Impact of Technology on Work: Technical Functionalities that Give Rise to New Job Designs in Industry 4.0

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S. Waschull, J.A.C. Bokhorst, J.C. Wortmann

University of Groningen, Groningen, The Netherlands
s.waschull@rug.nl

Abstract. With rapid advancements in the application of Industry 4.0 technologies throughout industries, a collection of different views on its potential implications for workers are emerging. Various authors agree that these technologies and their application in manufacturing systems is structurally different compared to current methods of production. Consequently, it is expected that the impact on manufacturing jobs, specifically on the tasks, is profoundly different from what we already know from literature. However, authors often borrow from existing literature to describe changes in work, and are not explicit on how and why Industry 4.0 and the implications is conceptually different. Until now, little research has focused on defining the technical functionalities that give rise to new job designs. This paper therefore focuses on synthesizing the diverging views on the effect of Industry 4.0 on employees' jobs and specifically aims to understand how the technical changes of the transformation towards a Cyber Physical System in production relate to changes in job design. The central question this paper addresses is: How do the technical changes of the transformation towards a Cyber Physical System impact job design in industrial production? The contribution is an overview of the technical functionalities of Cyber-Physical Systems that are conjectured to change direct and indirect value-adding jobs in industrial production. This model will be used as a basis for further empirical inquiries. Moreover, it provides central points of interests for organizations involved with the design and implementation of Industry 4.0, focusing on job design.

Keywords: Industry 4.0, Cyber Physical System, technical functionalities, job design

1 Introduction

Since the German government launched the Industry 4.0 initiative as one of the key high-tech strategies in 2011 [1], the term is being used as an umbrella term to describe the intensified application of an array of digital technologies in industrial production. They include a growing use of sensors, the expansion of wireless communication, growing computational power and storage capacity as well as growing data connectivity and AI applications [2]. Industry 4.0 is often described as the next industrial revolution following the digital revolution of information technologies and computers in production [3]. On the basis of this initial digitization, further technological developments defined in the concept of Industry 4.0 are projected to introduce a new paradigm shift [4] by allowing new methods of production [5]. This implies a drastic change for the design of jobs, specifically the quality of work, work organization and human-computer interaction [6]. These changes are described in two different development scenarios in literature, evolving around the potential of the new technologies to augment the worker in more complex tasks or to fully replace the worker and his skills [7]. Similar changes in work have also been discussed earlier in the context of computer-integrated manufacturing (CIM) and evolve around the up- and deskilling potential of new technologies. Despite the fact that changes are forecasted, we still know little on specifically the technical functionalities that give rise to new job designs in the context of Industry 4.0. This is because the term is relatively new and lacks a strong conceptual foundation. Moreover, the level of technological sophistication in Industry 4.0 developments at organizations is still rather low. Hence, empirical insights into implications of developments are scarce and we still have to rely on forecasts. To further develop this understanding, this paper synthesizes the different perspectives of the effect of manufacturing technologies on work, specifically in the context of Industry 4.0. We then aim to define the technical functionalities of the transformation towards a Cyber Physical System (CPS) as a core concept of Industry 4.0, and discuss how these relate to changes in job design.

2 Impact of Technology on Work

2.1 The Deskilling vs. Upskilling Perspective

Throughout the last decades, two main schools of thought were represented referring to the changes in skills originating from technological change [8]. The adoption of these perspectives by scholars changed periodically and many rejected the deterministic relationship it implies. On the one side, the de-skilling perspective describes the simplification of jobs and the reduction in skills of more highly skilled craft workers [10]. This perspective first appeared during the first industrial revolution of mechanization as a result of the replacement of craft skilled labor through machines [11]. It was reestablished during the introduction of computers into the manufacturing environments in the 1970’s as the concept of the automated factory, or lightless factory emerged. This viewpoint has also been referred among others as the degradation of work or polarization of skills approach [12]. In general, a capitalist management focuses on automation technologies with the goal to gain greater control over their production workers, thereby simplifying and routinizing work processes, reducing the need for individual skills and knowledge of the process, materials or quality issues involved. Consequently, management is less dependent on the individual skilled craft worker whose special knowledge, insights and skills will be transferred from the production worker to technical professionals. The work is organized so that the production worker often has to follow routines and procedures on simple tasks determined by others, diminishing the need to conceptually understand one owns work or to take decisions. The tasks are then polarized into jobs with routine tasks and highly complex tasks, respectively. On the other hand, the upskilling perspective identifies technological change as making work more demanding in terms of skills required for the job [12-15]. This perspective appeared in the mid of the 20^{th} century when the first computers entered the production environments. Fearing that computerized work settings and potentials for automation could affect workers, various researchers started examining the impact of automation on the tasks and skills of the workers [16-17]. The upskilling perspective contrasts the de-skilling perspective, stating that rather than automating complex and skilled tasks, simple and routine jobs are automated, resulting in jobs that focus on the more challenging and complex aspects of tasks posing higher cognitive demands [13]. Workers are freed to take up new tasks such as monitoring and controlling equipment and become troubleshooters for automated processes [e.g. 13, 17]. Both views have received much criticism throughout the years as they tend to oversimplify and generalize matters and assume a unidirectional effect of technology on work. However, this effect often differs per type of technology [17] due to different functionalities made available with that technology. Moreover, studies indicate that the impact of technology on job design depend on a variety of other various organizational factors [18], such as management choice, their vision and goals [19].

