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Investigating current smart production innovations in the machine building industry on sustainability aspects

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Abstract

Driven by the rising demand for individualized high-tech products the machine building industry continuously introduces a wide variety of smart innovations. Manufacturing companies face growing production requirements which can only be only handled by intelligent systems. During the last decades the trend in manufacturing has shifted from the classic mass production to complex individualized products which have to be produced to compete with the costs of mass products. Smart Production Systems are characterized by its flexibility, resource efficiency, ergonomic design and the ability to integrate customer and business partner into the value creation process. This research study investigates current smart production innovations and trends in the machine building industry. The sustainability aspects and the potential of various smart innovations are outlined.

1. Introduction

Networking of all kinds of equipment and machinery on the basis of cyber-physical systems are on the rise. In the field of manufacturing the increasing level of computerization is used to face the growing production requirements. Smart Production Systems are characterized by its flexibility, resource efficiency, ergonomic design and the ability to integrate customer and business partner into the value creation process.

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For many decades in the twentieth century manufacturing was driven by the rising demand for standardized products. After the invention of the mechanical loom in 1784 the concept of the electrically driven conveyor belt which was first used in 1870 is seen as the second industrial revolution. Henry Ford`s conveyor-belt assembly line which was used for car manufacturing at the Ford factory in Michigan in the early twentieth century is a popular example for the improvements of the second industrial revolution. With the mass production of relatively small numbers of products many companies had been successful for many decades. Volkswagen as one of the leading global car manufacturer had only three different types of cars in its portfolio until the beginning of the 1960`s.

In the last few decades the trend has been shifted from the classic mass production to individualized, customer-driven, high-tech products. Currently Volkswagen offers over 30 different car models, each with hundreds of individual selectable options. Complex processes on every hierarchy level, high numbers of product varieties and short product life cycles require a solid knowledge and permanent interactions with customers, suppliers and all kind of stakeholders. Under the perspective of globalization and rising competitive pressure an effective use of resources is indispensable. To cover all requirements, the effective use of IT systems and the available data is essential to secure an enterprises market position. The connection and communication between software components and mechanical and electrical parts via wired or wireless data infrastructure like the internet are called cyber-physical systems or short CPS. Through the technology of CPS, it is possible to monitor and steer production systems in a very effective way to facilitate a cyber-physical production system or CPPS. The current technological literature speaks in regards to that form of intelligent or smart productions systems or the smart factory. A pioneering role takes the German government with a high-tech strategy project that speaks about the fourth industrial revolution.

2. Smart Production Systems

The origin of the term "Industrie 4.0" comes from the German ministry for education and research who started a project related to computerized manufacturing of the future in the year 2011 [1]. "Industrie 4.0 is based on a concept that is as striking as it is fascinating: Cyber-Physical Systems (a fusion of the physical and the virtual worlds) CPS, the Internet of Things and the Internet of Services, will collectively have a disruptive impact on every aspect of manufacturing companies. The fourth industrial revolution allows companies to take specific actions before it happens. Manufacturers can begin now to define their target manufacturing model and then plan a transformation roadmap. Despite the significant hype around the topic, nobody knows what the exact consequences are for manufacturing operations or when will these happen, although there's a clear notion that the later-movers will most likely be forced out of the market" [2].

