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From the smart factory to the self-organisation of capital: 'Industrie 4.0' as the cybernetisation of production

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abstract

Governments and private sectors have collaborated on national initiatives that will introduce 'cyberphysical systems' and the 'industrial internet of things' to the sphere of production in a new wave of capitalist development currently referred to in Germany as 'Industrie 4.0'. We refer to the historical and technical development of the means of control within the capitalist mode of production that began with scientific management, management cybernetics, digital process control, and now Industrie 4.0, as the *cybernetisation of production.* This article analyses the German context of Industrie 4.0 as a new regime of production. Data drawn from a series of semi-structured interviews with managers and engineers of Industrie 4.0 companies reveal current developments and future visions for the digital transformation of German industry. Based on these data and some theoretical considerations, we argue that Industrie 4.0 is designed to automate the self-organisation of industrial capital in 'smart factories'. This will shift the personal control of middle management toward the more direct and immediate cybernetic control of market forces over the production process. The article concludes that as direct labour and managerial labour is replicated, extended and/or entirely replaced with autonomous machines, the cybernetisation of production is advancing capital's real subsumption of the labour process toward capital's autonomisation from labour-power, which is creating new *autonomous forms of production.*

Introduction[1]

The digital transformation of industrialised societies is projected to affect several sectors, including healthcare, business, government and consumption. However, it is industrial capitalists' appropriation of cyberphysical systems, the internet of things, big data and cloud technologies in the sphere of production that has received significant public attention, prompting responses ranging from business hype to new areas of academic research (Kirazli et al., 2015). The digitalisation[2] of manufacturing is driven by industrial capital's demand for even greater forms of 'flexibility' in the production process, which the sellers of advanced digital systems promise to deliver by further integrating digital and physical entities into 'cyberphysical systems'. Governments and private sectors have developed their own national initiatives to communicate and implement the digitalisation of manufacturing. For example, in the United States, the National Network for Manufacturing has enacted an initiative called 'Advanced Manufacturing Partnership 2.0', the United Kingdom has introduced 'Catapult-High Value Manufacturing', and China is pursuing its 'Made in China 2025' initiative. Private sector initiatives include the Industrial Internet Consortium in the United States and the Industrial Value Chain Initiative in Japan (Oks et al., 2017). This article focuses on the German context where this trend is referred to as 'Industrie 4.0'.

While it appears that previous industrial revolutions have been driven by the development of new forms of energy and the reorganisation of production, Industrie 4.0 involves digitalising and networking all industrial capital for the purpose of increasing various aspects of automation and cyberphysical control over the direct production process, management of the labour process, and feedback from industrial and consumer demand. This article begins with a historical review of the scientific, technical and management

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2 We distinguish between digitisation and digitalisation in the following sense: *Digitisation* describes the transformation of data into a digital form whereas *digitalisation* describes the process of restructuring social life around digital communication and media infrastructures (Seibt et al., 2019).

paradigms that have developed the human and non-human means of feedback over the labour process. We refer to this as the historical process of the *cybernetisation of production,* which creates new forms of *cybernetic work* and leads toward full automation of the labour process. As cyberphysical systems are rooted in the control logic of cybernetics, we therefore suggest that Industrie 4.0 is the technical realisation of capital's self-organisation, extending from the shop floor to the top floor of 'smart factories'.

The article then analyses empirical data from an ongoing research project to illustrate the historical continuity of Industrie 4.0 as part of the contemporary process of the cybernetisation of production. The empirical data stem from a series of 20 semi-structured 'comprehensive interviews' (Kaufmann, 2015). Interviewees were managers and engineers of companies based in the German high-tech industry areas of Bavaria and Baden Württemberg who consider themselves to be part of Industrie 4.0. The cases were selected to generate an overview of the vision pursued by engineers and managers of industrial organisations as exemplars of the digital transformations of Industrie 4.0. The data were analysed with the coding software *dedoose* according to the standards of qualitative content analysis. The code system followed the theoretical research question but was, in its concrete form, derived inductively from the material (Kuckartz, 2016). Drawing on the empirical data, we argue that the introduction of the industrial internet of things and cyberphysical systems to the sphere of production will advance industrial capital's self-organisation of the production process. Industrie 4.0 therefore could advance what Marx referred to as capital's real subsumption of the labour process toward a third and final stage that we refer to as capital's *autonomisation from labour-power*, which we suggest could lead to a new *autonomous mode of production*.

