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Investigating the effects of Smart Production Systems on sustainability elements

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Abstract

The next generation of manufacturing systems will be self-organising. Networking of cyber-physical equipment and machinery are on the rise. In the field of sustainable manufacturing, an increasing level of computerisation is used to face the growing production requirements. Smart production systems will foster opportunities from its artificial intelligence to create value within the business and the community it operates. Smart production systems will integrate the virtual and physical worlds on these Internet of Things (IoT) platforms to ensure flexibility and resource efficiency. This research study investigated the dynamics of the next industrial revolution (Industrie 4.0) and used case studies on the market, suppliers and customers as benchmark to identify current trends. The technical, economic, social and environmental elements of possible smart innovations were evaluated in terms of resource efficiency. Prerequisites for tooling companies to use smart production systems were discovered. Future work was also discussed.

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Keywords: Smart Production Systems; Social Manufacturing; Industrie 4.0, Industry 4.0, Internet of Things, Big Data

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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.

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. Figure 1 shows an overview about the four industrial revolutions [1]. 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 which brought the Ford Motor Company in a market leading position. 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.

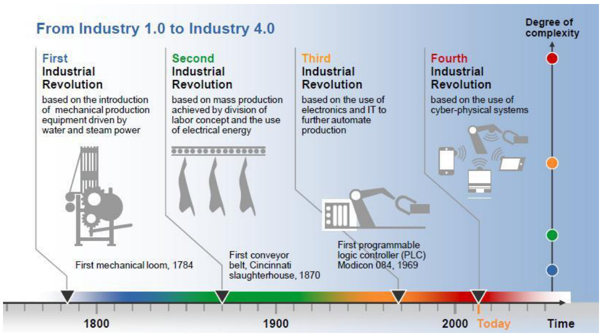

Fig. 1. Milestones in the history of manufacturing [1]

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 33 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 communication 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 and formed the term “Industrie 4.0” starting in 2011.

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 [2]. "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, which unlike all others, is being predicted, therefore allowing 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" [3].

2.1. Technical, economic, environmental and social impacts of Smart Production Systems

Society is continually working to improve the standard of living. Industry has been growing and developing to measure up to the high quality of life sought by society. There are continuous developments in industry to help meet the life quality. Nonetheless, the current advancements in production are not sustainable. These developments contribute significantly to climate change and the depletion of fossil fuels such as oil. Moreover, aging as well as death reduce the workforce supply and leads to loss of key skills. Industry needs a more sustainable manufacturing plan to continue the production of high quality products [4]. Therefore, Industrie 4.0 is a viable strategy to establish sustainable manufacturing. Implementation of Industrie 4.0 in production has several impacts. Technical, economic, social and environmental impacts of Industrie 4.0 on production are discussed in this section of the paper.

2.1.1 Technical Impacts of Smart Production Systems

Conventional production lines consist of a single line which manufactures single type of products. There's an open-loop conveyor belt with input and output ends and the machines run along the line. In most cases there's no communication between the machines in the production line. On the other hand, the objective of smart factory production system is to process multiple types of products simultaneously. The conveyor belt is a closed-loop supporting different production routes. In smart production systems there is a connection between machines, information systems, products and people through a high speed network system [5].

Big data analytics usually makes maintenance easier. People from all over the world can work together to perform repair work since individuals and machines can communicate through cloud. There are control functions responsible for the distribution of smart entities which possess the ability to organise themselves to deal with system dynamics. In conventional production systems reconfiguration of the machines is done manually. However, smart production systems can be reconfigured automatically to manufacture multiple products [5].

2.1.2 Economic Impacts of Smart Production Systems

The main aim of a manufacturing company is to be a profitable organisation. Therefore, it is important to assess the economic impacts of smart production systems. The initial implementation of the system is more expensive than implementing a traditional open-loop production system.

According to Moore's law, the cost of information technologies will constantly decline, however the quality will continually improve. The operational cost of customization will be low relative to the fixed production line because of flexibility, readily available resources and energy efficiency. Once-off products can be manufactured in a smart production factory [4] [5].

2.1.3 Social Impacts of Smart Production Systems

For smart factories there are no workers required to run routine tasks. Humans are faced with new tasks. The direct communication will be reduced in some specific areas because cyber physical systems are able to communicate with each other. Consequently, the M2M (machine-to-machine) communication will increase. Nevertheless, humans will remain in a very important role as in planning, controlling, dispositive and exporting functions [6].

The implementation of smart production systems will create a demand of information technology specialists. The information technology sector will require skilled people to design, develop, run and maintain network programs. Therefore, there will be a rise of job opportunities in information technology. However, in production factories machine operators and other employees are at risk of losing their jobs [5].

The increasing need for highly qualified specialists means that excellent qualification measures have to be available. Besides the education opportunities in schools and universities, vocational training provided by companies as well as training on the job programs are very important qualification measures. Especially for emerging countries like for example South Africa investments in modern training and education opportunities are of utmost importance. As academies and trainers will be in great demand new job opportunities in the education and training sector will be created.

2.1.4 Environmental Impacts of Smart Production Systems

Due to intelligent steering of the whole manufacturing process, smart production systems reduces 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 lower sales rates fewer raw material is ordered [5].