2.1. Attitude of machine building companies towards Industrie 4.0

In a survey among 12 randomly collected, globally acting machine building companies the author investigated the attitude towards Industrie 4.0 in October 2016. In the first part of the survey the participants were asked for their knowledge regarding Industrie 4.0. As Figure 1 shows most of the company representatives have followed up with Industrie 4.0 intensively or at least in part. It can be assumed that the contact persons have a very good understanding of the topic in the survey. The interviews were held personally with companies from Germany (6), Italy (2), Switzerland (2), Spain (1) and Japan (1).
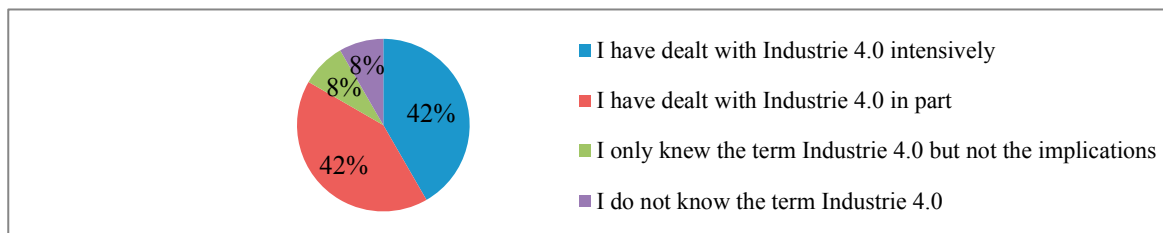

Figure 1: Knowledge about the topic Industrie 4.0

According to another study by the IMPULS foundation of the VDMA from October 2015 about 57 per cent of the German companies in the machinery and plant engineering industry concern themselves intensively with the topic Industrie 4.0. In the manufacturing industry in general this value is only about 10%. Nine out of ten companies which concern themselves with Industrie 4.0 see significantly more opportunities than risks to differentiate their products on the market [3]. The consulting company Mc Kinsey carried out a survey among 300 participants from the US, Germany and Japan. 100 companies with at least 50 employees were interviewed in each of the three countries. Different industry sectors such as automotive OEMs, automotive suppliers, chemicals, consumer goods, healthcare, paper and packaging, software, transport and logistics, industrial equipment, industrial automation, and semiconductors are represented.

Remarkably the companies from the US are ahead of the German and Japanese companies regarding Industrie 4.0 investments and revenue. The German and Japanese companies are still cautious with investments. Only 15 per cent of the total R&D budget is spend on Industrie 4.0 related innovations. Another general finding of the survey is that Industrie 4.0 will have a high impact on minimizing machine replacement. Only about 40 to 50 per cent of the installed base has to be replaced within the next 10 years [4]. Compared with the efforts for changing equipment in previous industrial revolutions this value is relatively small. Machines and equipment are often already Industrie 4.0 suitable. The existing machinery is often already equipped with interfaces and sensors.

Furthermore the participants were asked for the measures that have been taken in their company regarding the subject of Industry 4.0. It is remarkable that the majority of the companies have planned (58%) or already implemented (67%) Industrie 4.0 applications. Half of the companies have project teams which work on the topic Industrie 4.0. Only three companies state that none of the statements fits for them. It can be said that most of the companies in the machine building branch work on Smart Innovations. However there is a clear trend that larger companies are ahead while especially small companies often unsure about the topic Smart Production Systems. Barriers for SMI's are often a passive or sceptic management, too small investment capital or the fear of risks like data theft etc. [5].

2.2. Smart products and functionalities

Furthermore the machine building companies were asked for their use of specific smart functionalities. The first part comprised a check list sorted by different topics. The topics cover the areas machine steering, machine and production monitoring, production planning and control, network technology, inspection, maintenance, repair, mobile devices, logistics and energy management.

All interviewed companies stated that they use network connection and remote access. These functionalities are state of the art. The same applies for a personal machine visualization profile (number of naming: 10) which means that there are different profiles for example for machine operators and maintenance technicians. About half of the machine building companies offers an interface to transfer production data on personal computers (8), customizable visualization (7), optimized energy consumption (7), process and/or quality monitoring (7), track & trace functionalities (6) and simulation of the production process in advance (6). The minority assesses the data from the operator / customer (4), identifies energy saving potential (3), use predictive maintenance technologies (3), integrates external data e.g. from suppliers or customers (2), use augmented reality (2), offers an app (2), use RFID technology (2) or use QR codes (2). None of the companies use fingerprint authorization and NFC technology.

2.3. Individual Smart Features

The machine building companies were also asked for further smart functionalities. These product highlights are summarized in the following subsection.

Digital Platform Solution: A software platform for PC's and mobile devices is used to reduce complexity in the order process and to monitor and steer the production.