Industrie 4.0: A new production regime

In Germany, the label 'Industrie 4.0' was created by politicians, entrepreneurs and engineers who founded the public and private sector coalition 'Plattform Industrie 4.0'. This includes among others the German ministry for education and research and promotes the concept of an emerging fourth industrial revolution. The German ending '-ie' was internationally defended by its patriotic inventors, who coined the label, hoping to recapture raw materials produced in low-wage countries, and with that, an increase of profit margins. Fuchs has suggested that Industrie 4.0 is ultimately rooted in German industrial capital's demand for lower labour costs, which it hopes to achieve through automation (Fuchs, 2018). As an example of what Fuchs has referred to as the new 'digital German ideology', a manager of an Industrie 4.0 company describes the overall mood in German industry as a 'pioneering spirit, a revolutionary mood' and divides the positions towards the trend into 'hesitators versus entrepreneurs'. The German business magazine *Wirtschaftswoche* recommends investing in Industrie 4.0 enterprises and declares the development as non-negotiable. As noted by *Deloitte & Touche*: 'the trend is irreversible: What can be connected, will be. The technical and economic logic will not allow anything else' (Hajek, 2016: 75). Plattform Industrie 4.0 therefore expresses an ideology that has gained high performative power accompanied by a concrete, though protracted, digitalisation of industry.

The entanglement of state-driven ideology and the technological development of industry is best grasped by Burawoy's (1985) notion of a *production regime*. According to Burawoy, a production regime refers to the intersection of state politics and the politics of production that regulates industry. By extension, we argue that, through the implementation of networked digital technologies, Industrie 4.0 is part of the historical process of the cybernetisation of production that represents the tendency of industrial capital to become increasingly autonomous from the labour-capital relation. This leads toward a cybernetic regime (Schaupp, 2017a). The following analysis develops this argument by discussing how middle managers became capital's early means of delivering feedback to the labour process, which would eventually be replicated, extended and/or replaced with automation technologies as the means of cybernetic control over the labour process.

The cybernetisation of production

The introduction of scientific management to the assembly line in the early twentieth century focused initially on the production of a greater mass of products in the same or smaller amount of time by calculating the number of products produced within the labour process. Scientific management physically restricted options for deviating practices on the side of the workers and was therefore often quoted as the prime example for technical control (Edwards, 1979). At about the same time, large industrial companies began to introduce differentiated rules and procedures, fostering a top-down hierarchical order that was described as bureaucratic control (*ibid.*). Both technical and bureaucratic control became the basis for scientific management, which developed in the Fordist era as a result of the division of manual labour of production from the cognitive labour of management and planning (Braverman, 1974). The replication of this division of labour in turn further divided social development of the technical aspects of manual and cognitive labour.

Grids, graphs, and other informational tools for measuring the labour process provided management the means of objectifying, and thus representing, various aspects of the labour process in *data*. Scientific management included measurements of the labour process such as Taylor's 'time studies'. These measures would become coupled with the motion studies of Gilbreth when managers calculated the physical motion of the labour process in relation to the number of products produced in a given amount of time for the purpose of identifying inefficient activity (Gilbreth and Kent, 1921; Taylor, 1913). These forms of analyses were used for the systematic measurement of productivity in the labour process in order to physically alter it for the purpose of increasing productivity, and therefore, total output. The forms of managerial action taken as a result of these measures were therefore an early form of data-driven feedback. Hence, scientific management's systematic and detailed collection of data from the labour process foreshadowed the logic of cybernetic control in industrial production, but in a form more heavily reliant on human managers. Central hierarchical order, however, was still personified at its core by the figure of the manager, inspiring Edwards (1979: 132) to write about a 'managerial revolution'. In this respect, industrial capital developed its own human means of control over the labour process through the division, reorganisation, and thus, development of the productive forces of labour in the historical stage of capital's real subsumption of the labour process. This meant that managers functioned as capital's means of control over the direct labour process through the open-loop of managerial feedback. Thus, we suggest that the development of managerial labour is capital's historical development of the means of enforcing the technical requirements of valorisation within the production process.