Manufacturing companies are linked with the power plants and can plan energy intensive task 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 [2].

On the other side smart production systems will require massive data centres to process and support their network needs. Data centres consume large amounts of energy and resources to needed for energy production will impact the environment negatively. In addition, new devices will be needed to be manufactured and this will add burden to the environment [5].

2.2. Sustainability Elements

Industrie 4.0 will be a big data problem where data collected from abundance of source will be collectively incorporated in production as to become a smart production system [7] [8]. Therefore, some sustainable elements countermeasures should be put in place to accommodate the growth and production potential of smart production systems.

These sustainable elements should comprise of technical, economic, environmental and social investigation with countermeasures similar to that of an Environmental Impact Assessment Report or EIA [9] [10].The following key aspects should thus then be taken in consideration: Beneficial or detrimental, naturally reversible or irreversible, reparable via management practices or irreparable, short term or long term, temporary or continuous.

Where the EIA discusses the influence on social and environmental impacts of a project over a time period of five to twenty years, the smart production system's sustainability elements assessment should assess all four influences over one to five years due to the rapid development in the field. Most importantly, these sustainable elements could be influential on their own, but could have greater impact when combined with other or multiple elements. Clark describes these effects as being directly or indirectly related and therefore have cumulative impacts [9], for instance:

A social and technological sustainable element could be directly affected, because of machines becoming smarter and that they would eventually take over low technical labour jobs. These workers should then be educated to fill the job opportunities for maintenance of the before mentioned smart machines. A social and economic sustainable element might entail that the community wouldn't gain from the manufacturing processes that would produce products to be shipped internationally. A technological and economical issue might be that the initial implementation cost, and therefore risk, for the company will just not make economic sense. A technical and environment is another indirect effect that might add stress to our natural resource and then suffer maintain economic viability from such an endeavour. These are examples of sustainable elements that might influence the overall acceptability of a smart production system.

2.3. Prerequisites for an organisation to use smart production systems

Despite smart production systems being a recent scientific development, the implementation methodology could be summarised in Fig. [11].

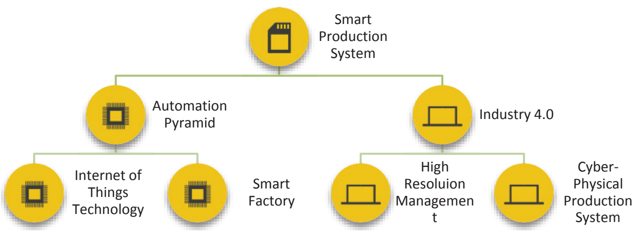

Fig. 2. Smart Production System Methodology [11]

In this methodology Steenkamp describes the implementation process as the following [11] where the hardware framework should firstly be implemented to form a good foundation for the software implementation. The hardware aspect includes Internet of Things technologies to a level where the shop floor would consist of smart or intelligent machinery that would have machine to machine communications capabilities, becoming a smart factory. Following this implementation, a communication and data gathering structure must be set in place to produce information to higher levels of management which includes manufacturing execution system and enterprise planning systems.

Thereafter software implementation could commence that would comprise of high resolution management system in conjunction with a cyber-physical production system to form the basis of the Industrie 4.0 framework. At this level of implementation, the smart production system could be compared to a smart service and thereby succeed in becoming a smart production system [11].

2.3.1 Barriers and challenges on the way to smart production

Nevertheless, there are a couple of challenges that have to be taken before smart production systems can be used effectively. Many processes will be controlled and coordinated in real time over long distances. Prerequisite for that is the standardization and modularization of many single process steps as well as the programming of virtual editable models of these modules [12].

The incomplete presence of broadband expansion is a risk as well as the absence of a comprehensive mobile data network [13]. Regarding to evaluations of the Fraunhofer Institute even a highly developed country like Germany needs 10 to 20 times shorter latency and 12 times higher data rate relative to the standard of current telecommunications to achieve a proper standard for Industrie 4.0 [14].

One of the decisive obstacles is still the missing IT knowledge among the employees [15]. Workers in every field of the smart factory need to have solid IT skills. Training on the job will be more important than ever to teach specific skills and to generate acceptance among the employees for the new technology.

Another risk is the high investments that often have to be done to implement smart production systems. The amount of investments can be higher than the medium-term sales that can be generated through the improvements. Especially small and medium sized enterprises might be restrained to invest in smart innovations [13].

IT security is one of the most important topics regarding the challenges of smart production systems. Companies are used to keep their sensitive data as safe as possible and not a few of them have massive concerns when they think about the idea of putting production data into a cloud. IT security companies have to develop new technologies to protect the confidential data better than ever before from spying, fraud, hackers, viruses or terrorism.

3. 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 [12].

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. Governments and organizations have the responsibility to set standards to ensure a sustainable use of resources.

Attention should be paid to the challenges and barriers regarding Smart Production Systems. Important prerequisites are for example functioning IT security systems, an extensively, fast and stable data network, standardized process steps and not at least qualified employees. If solutions can be found for those challenges, Smart Production Systems enable a wide range of unprecedented opportunities.

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