The system is able to integrate machines from different manufacturers. The system is based on an open and modular platform that is able to integrate the customers of machine building companies, their suppliers and service contractors, as well as other partners [6]

Online offer calculation: The web application is a service for the machine operator which he can offer his customers. With that tool customers can upload a drawing of a part and get an approximate and non-committal feedback about the production prize per part.

Track & Trace functionality: The machine lasers a data matrix code on the produced parts. With that unique code every part can be tracked.

Virtual Production Simulation: A system detects possible production errors before the manufacturing process starts. For example if two metal pieces shall be welded the systems checks the quality of the material, proofs the welding gap etc.

Intelligent Machine Documentation: The operation manual of the machine is placed on a cloud. The operator has permanent access to the latest version of the manual. If a part is changed on the machine the technician scans the QR code of the new part and the information is send directly to the manual in the cloud.

Tooling management with barcodes: One machine has often many different tools. Software makes the management of tools easier as every tool has its individual barcode. The software knows the storage location of every tool.

Active tools: The machine records tooling, cutting and process data to implement more intelligence in the production process. The machine knows for example the condition of each tool in terms of wear and is able to adapt the production process accordingly.

3. Current Industrie 4.0 Applications and Trends

A selection of current Industrie 4.0 innovations which were for example introduced at the Hannover fair 2016 are introduced in the following section.

Physical assistant systems: Robots are used to support the worker e.g. by holding or turning heavy parts. Sensors make sure that the safety distance is guaranteed. In the concept of the smart factory the human is in the centre and robots act as assistants. The German technology group KUKA is one of the most innovative producers of industrial robots worldwide. With the focuses mobility, steering and human-robot-collaboration, intelligent robot and system solutions are implemented in the smart factory [7].

Machine to machine communication: Machine-to-machine (M2M) communication in terms of Industrie 4.0 means that machines are able to communicate with each other to improve the process flow, do capacity planning automatically and reduce the process time. The condition of machine components is permanently monitored. In case of increased wear the machine reports to the employees at the maintenance department. Unscheduled machine breakdown time can be reduced or prevented.

RFID and NFC technology: Radio Frequency Identification (RFID) and Near Field Communication (NFC) are technologies which makes it possible to send information by wireless. RFID, as the name suggests works over radio frequency. A wide range of different chips and reading devices are available. The techniques differ in storage capacity, production methods, costs, frequency range and transmission range [8] [9].

NFC is based on RFID technology and characterized by a special coupling method which is standardized on a specific frequency range. The standardization of the frequency range enables active-active communication so that a so called "handshake" is possible which ensures a safe connection. NFC is therefore a specialisation of the RFID technology which is especially useful for safety critical communication over a short distance. The maximum transmission range is about 10 cm [8]. Some of the current uses of RFID technology in industry include warehouse management and logistics, product tracking in a supply chain, product security, raw materials tracking, point of sale, etc. [10]. The Fraport AG which is the operator of the Frankfurt Airport in Germany uses currently about 180.000 RFID chips per year on components. A capacity of 1 KB is enough to store the technical ID number of the object, serial number, date of last maintenance, time in use etc. [11].

QR-Codes: Barcodes have been used for many years to label or identify parts or products. Information is encoded and plotted according to specific standards. The further development into two-dimensional Quick Response Code (QR-Code) allows the storage and recall of large data volumes. Among the original use in the area of logistics, QR-Codes are nowadays used in many fields. The increasing popularity of smartphones has led to a rising use in the field of mobile marketing. Consequently, QR-codes are one of the most widely encountered codes [12]. For industrial uses QR-Codes can be used to identify parts or tools. The information can be automatically transferred to a database. QR-codes are also often used to provide customers with more information about a product [13].

