconnected companies. The internet shall retrieve every detailed company's data. The huge amount of data shall be generated through the connecting devices. Thus, the company needs to prepare business insights for complementing the interoperable business model, in the manner of data protection.

Therefore, when sensitive data is exchanged with other companies through the network, it is riskier for the data liability because it is getting possible for being hacked and sniffed by other irresponsible parties. Consequently, smart factory needs to be supervised by regulatory framework for securing the data assets. Technology based documentations and procedures, such as personal-based digital signatures shall play a big role within the smart factory's researches. Hence, the challenging part for the company to handle the personal data is how to implement the amount of regulatory framework across national borders. The future scope of researches for data protection and new contractual models is needed for allowing business to retain data sovereignty.

6.3 Resource Efficiency

The nature of industrialization consumes a large amount of resources. The distinction between all the resources of companies used in manufacturing process are natural resources (raw materials, additive, energy, and power supply), human resources and financial resources (investments and operational costs). Nowadays, production processes have gradually evolved into sustainable manufacturing. The resources efficiency is driven into every decision of using manufacturing goods for consumers. Rising energy prices, increasing ecological awareness and changing consumer behaviors toward greener products are influencing the decision makers to put green manufacturing and energy efficient processes at the top of their priorities (Kyukasov, Rumen, Jens Eliasson, Robert Cargie, 2015).

The trend of green products defines that the manufactured products are produced within as small energy consumptions as possible and consuming less energy when it used by customer (Forschungsunion, Acatech, 2013). Thus, it implies the challenge that smart factory need to overcome in the next decades. The key challenge is how to collaborate the resources efficiency and productivity in the process where cyber-physical world is interconnected. Companies need to demonstrate how the additional infrastructures, implemented CPSs and associated infrastructures should provide the opportunities of efficiency and added value into the resource consuming in the existing manufacturing.

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Declaration of authorship

We declare that the work presented here is, to the best of our knowledge and belief, original and the result of our own investigations, except as acknowledged, and has not been submitted, either in part or whole, for a degree at this or any other university.

Formulations and ideas taken from other sources are cited as such. This work has not been published.

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Signatures