As Noble (2011) noted, the history of the 'automatic factory' began with the development of the process industries in the early twentieth century. These were developed on the principles of process control that were objectified in the development of industrial automation technologies that replicated, extended and/or replaced the labour-power of the direct production process. As Noble (2011: 59) described it, 'all continuous process production demanded unprecedented devices-sensors and effectors (actuators) for carefully monitoring and adjusting direct production operations too complex for complete human oversight and manual control'. However, early computerisation meant that process manufacturing still relied on the decisions of human operators to monitor and respond to the production process based on the information produced by computers, which is understood as an open-loop form of feedback. Hence, early process control was neither about physically restricting options – as in technical control – nor about bureaucratic top-down order. Rather, its primary goal was the development of computer monitoring combined with human control in the direct production process. With the development of closed-loop automation in the process industries, automation technologies that were produced and used as the means of control of the direct production process were developed to replicate, extend and/or replace the labour-power of managerial feedback.

The principles of control were later formalised with the development of cybernetics, an interdisciplinary science that was shaped by neurophysiology, information theory, statistical mechanics, psychiatry, physics, biology, anthropology and other sub-disciplines in the natural and social sciences (Kline, 2015). Cybernetics was conceived and promoted during the well-publicised Macy conferences in the post-wartime era of the late 1940s and

1950s by natural and social scientists such as Norbert Wiener, Claude Shannon, Ross Ashby, Margaret Mead and Gregory Bateson who had aspirations to develop it as a universal science of control and communication (Wiener, 1948). Early cybernetic theory was initially derived from observations on the self-organisation of biological systems that 'automatically' adapt to changes in the environment instead of first making a cognitive plan or hierarchical instruction. Its epistemology relied on models, analogies and other abstract representations of complex systems for the purpose of interdisciplinary comparison, including, for example, modelling the human nervous system as an electronic machine and vice versa.

At its core, cybernetics used prediction and filtering to combine communications and control engineering (Kline, 2015: 22). Feedback loops were designed to bring a given system to a state that cyberneticists call homeostasis. For this, at least two entities influence each other through mutual feedback until they reach a state of equilibrium. Homeostasis, however, was not conceptualised as a static optimum. Rather, homeostasis was considered a dynamic process of optimisation through adaptation, referred to as the *Viable System Model* (Beer, 1959). With the development of management cybernetics, industrial managers adapted cybernetic principles to the design and management of human communication in organisations, while engineers objectified the general principles of cybernetic control in the production of machines designed to replicate, extend and/or replace both the productive forces of labour and managerial feedback in industrial production.

Introduction of industrial cyberphysical systems to the production process

Contemporary automation technologies have been designed to introduce cyberphysical control to the direct labour process and connect it to higher level planning through digital networks, automated data collection, processing and feedback (Hirsch-Kreinsen, 2016: 2). Industrial cyberphysical systems (ICPS) were developed primarily by the engineering community and involve the integration of automation technologies with mechanical, electrical or chemical production processes (Feeney et al., 2017: 81). In the

1970s, the first industrial applications of cyberphysical systems were called 'computer-integrated manufacturing' (CIM). Another early application of ICPS was called 'mechatronics', which referred to the integration of mechanical processes and information technology (Jeschke et al., 2017). Finally, another closely related ICPS technology is 'embedded systems', which rely on a cyberphysical control relation between sensors that collect information from the physical environment and actuators that translate numerical values into physical effects (Marwedel, 2011).

We present two empirical examples of industrial cyberphysical systems that are being developed as part of Industrie 4.0 at the level of the labour-process. The first is a 'smart glove', a wearable cyberphysical system used for manual operations within the labour process. The smart glove contains a microcomputer attached to the back of the hand and sensors integrated within the sections designated for each finger. The control functions include barcode scanning, documentation of workflow, and feedback. As the developer explained, the smart glove was designed for a variety of purposes including:

> To give the worker an instant feedback on his actions, on his working steps, so if an error occurs, if something happens, he gets informed directly on his body. I think that's the best aspect of wearables in this case. As it is attached to his body, that means that he does not have to focus on some external screen, for his working station. He has the feedback in an instance whether it was the right part that he picked or the wrong part. We confirm the right parts and scan it into the system by green light and we have a buzzer, a sound, if something went wrong.