Augmented reality: Augmented reality makes it possible to extend the perception of reality with additional information. PC's, tablets, smartphones or wearables like smartwatches or smart glasses can be used to display additional information. The scope of application is nearly unlimited. The furniture company IKEA uses augmented reality in their advertising catalogues. User can scan selected pieces of furniture from the catalogue and display them into their own flat by using the camera [14]. For industrial purposes one application is the use of smart glasses to show technicians instruction help. The head mounted display shows assembly, repair or maintenance instructions. Digital handbooks can be presented directly in the technician's field of vision. Individual steps can be explained precisely and clearly at the work station at any time which reduces safety risks and contributes to better results. New augmented reality content can be recorded with the head-mounted camera and sent into the system [15] [16].

Mobile devices: Besides the private use of smartphones or smartwatches they are more and more used for industrial purposes. Mobile device applications can give instructions to the worker or list the most urgent work steps. Apps are used to monitor or even control machines. Further functionalities are machine tracking via QR-Code, for the support of service notifications via pictures or videos, handbooks, documentation, as communication platform, as link to an online shop or spare parts lists, calculation tools and many more. Referring to a market analysis of the Schuler Group six out of ten examined companies in the machinery and plant engineering industry are currently offering apps. Three companies offer more than one app. The feedback from the users is positive as shown in customer evaluations in the App Store [17]. Most likely the amount of apps offered by companies in the machine and plant engineering industry will rise in the near future.

Condition Monitoring / Predictive Maintenance: The reduction of unscheduled machine breakdown is a very important goal for every manufacturing company. For many years preventive maintenance has been the preferred method to contain machine failures. Within the scope of preventive maintenance, parts are replaced from time to time as soon as a specific operating time is reached or other criteria like for example a defined number of strokes are reached. A more exact way to react on the wear of a component is realised by predictive maintenance. The classic approach of predictive maintenance is to measure the condition of components and react correspondingly to experience values. Predictive Maintenance suppliers like Siemens, Schaeffler or ABB use branch expertise, product knowledge as well as the information about the use of components as a digital service business model. Electric motors permanently measure and track different data about mechanical stress and operating temperature. The data is send to the cloud and centrally stored in a database. Predictions about motor malfunctions based on branch and product knowledge can be made [18] [19] [20] [21].

4. Sustainability aspects of smart functionalities

Transformation from Industrie 3.0 to Industrie 4.0 should lead to agile and adaptive manufacturing strategies. These strategies should also be resource efficient. The industrial sector is undoubtedly an important factor in terms of sustainability questions. For example in Germany the industrial sector causes currently 15% of all CO^2 emissions and consumes about 29% of the produced energy. At the moment it is unclear how the current transformation process of Industrie 4.0 affects sustainability questions in detail [22]. Nevertheless experts attribute a big chance in the digitalisation process. The EU commission sees the fourth industrial revolution as an opportunity and encourages environmental friendly and social sustainable products [23] [24]. At the heart of resource efficient strategies are Industrie 4.0 enabling technologies and functionalities. These technologies and functionalities are discussed in this chapter.

4.1. The vision of a sustainable industrial revolution

Due to intelligent steering of the whole manufacturing process, smart production systems reduce waste, overproduction and energy consumption. The logistic in the smart factory uses the pull principle which means that raw material or semi-finished production material is requested on demand. The production system of the manufacturing company orders the material or parts automatically from its suppliers when needed. In times of reduced sales experience fewer raw materials are required resulting in lower stock levels, reduced storage space and improved cash flow. Manufacturing companies are linked with the power plants and can plan energy intensive tasks when there is a natural overproduction of energy through wind or solar energy. Energy surplus can be used by other companies or private households in the surrounding area. The German federal ministry for education and research estimates that companies can save up to 60% of energy consumption [25]. Table 1 summarizes various possible technical developments and describes their effects on the environment.