2.2 Industry 4.0 – Human Centered or Intelligently Replaced?

There are two main positions taken in literature focusing on different implications of Industry 4.0 technologies for work [20]. These development scenarios include on the one hand the enabling scenario closely resembling the up-skilling perspective. On the other hand, the replacing scenario mirrors the deskilling perspective. Enabling technologies often provide means to increase the performance or the capabilities of a user or process. As opposed to the workerless facilities as proclaimed by CIM in the 70's, the Industry 4.0 movement often emphasizes the importance of the people in the system as an integral factor of the production environment [7, 21]. Humans are forecasted to keep a high level of autonomy and are highly skilled. Technological support should be provided in such a way that the full potential of these skills and talents can be realized [22]. As such, people are charged with a new role of strategic decision makers and flexible problem-solvers. Routine, simple execution and control tasks are then automated [23]. The nature of tasks will shift towards a higher degree of complexity. Employees will have to interact, monitor and control more complex technical systems, increasing the need for knowledge on e.g. software architecture, automation and IT. Furthermore, tasks can become more unstructured and diverse. This is what Koelmel [24] refers to as increased technical and contextual complexity. This changes their work towards more mental work as information processing, abstraction and problem solving requirements will increase [7,25]. The human will become the central decision maker, augmented by technology. Windelband et al [26] refer to this perspective on change as the tooling scenario. The information available and the analysis done by computer systems are geared towards augmenting the knowledge and expertise of the employee. Therefore, by assisting workers better in their jobs, they can take over more complex tasks [27]. On the contrary, new technology in Industry 4.0 is perceived by others as a possible constraining factor, thereby replacing human insights and technically enabling controlling and monitoring possibilities. This scenario is also referred to as digital Taylorism referring to Taylors principles of work simplification and control [28] and resulting in a strong deskilling effect. Edwards & Ramirez [29] refer to the paradox that Industry 4.0 is a fully configured system linked by information technology resulting in a reduced ability to shape the wide contours of the system. In accordance with this is the expectation that especially low skilled jobs will have to follow a pre-determined sequence of steps and will have less possibilities to intervene in the working process [25]. In line with that thought is the potential of technologies to fully replace the human skill and expertise as autonomous human decisions can increasingly be taken over by the computer or the application system that control the processes. In the digital factory, increasing autonomy of IT systems and corresponding integrated manufacturing equipment can potentially lead to human workers being pushed to the background [30], only intervening as a troubleshooter. The question then is to what extend the decoupled worker is still able to intervene and react to problems if he is taken out of the loop. Moreover, as systems are becoming smarter, they have the potential to further emit the worker and take on the formerly human based control decisions. Thereby potentially they are becoming less dependent on the skills and control of the worker. The two development scenarios presented represent two very different implications for the design of jobs and it is expected that depending on local application conditions and other factors, different job designs will emerge. The changes through CPS are expected to be dependent on the organizations choice of design of technology and the corresponding provided functionality as well as how they organize work around it [23]. To obtain a better understanding into the functionality provided by Industry 4.0 technologies and how it relates to work, in the next section we propose distinct functionalities that are provided through a combination of technologies that transform production into a cyber-physical production system. Subsequently, we shortly discuss what this means for the design of jobs in direct and indirect value adding tasks.

3 Technical Functionalities of Industry 4.0 and Job Design

Th*e interconnected cyber-physical production system.* A central element of Industry 4.0 in industrial production is the creation of a factory wide information network integrating data, models, machines, processes and software tools vertically and horizontally [2]. In its essence, CPS are physical production components that are represented in a cyber-counterpart, a logical layer that processes pre-specified information and that, depending on its capabilities, can communicate, negotiate and interact with other actors in the information network [31]. Embedded computers such as Programmable Logic Controller (PLC) or embedded systems can monitor and control the physical processes [32] and can share the information horizontally across the process or vertically up to higher level information systems. This is projected to result in interconnectedness, information transparency and increasing autonomous behavior of production components [33]. However, the transformation towards a CPS is not a turn-key project, but we expect that different stages will emerge. We characterize these states by a passive or active role of production components and the level of intelligence of production components, respectively. First, we distinguish between a passive and an active role of production components. A passive role means that production components will obtain an identification technology, such as a RFID chip, and as such will be able to respond to inquiries concerning location, environmental conditions or states. This so called passive role of a component mainly provides real-time data capture and as such, promotes the further digitization of manufacturing processes as real-time data can be collected and distributed within the information network of systems, machines, products and processes. Hence, this system is characterized by passive actors that can communicate pre-specified data when initiated by other active actor, most likely humans that take the initiative. The active role of production components refers to physical objects such as products or machines being capable to use their processing power to not only collect data but also to communicate, to negotiate and take autonomous actions to meet pre-specified design objectives. A key characteristic here is the ability to act autonomously without the intervention of human beings. The production system increasingly becomes an active actor that takes autonomous decisions. Second, we distinguish between different levels of intelligence that can be present in a CPS system. The level of intelligence refers to production components and other embedded systems having increasing processing power to convert data to useful information based on pre-specified design objectives. If production components solely collect and communicate data, they are characterized by a low level of intelligence. However, if they are capable of converting this data into useful information and use this information to fulfill a pre-specified purpose, they are characterized by a high level of intelligence. This translates into the phases as specified by figure 1. First, production components receive a cyber identify and the capabilities to be identifiable and communicate passively. Subsequently, the production components are increasingly interconnected with each other and within the information network, and they begin to exchange information and communicate and negotiate with each other [1]. To do so, they need processing power, which also increasingly allows them to process the data into information that they can share. In subsequent phases, production systems then move towards intelligent automation, in which active production components increasingly take autonomous actions without human intervention.