The developer emphasised the immediacy of cyberphysical feedback that the smart glove provides the worker. For example, a manager may be delayed in noticing the inefficient use of a screwdriver in a particular workflow, in which case there will be a lag between the current state of the workflow and the feedback needed to optimize the labour process. In contrast, if a worker is wearing the 'smart glove', it provides immediate haptic feedback to adjust the labour process instantaneously. Hence, instantaneous feedback from labour's use of the means of production cyber-physically manages the physical motion of work in the labour process. The efficiencies gained by the introduction of cyberphysical systems to the direct labour process therefore appear due to the immediacy of cyberphysical feedback, which reduces 'lag' between input events and feedback caused by slow data processing. From the developer's perspective, the immediacy of feedback enables more efficient self-organisation of the workflow, which he praised as one of the central benefits of his technology:

> On the one hand, you can give the management more tools … to optimise processes or to get a feeling of what is happening. And on the other hand, you give the worker more power for self-organised working. … Because by giving him more information you can enable him in the end to organise his work better.

In the first step, the interviewee postulates management's demand for data about the labour process as the precondition for optimizing production. In the second step, he delegates this optimisation to the interplay of the worker and the glove. As the developer explained, the purpose behind introducing the smart glove to the labour process is not to suggest that, 'oh he [the worker] is not doing it right, but rather, to see how the worker makes his workarounds because there was maybe some misconception, something that you maybe have not thought of while designing the working station'. Thus, rather than develop the labour process from the interaction of human managers and workers, the interviewee describes a labour process that is developed from the interaction of cyberphysical systems and workers.

The second cyberphysical system is the 'smart workplace', a desk for industrial technical developers. The smart workplace is equipped with an integrated computer that tracks and documents every work step that is performed and automatically adjusts the workplace to the user, for example, by giving workers certain access rights and denying others. As the manager of the company that is both producing and using the smart workplace explained:

> [The worker] gets the light he needs; he can access what he is allowed to access. If it is someone else, another light turns on, he cannot access the computer and everything remains closed. … Or if I say, it's afternoon, from now on I need motivation light, then the computer does that, it adjusts the motivation light.

The control logic of the smart workstation is such that the work environment adjusts for each worker individually. The system registers the tasks the worker is given, it registers what the worker is actually doing, and it subsequently automatically reacts to this input data with cyberphysical feedback. For example, if either the worker or the machine registers that performance is declining, the system may counter-steer performance by projecting a 'motivation light', or the system may physically restrict access to workstation features while enabling others. Thus, the smart workplace operates by entangling the employee within a bi-directional feedback loop that links worker status to the performance requirements of the production process.

In the interviews, managers and engineers referred to the cybernetic theory of control rather implicitly in most instances. In some cases, however, they explicitly stated the origin of their ideas. As one management consultant explained:

> I think this [the cybernetic] model has to be there! At least in all instances where you don't have a simple homeostatic control circuit. In organisations and especially in management systems you have to apply the Viable Systems Model and I would say, digitalisation already goes in this direction.

The relation of these cyberphysical systems to workers and developers is such that feedback from these systems to the workers adjusts the workers' execution of tasks while feedback from the worker to the system adjusts the developer's work plans. On this point, the interviewees expressed ambivalence concerning worker autonomy with respect to our discussion of the 'smart workplace' for developers in mechanical engineering. For example, a manager emphasised the possibilities for traditional forms of surveillance and control that his technologies offer when he claimed, 'I track everything'. The tracking of all data suggests that digital process control does not seem to overcome the traditional model of surveillance, but actually enhances the technical possibilities of surveillance. The manager continued by stating, 'I was shocked myself' about the extent of surveillance that was technically possible, but he also stated that he didn't want to use the data for repression. Rather, the intention behind the technology was to develop the self-adjustment of the worker: to '*tune himself*' and to 'recognise for himself, I am worse than the others' (our emphasis). This paradoxically makes it possible for managers to use sensor technology to increase machine-driven surveillance and control over the labour process while increasing worker autonomy from human management.

The manager we interviewed expressed hope that the employee will engage in self-optimisation based on data-driven feedback. However, this is only possible if the employee is motivated in some way to actually work with the feedback the system provides. Indeed, the manager noted that the motivation to 'tune oneself' cannot be created through technology alone. Rather, motivation was conceptualised as an organisational achievement that is created through a process of reinforcement. The more the worker uses machine-managed autonomy responsibly, and in alignment with the goals of the organisation, the more likely the possibility of increasing worker autonomy from human management. As the manager explained:

> On the one hand, we decide some things in advance, but on the other hand … you can also report errors, you can intervene, you can make suggestions for improvement, you can do everything, but please, digitally.

