Implementation of digital technologies in smart factory processes

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Abstract. *Digital transformation implies changes in organizations through application of digital technologies to enhance existing or develop new processes. One of key features of digital technologies is the development of smart systems, whereby, when considering the manufacturing sector, traditional factories are transformed into smart factories. This article defines smart factories, explains main approaches to transform from traditional to smart and investigates the implementation of digital technologies in smart factory processes involved. The research aims to integrate and extend different approaches to transformation as well as to show how factories should use the digital enablers to benefit and improve their work.*

Keywords. Smart factory, digital transformation, Industry 4.0

1 Introduction

Realization of smart factories implies the use of Industry 4.0 technologies for creating Cyber-Physical systems that connect physical reality with virtual reality. This concept can be a big challenge for traditional factories, which need to adapt their way of doing business. Smart factory requires manufacturers to make a sustainable and optimized use of resources and quickly adapt to changes in market demands and to partners in the supply chain (Zhang et al., 2017). On the other hand, smart factory realization is an opportunity for developers to create intelligent solutions. Smart-makers develop new solutions on daily basis under the influence of digital disturbances on the market, which are more or less accepted and implemented in business processes of some industries (Zhang et al., 2017).

Loucks et al. (2016, 16-17) introduces The digital vortex, which illustrates how digital disturbances affect industries by explaining the rotational force that draws everything near its center, whereby the analysis is made periodically every year. Industries that are more susceptible to digital changes are closer to the center, while industries that are less inclined to digital disruption are further away. Digital vortex is explained through three major features relevant to digital disturbance, namely withdrawal, chaos and disassembly or merging. When a certain industry approaches the center, exposure to change is getting faster and stronger. Manufacturing, as a basic process of a smart factory, in digital vortex is not one of the industries highly exposed to disruption, but since some of the connected processes to it, like production, transport and logistics and consumer packaged goods are closer to the vortex center, it is to be expected that the change will affect manufacturing soon as well.

This article will show which are the processes within the smart factory that are most significantly exposed to changes, as well as which technologies are used in these processes to implement the change and bring improvement.

The paper is structured as follows: first, we define the smart factory with its key processes and technologies, then a classification of approaches to transformation to smart is made, followed by identification of digital technologies related to these approaches. In the conclusion section main findings of the research and indications for further research are given.

2 Smart factory

Smart factory is defined as the way that factories transform and integrate entire business processes (Park et al., 2018) using Industry 4.0 technologies to digitally connect all parts, systems, and people involved in production (Lederer et al., 2018) for the intelligent management of automated manufacturing equipment and defect detection equipment with the purpose of improving production efficiency and quality (Huang et al., 2018).

Industry 4.0 implies the application of contemporary digital technologies for business process transformation. Smart factory assumes a certain interaction between people, machines and products using digital technology (Wang et al., 2019). When it comes to smart production systems, the physical context and cyber context (Longo et al., 2017) are different, and just building such a cyber-physical system as a tightly integrated intelligent network system is the biggest challenge for the smart factory (Kang et al., 2016).

Schwab (2016, 120) made a list of Industry 4.0 technologies, including Implantable technologies, Wearable Internet, Internet of things, Big data, Driverless cars, Blockchain, 3D printing etc.

The key technologies that are recognized in the development of smart factory are Computer Technology, Internet of Things, Big Data, Cloud Computation, Cyber Security and System Integration (Zhang et al., 2017).

In smart factories digital technologies enable data gathering and analysis, as well as faster, more flexible and efficient processes for producing more quality goods at reduced costs. They also imply the creation of production systems that communicate, analyze and use information for the purpose of further intelligent activities that will lead to greater efficiency and changes in traditional manufacturing relationships between suppliers, manufacturers and customers, as well as relationships and communication between man and machine.

Business processes related to planning, production and distribution of goods in the smart factory, through optimization of human and physical resources, and the application of digital technologies, should initiate better reply on real-time customer needs. Traditional factories and operations are supposed to be changed and improved in order to create a flexible and connected system that is agile, proactive and transparent. One of the features of the smart factory is that a constant amount of data from related operations and production systems can be used to learn and adapt to new requirements.

3 Approaches to transformation to Smart

Park et al. (2018) defines a smart factory as a set of integrated business processes that, with the support of information and communication technologies, optimizes the use of resources and monitors customer needs in real time.