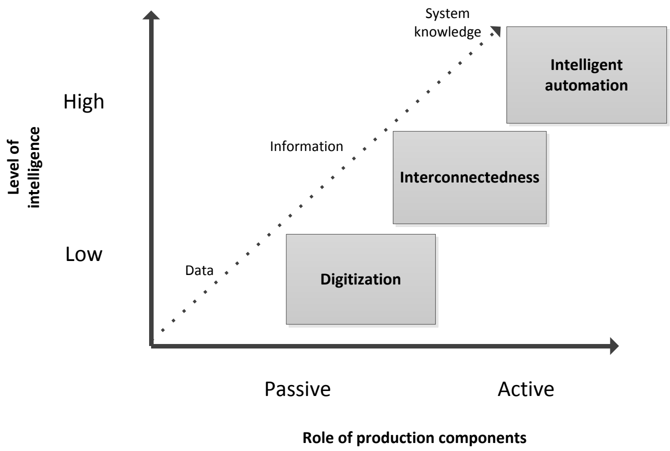

Fig. 1. CPS typology

Implications for job design*:* It is expected that the transformation towards a CPS does not only radically change existing manufacturing practices, but will change the design of jobs too, currently described in two diverging development. Based on the functionalities described, we expect that during digitization, the human worker will remain the key information processor and decision maker. Workers, especially supporting functions such as planning, control or maintenance workers will then be required to work with and process larger amounts of digital information, possibly resulting in higher cognitive demands and need for information processing. Simple, repetitive work related to the collection and administration of data will increasingly be automated, promoting a shift of the human workers towards tasks related to the control, coordination and improvement of production based on the improved information transparency. These changes will potentially mostly be felt by supporting functions. Also, certain aspects of jobs might be simplified or also enhanced, as new ways to interact and present information will increasingly augment the human in his work. At the same time, manual work might be simplified and constrained as detailed and standardized digital work instructions can be provided that allow little room for deviation and job autonomy. As production components move from passive to active actors and are becoming more intelligent, these interconnected systems can increasingly aggregate and visualize information comprehensively so that it can provide tailored information that augments the human in the decision making process. For example, to provide information on certain possible product routings or alert him of changes. Finally, in the last stage of intelligent automation, the technology can increasingly be empowered to take over certain control and production management tasks, potentially eliminating or decreasing human tasks. In this case, human knowledge and skills might increasingly be substituted by intelligent control algorithms and computer programs. Based on these development perspectives, we expect that the total share of human work in industrial production will decrease due to the transformation towards a CPS. Moreover, the composition of human tasks in production will change due to the reduction of repetitive, manual and simple work, for example simple administrative tasks and the increase in cognitive, mental work posing increasing skill requirements. As such, this can lead to a growth of supporting work related to the control and improvement of processes and less manual work. Ultimately, the implications for the human worker depend on how the technology is designed and how work is organized around it. As such, management has significant over the technology selection, design and implementation process. The role of the human worker in CPS hence is not determined by the technology itself, but a variety of other factors.

4 Conclusion

Throughout the history of industrial production, two development perspectives on the implications of new technology for work have been discussed. The possibilities to up- and deskill employees are also central in the discussion on changes in work in the context of Industry 4.0. As such, the adoption of either perspective depends on a variety of factors, among which the technological functionalities that provide opportunities and constraints for the design of jobs. This paper aims to increase our understanding on these technical changes in the transformation towards a CPS that give rise to changes in the design of jobs, and we presented two key dimensions. These two dimension include the level of intelligence of production components and their active or passive role, respectively. In the long term, the transformation towards a CPS will reduce human work in industrial production. Moreover, human work will focus on cognitive and mental tasks. Ultimately, this impact will not solely be determined by the technology itself. Management often has significant discretion on how new technologies are configured and the way that work is organized around it.

5 References

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