This development strategy appears to target increasing technological control over the labour process while at the same time increasing the responsibility of labour. Hence, in management rhetoric, this apparent contradiction is expressed in the metaphor of the worker 'tuning himself' to the technology. Interestingly, workers as well as managers expressed a feeling that they may lose control over their own decisions to machines, which does not seem to be a coincidence.

Integration of the industrial internet of things with industrial cyberphysical systems

In contrast to the cyberphysical paradigm, the internet of things (IoT) paradigm originated in the computer science community. As it has been well documented, the Internet first began as a US military project with the development of the ARPANET nodes in the late 1960s and early 1970s (Levine, 2018). While these nodes were later expanded to the university system, and eventually, to the commercial sector, it was not until 1999 that the phrase 'the internet of things' was first used to refer to the use of computers for producing knowledge about 'things' and the efficiencies this knowledge could bring to industry. Early applications of the 'industrial internet of things' (IIoT) were used to organise and control the flow of data and people with technologies such as product data management and product lifecycle management (Jeschke et al., 2017: 5). Therefore, ICPS refers to information technologies that are applied to the direct production process and the IIoT refers to information technologies that are applied to overall production planning and management and that may integrate with ICPS technologies. On this point, it has been suggested that the objective of the IIoT is to fully digitise and network all 'things' and processes in factories for the purpose of creating digital or 'smart factories' (Krumeich, 2016). Wang et al. conceptualize smart factories as a dual closed-loop system in which 'one loop consists of physical resources connected to a 'cloud', while the other loop consists of supervisory control terminals and cloud' (Wang et al., 2016: 159). This dual closed-loop system connects smart objects on the shop floor with control technologies at the management level which are in turn connected to global smart factory monitoring and control systems. With respect to the intended purpose of designing and implementing higher-level production planning systems in smart factories, the interviewees have stated that their systems will eliminate the influence of human managers in order to make production 'organise itself'.

One developer of a cyberphysical system – who aims to connect different levels of industrial control systems from the point of enterprise resource planning (ERP) to the point of control over individual operations – explained that the efficiency gains his system provides are specifically due to the replacement of human planning and decision making with automated data analytics:

> You *don't have any management -influence*. Especially with the keyword 'lot size one', it is exactly about this *planning organising itself*, that you always have enough material, that the material is there in time, that the machines are always running. Management decisions only occur if I either have a scarcity of resources or in case of some exceptional situations. (our emphasis)

The claim here is that it is precisely the replacement of human production planning with automated data analytics that increases production efficiency. The IIoT may also reduce production time by predicting machine maintenance and by tailoring commodity production more precisely to the requirements of both industrial and consumer demand, which suggests that

Industrie 4.0 will automate several aspects of the lean manufacturing paradigm (Sanders et al., 2016).

As suggested by the interview data, the introduction of smart glove and smart workstation technologies to the labour process may be considered part of an overall development strategy of Industrie 4.0 that includes the automation of production planning. On this point, it is important to examine the relation between the 'self-organisation of the means of production' and its effect on the autonomy of labour within the production process. Interviewees have suggested that the design and implementation of machines that replace the organising function of human management is leading toward the self-organisation of labour. As one researcher who is developing a cyberphysical system for 'self-organised workforce allocation' noted:

> Self-organisation on the technical level is an important topic. We focus on the need for humans and machines to communicate with each other in Industrie 4.0. Through the connection of sensors and actors a lot of self-steering becomes possible, theoretically. The machines will become ever more intelligent, so that for the employees the challenge will mainly be to follow how the participating systems have coordinated themselves, which states have been communicated and how did the intelligent software decide why to produce these orders in that way.

In this, however, the interviewee sees a big challenge,

> …for the human being to stay on one level with technology. Because the technology controls in ever more intelligent ways and organises itself. How can the human being participate in this self-organisation? This actually is the central question. In [our project] the idea was that the employees just also organise themselves, almost as a supplement to the machinic or IT-self-steering.

Similar to the possibility of automating planning with artificial intelligence, these points illustrate the paradox of the subordination of human reflexivity to the technological rationalisation of the labour process on the one hand, and, on the other, the potential empowerment of labour as a result of increased participation in decision-making. Similar observations have led Dyer-Witheford (2015: 51) to provocatively claim that '[t]he machine is not over and against the worker – because the worker is part of the machine'. As part of the process of the cybernetisation of production, the introduction of

ICPS and IIoT to the production process does appear to free labour on the shop floor from specific aspects of the organising function of human management while advancing capital's development of the machine management of labour. This appears to create new forms of human-machine integrated work, or *cybernetic work*.