Smart factory connects a variety of processes, including production and facilities, warehouse systems, logistics and other systems (Ren et al., 2017). There are 3 approaches that can be considered to transform a traditional factory into smart one (Lederer et al., 2018):

- **digital development and product innovation**, which emphasizes the importance of customer involvement in business design, production and distribution processes. Industry 4.0 enables new forms of collaboration between manufacturing companies and users. For example, users participate in the product design process, and the needs generated by the user themselves are embedded in a finished product or service. So it's not just about product use but about active participation in the design, development and distribution of new (digital) products
- **digital manufacturing (e-manufacturing)** which should enable Industry 4.0. technologies application on operations. For example, flexible autonomous robots with artificial intelligence make optimal decisions for the production of innovative products while cloud storage allows a new level of production thanks to decisions based on processed data
- **digital business transformation** which refers to overall improvements of the way of doing business in a factory by developing entire new business models.

The smart manufacturing system aims to build global value creation networks by combining various industrial production factors such as manufacturing facilities, storage systems and logistics systems. These systems, in order to improve business processes, are focused on integrating various industrial devices with Industry 4.0 technologies to establish a networked product system (Ren et al., 2017).

4 Implementation of Industry 4.0 technologies in processes at the smart factory

Cyber-Physical Systems, as already mentioned, are integrated systems of cyber and physical components. The physical components of a factory are machines, objects, infrastructure or employees, while the cyber components of the factory are sensors, machine controllers, information systems or surveillance applications. In traditional factories cyber components are used to measure, analyse and control what is happening in a factory. Smart factories use cyber components as a decision-support agent or as a role of an integrator that controls production and process of automatic decision making (Kang et al., 2016). With the development of information and communication technologies, manufacturing machines and products with built-in intelligent sensors can at any time monitor the current condition and changes in each machine's operation or product design (Suginouchi et al., 2017) and at the same time, make decisions. The smart industry, with the application of Industry 4.0 technology, would have to make interactions between people, machines and products more responsive to challenges such as the need to improve standardized communication mechanisms, effective monitoring and flexible resource management, transparent data processing, better system scalability and reconfiguration, with the application of new concepts and approaches to the design (Wang et al., 2019). Apart from the integration of people, machines and products, the combination of elements known as 4M1E (ie man, machine, material, methods and energy) is the key to achieving integrated synergy effect, minimal raw materials and the least amount of energy using the best method, with a low rate of defective products and higher production yields (Park and Lee, 2017).

Smart factory implies a vertical integration through the manufacturing system connecting equipment with technology and a horizontal integration where the value chain is linked to product development driven by customer needs (Park et al., 2018).

The vertical integration of the smart factory, which follows the trend of Industry 4.0 (Ha et al., 2017) refers to data collection through sensors and devices for product manufacturing, and control of objects through management technology such as programmable logic controller (PLC) and human machine interface (HMI). The goal is to increase production efficiency through improved business processes.

The horizontal integration deals with business processes such as market research and product planning to meet customer needs, product research and development and manufacturing process to produce products and services (Park et al., 2018).

These two integration views will be further elaborated in the next subsections.

4.1 Vertical integration of the smart factory

Smart factories require impeccable integration of advanced production capabilities with digital infrastructure which enables capturing, generating and expanding intelligence through improved monitoring, analytics, modeling and simulation (Longo et al., 2017). The smart factory faces challenges such as structural, operational and managerial independence, interoperability, reliability, energy awareness, integration and co-operation at higher levels, event and incident management, and industrial large data analysis (Wan et al., 2019, 17969). These challenges lead to necessary improvements in the field of standardized communication mechanism, efficient monitoring, efficient and flexible resource management in production, transparent data processing, better system scalability and reconfiguration, with new concepts and approaches to design (Wan et al., 2019, 17969) so the answer to the challenges lies in true combination of these elements.

Key technologies in the context of smart factory extend through the vertical integration, made up of the cyber and physical components of a related rounded system and can be clarified through layers. Each of these layers has a certain role in running a business processes in a smart factory and through these layers, interaction between people, machines and products has been recognized.