Table 1: Sustainability aspects of possible smart innovations

Innovation / Technical development	Sustainability aspects
Intelligent steering of production on the basis of the pull principle. Products are produced regarding the current demand of customers. Manufacturing companies are connected with their suppliers, customers, etc.	Reduction of overproduction and waste
Connected machines and plants. Intelligent energy management systems use energy recovery for other machines.	Reduction of energy consumption as energy intensive tasks can be done when there is overproduction. Use of energy recovery for the whole system.
Use of innovative technologies like for example 3D-printing [24]	Reduction of waste especially in the product development phase
Increase of local purchased parts especially in countries with medium or low salaries [24]	Reduction of transportation effort
Production processes can be monitored and controlled from all over the world. Increase of home-office work.	Reduction of transportation and travel effort
Increase of digital (paperless) processes	Saving of natural resources
Retrofitting long use phase factories	Contribute to the environmental dimension of existing manufacturing plants

4.2. Sustainability aspects of current innovations

While some of the above mentioned approaches are still visionary the next part focuses on technical innovations which are already in use.

Remote Access: The use of remote access for machine maintenance reduces the necessity of on-site assemblies which saves travel expenses and protects the environment. According to Schuler Pressen, the market leader in metal forming machines, 90% of all customer problems can be solved via Remote Service [26].

Virtual Reality / Augmented Reality: The use of virtual reality for product presentations or in virtual conference rooms often replaces physical meetings. Travel costs can be saved and the environment is less burdened.

Predictive Maintenance: The technology of Predictive Maintenance systems allows it to use wearing parts as long as possible. In comparison to the classical method of preventive maintenance, where parts are replaced after a specific pre-defined life time, waste can be reduced [27]. The degree of wear is often completely different depending on the application for a specific product. Therefore user data has to be used to generate a prediction about the life time of a product. This is a classic example of Big Data analytics [28]

Production Simulation: Sensor monitored production methods make it possible to simulate the production process before the process starts. Intelligent laser welding machines are for example able to measure the surface quality of the parts and the weld gap. This resource efficient system is able to make corrections before defective parts are produced.

Process Monitoring: With sensor technology the production can be monitored and corrections or adjustments can be made automatically. This reduces the amount of defective parts and saves resources. This technology is for example used by the German robotics and automation specialist KUKA [29].

4.3. Critical view on the digital revolution in terms of environmental aspects

As described in the previous parts experts see a great opportunity in the increasing digitalization of manufacturing processes to improve the environment. Research in general mainly outlines the positive aspects in terms of sustainability. Without a doubt specific smart innovations bring improvements for the environment. Nevertheless it can be questioned if the fourth industrial revolution will lower the burden on the environment.

Every industrial revolution aims to increase productivity. A higher volume of goods produced leads to a higher demand for resources and therefore stress on the environment. Not least globalization causes a larger transport volume as products are produced in low-wage countries and sold all over the world [30]. An example is the global fuel demand for cars. The fuel consumption of cars is getting lower from generation to generation but the global fuel demand still does not decrease as people tend to drive more when car fuel consumption drops. On the bottom line manufacturing companies use smart innovations when these systems help them to produce a lower unit price. Falling product prices in combination with an increasing prosperity of the global population will lead to a higher consumption of goods and resources. It can be argued that this process is anyhow unstoppable. Considering this, the focus on a sustainable product development is even more important.

5. Conclusion

The approach of Smart Production Systems promises far-reaching improvements on every company level. To the costs of mass production parts companies will be able to produce high-tech individualized parts according to customer's requirements. The production can be adjusted in a very short time and monitored and controlled even via long distances. Robots will assist humans to make work stations more ergonomic and flexible. Due to the achievement that production processes can be monitored and controlled from all over the world, work can be adapted more flexible regarding the personal situation of the employees. The compatibility of family and job will be improved [31].

On the perspective of sustainability the fourth industrial revolution has the potential to bring fundamental improvements. Manufacturing companies will use network technology to link their production with suppliers and customers. Therefore it is possible to react faster on changes, waste and overproduction can be reduced. Through intelligent energy management systems and network technology, renewable energy sources can be used more efficiently. The author's investigation on the latest, already implemented, smart innovations show, that there are improvements which help to save natural resources and reduce waste. The vision of a sustainable digital factory is no longer just theory whenever there is still a lot to do. Considering the unstoppable trend of globalisation and increasing wealth and industrialization it is more important than ever before for mankind to find resource efficient and sustainable production solutions. Governments and organizations have the responsibility to set standards to ensure a sustainable use of resources.

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