Wan et al. (2019, 2) divides the smart factory into three layers: executing layer, deployment layer and perception layer, while Wang et al. (2019) divides the smart factory into four layers: physical layer, cloud, supervisory control layer and industrial network layer. In Figure 1 we integrated these two classifications of layers and added the external part of the smart factory, namely new technologies, customer needs, market research and other aspects that are not within the reach of the company, but we consider as an important part of the smart factory concept.

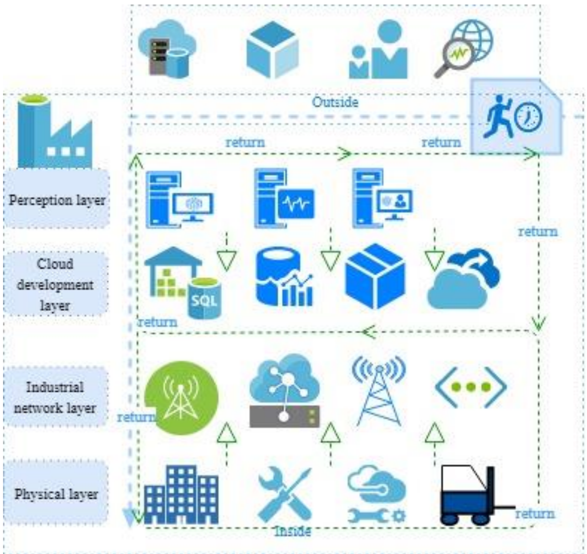

Figure 1. Vertical integration of smart factory

The Physical layer is an organized network of machines, carriers, robots, tools and other aids, ie everything that helps in carrying out transport, moving, packaging, delivering and storing as core manufacturing processes. Building a production line is the first step in creating intelligent production, with robots, intelligent automation equipment, smart machines and more. In traditional factories, this layer sought the physical response of a man who did most of the work. In a smart factory, the situation is reversed, ie the operations are simplified and the requirements for man are very simple.

The second layer is the Industrial network layer whose role is to ensure the free movement of digital information. Enterprise information systems applied in a company are various, so data acquisition and application switching are the focus as a basis for data analysis and optimization.

The third layer is the Cloud development layer where data related to production and information on physical layer status are collected. After collecting data, useful data should be reviewed and classified for research. The Cloud Computing concept allows central processing but is also quite complex as it receives data from two directions. Therefore, this layer can be clarified through two phases, design phase and implementation phase (Wang et al., 2016). The design phase takes over the production plan from the clouds and based on data processing, reorganizes business tasks to the functional blocks. As a result, business tasks will be generated and assigned to the functional blocks at a specified time according to the order of operations. Additionally, in the implementation phase, the work environment from the physical layer takes control orders from the first stage. Big data and large data analytics are important in this layer, because they help further production and control of the business. There are two types of data that have a major impact on creating a production plan, namely data on the status of sensors and machines at the physical level, as well as external production requirements. The functionality of smart manufacturing devices implies a direct connection to the cloud database, which updates the data. Other data is designed to be processed by server clouds, which will be converted into a legible format, eg XML format. Further, a legible data format should explain the reconfiguration plan with a number of new facts and then forward the signal to the implementation layer.

The fourth layer is the Perception layer, which is responsible for presenting knowledge and generating a plan for changes (Wan et al., 2019, 2). This layer actually refers to control and user interface terminals where a person receives digital information about the state of a particular work within a smart factory. Digital information is presented in the form of posters and special graphics through a comprehensive intelligent production management system. For example, information such as production analysis reports, order of operations and other can serve for optimum planning of production lines with the necessary data collected in time to monitor production status and to better diagnose failures using network technology.

The vertical integration inside the smart factory is a double closed loop system. One loop shows the exchange of information between the physical layer and the cloud development layer, and the second loop displays delivery of digital information through the cloud development layer to the perception layer. The perception layer gives the command and sends feedback to the cloud layer where the data is analyzed and further directed to the physical layer. All information that is coming from the environment, such as open data, data collected from research and obtained from customers are also included in this view.

4.2 Horizontal integration of the smart factory

Traditional factories have pulled out machines, material, energy and human potentials as key resources. With the development of the fourth industrial revolution, it became clear that digital technologies and their application would become an inevitable resource in all business aspects. It has already been mentioned that the smart factory can be seen through three approaches to transformation to smart: digital development and products innovation, e-manufacturing and digital business transformation (Lederer et al., 2018).

Second integration of smart factory concepts we made for processes along the value chain for each approach to transformation to smart separately. For that reason, this integration is named horizontal and summarized in Table 1. Related business processes, technological and methodological trends, and improvements they bring are described for each transformation approach. Digital development and Product innovation refers to business processes related to market and customer needs analysis, market research, smart product development and design. Big and open data with analytics, cloud, digital concepts and virtual collaboration, IoT (Internet of Things) are recognized as major trends here. Digital manufacturing or e-manufacturing refers to manufacturing business process / processes such as production planning and preparation, technological process and other related production processes. A wide range of digital manufacturing trends such as robotics, IoT, Machine Learning and more are recognized. Digital business transformation involves the transformation of all processes in a smart factory and brings together all technological and methodological trends that are already mentioned and presented in the table.

The digital development and products innovation trend can be identified through data collection and analysis processes, research on smart product development and product design and development. Collecting and analyzing data from the market starts from open and big data or independently collected data whose analysis can get the quality information needed for development. Furthermore, the research process of smart product development refers to the development of ideas and innovations that put at the center customer and its needs and relate to the digital value of the product. Also, in product design and development, customers are involved with new technologies and virtual forms of cooperation.

Digital manufacturing (e-manufacturing) encompasses all manufacturing processes, such as planning and preparation of production, product design and technological processes, functional testing and testing of products and assembly of products and packaging of products. The process of planning and manufacturing preparation is no longer based on customer orders, but on new combinations of auctioning techniques that mimic the negotiation process and use of production planning optimization methods to simulate consumer demands and model virtual negotiations between manufacturers and customers. The design of the product and the technological process are particularly emphasized by technological solutions and methods as a process in the smart factor. Namely, apart from robots that help to make harder physical jobs, sensor machines allow data collection and processing, as well as insight into the current state of the manufacturing process. The process of functional testing and product testing has enabled the defective product to no longer continue through other processes, which is reducing costs and increasing quality. The product assembly process is no longer the sole task of the manufacturer because the customer is also involved in the installation through the expanded reality, ie the integration of additional computer-generated information into the real-world environment. Augmented reality applications have great potential for improving user experience where users need to access and communicate with information that has a direct spatial relationship with their immediate environment.

Digital business transformation approach implies changes in all processes and is specific for every organization involved.

Table 1. Horizontal integration of smart factory

Approach	Business processes	Technology or methods trends → Process improvement
Digital development and Products innovation	Collecting and analyzing market data	Big data and analytics, the cloud → Real-time information as support for decision-making and problem solving, analytical calculations in real-time (Lima- Monteiro et al., 2017)
	Investigating the ability to develop smart products	Big data, digital concepts in product development → Development of virtual digital product values, development of designer thinking with the customer in the center when designing smart digital solutions (Lederer et al., 2018)
	Design and product development	Internet of Things, virtual collaboration → Active participation of users in the design, development and distribution of new products (Lederer et al., 2018)
E- manufacturing	Planning and preparation of production	Optimization method for production planning and production scheduling method using the combinatorial auction → Simulation of consumer demands and adaptation to requirements, production planning through virtual negotiations between manufacturers and customers (Suginouci et al., 2017)
	Product design and technological process	Autonomous robots with artificial intelligence and cognitive bots → Robots perform harder operations and physical work (Lederer et al., 2018) Production machines and products with built-in intelligent sensors → Insight into the current conditions and changes of each machine and product (Ha et al., 2017) Human machine interaction and technologies Industry 4.0 (Ivanov et al., 2016), Cloud based big data analysis services, RFID, robotics (Wan et al., 2019, 4-5), RFID technology, Artificial intelligence, Application of industrial robots (Pei et al., 2017), Internet of Things (Wan et al., 2019, 17969), Machine learning algorithms (Choi et al., 2017), Edge or Fog Computing and real time analytics (Trinks and Felden, 2018), Cybersecurity and Safety-Critical Systems (SCS) (Ren et al., 2017) → Rapid reaction of man in real-time Additive manufacturing (3D printing) and 3D technologies → Fast prototype production (Zhang et al., 2017) Proactive task dispatching method based on future bottleneck prediction, IoT and Intelligent algorithms → Forecasting bottlenecks in production (Huang et al., 2019) Functional testing equipment and defect detection equipment and IoT → Real-time error detection, Anticipating the future narrow throat in production (Huang et al., 2018) Fault tolerance method and the application for change decision → Quick decisions about production without affecting man (Kang et al., 2016) Distributed optical network → Through the distributed optical network, factory control center can virtualize machines, thereby realizing machine co-operation and monitoring product quality (Guo et al., 2017)

	Functional testing and testing of products	Functional testing equipment with sensors → Identification of defective products and their exclusion from production, expense reduction and higher percentage of well-produced products (Huang et al., 2018)
	Installation of the product	Augmented reality (AR) Smart application (Integration of computer graphics with user's views on his current environment), digital installation instructions for customer or employees → Digital installation instructions (visual information directly in spatial context), reaching the user through the assembly process and tasks, improving user experience (Paelke, 2014),
	Packaging of products	Sensor technology and material, Cloud, Machine Learning → Smart packaging uses different sensors to collect data on quality, safety, durability, and usability of products, thus increasing product durability and constant product control, convenience and sustainability
Digital business transformation	All processes	Augmented reality → Instructions for moving and carrying out operations in the storage space (Paelke, 2014) Smart sensor, 3D printing, energy saving technology, IoT, cloud, advanced robotics, big data and hologram (Park et al., 2018), Big data and analytics, automation according to the analytic decision (Ha et al., 2017), Smart control devices (supervisory control terminals), industrial network, cloud, self-organized multi-agent system (Wang et al., 2016), Sensors, advanced metering infrastructure, smart meters, simulations (Park, 2010) → Performing operations in the warehouse, lower percentage of bad production, satisfied customers of finished products, money, energy and material savings, real time equipment and products monitoring Locality-Aware Replacement Algorithm in Flash memory to Optimize Cloud Computing → Advanced analysis and automatic signaling for inventory purchases, low power consumption, high read speed, high density, volatility and solid state reliability (He et al., 2017) Bluetooth Beacon System configuration and the location of Wi-Fi device following the structure of the factory → Factory employee safety (Park and Lee, 2017)

It is important to note that a smart factory should not be considered as "the ultimate state" (Burke et al., 2017), but it should go hand in hand with rapid technological development, which means continuous improvement, steady and flexible learning, new customized methods, application and integration of new technology solutions developing new knowledge and skills for people involved in work of the smart factory.

Key features of the smart factory include connectivity, optimization, transparency, proactivity and agility. Each of these features can be recognized in smart factory through improved business processes, no matter which business processes are involved (Burke et al., 2017).

5 Conclusion

In the time of the new industrial revolution, market demands are more dynamic and challenging, customers' needs are changed, the market is expanded and company demands are increasing, creating thereby choice for companies to be digitally transformed or to disappear from the market. For traditional factories this is still a tough decision.

Digital change is an opportunity for companies (factories) as well as for creators of new market solutions. For companies, creating a smart factory gives a chance to integrate production capabilities with a digital infrastructure and create intelligent and smart solutions focused on improved tracking, analytics, modeling and simulation in the business context. On the other hand, for creators of new solutions, the digital transformation of factories is an area for market capitalization. This is providing them with the opportunity to create innovative business solutions that can successfully respond to challenges such as structural, operational and managerial independence of business space systems and enterprise components, interoperability, energy awareness, integration at higher levels, incident and event management, and industrial large data analysis.

Smart factory is defined as a cyber-physical system in which business processes are transformed by incorporating Industry 4.0 technology into all layers to integrate all key business components and achieve better business results. The fast development of Industry 4.0 and the implementation of all kinds of industrial devices in the smart factory have resulted in the development of new methods and advanced technological solutions for improvement of business processes.

In this paper we performed an analysis of existing research in the field of smart factories related to corresponding digital technologies and processes that are improved by these technologies. The analysis resulted with the development of two views of integration between the technologies and processes: vertical and horizontal. The vertical integration is an extension to previously developed view, supplemented with external influence factors to transformation to smart. The horizontal integration gives a summarized overview through processes in the value chain and describes the improvements for each of them.

Future work on this topic could include the investigation of relevant case studies in existing companies, in order to complement the integrations shown in this paper.

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