Smart factory integration and autonomous production

The broader purpose of Industrie 4.0 within the current context of geopolitical and economic forces is to create 'more flexible organisations' that can 'better react to volatile markets'. This strategy aims to connect the production process more directly to market demand - which in turn necessarily implies heavier use of temporary and precarious employment and the 'flexibilisation' of labour. Hence, as an emerging regime of production, Industrie 4.0 resembles important aspects of another regime, which Burawoy (1985: 88-90) has called 'market despotism'. Thus, the short-term development goal of Industrie 4.0 is not only for the production process to become more technologically self-organised with the introduction of ICPS but also for production planning and management to become more rationalised with the introduction of the IIoT.

On this point, Steiner and Poledna note the rigidity of the classical 'automation pyramid' in which lower level systems focus on process controls and higher-level systems address production management (2016). Illustration 1 depicts a reconceptualisation of the automation pyramid that models the development and integration of networked digital control in smart factories. While enterprise resource planning systems such as SAP are typically based on a unidirectional flow of data and commands, the IIoT would create multi-directional feedback loops among all digital control systems. Thus, the development of smart factories would digitally integrate previously separated levels of control into one cybernetically-organised production process.

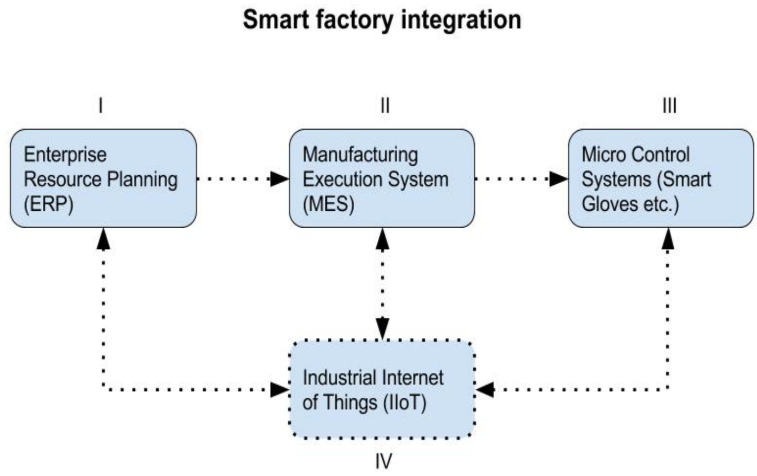

Illustration 1: Smart factory integration

In this model, ICPS are unified with the network capabilities of IIoT, which is envisioned to enable the entire production process to be self-organised (see illustration 1 above). As illustrated in the empirical data, digital control is no longer executed by an external source (e.g. such as a foreman or a video camera). Rather, control is integrated directly into the means of production equipped with sensor network technology, which is envisioned to automatically exchange data with planning systems on both meso (MES) and macro (ERP) levels. The integrated control of ICPS and IIoT in a smart factory would create a global system of planning and control in which the factory itself would become a cybernetic network of objects, humans and production processes based on the concept that 'everything – ranging from local production processes up to global value chains shall be digitally connected and decentralised' (Pfeiffer, 2015: 17). This would allow for big data collected from previously unconnected processes to be integrated and centrally controlled by automated databases and analytical software that generate a 'digital thread' of representation (McKinsey, 2015: 19) of the 'moments of production'.

However, as previously noted, sensor technology also allows for classical forms of surveillance, which was highlighted in one of our interviews with a works council member who noted the tendency of digitalisation toward 'total control'. This aspect has been most notably and thoroughly analysed by Zuboff (1988) as the dual capacity of information technology to both 'automate' and 'informate', and therefore deepen the managerial capacity to determine organisational behaviour. In our interviews, however, the engineers and managers did not envision that the primary purpose of digital control is to increase the human hierarchy of managerial power. On the contrary, the replacement of human production planning with automated data analytical machines, especially on the managerial level, appears to be one of their central goals. This obfuscates the possible replacement of the hierarchies of human management with hierarchies of machine management.

While the operation of smart factories may still require various forms of human management, engineering and other forms of cognitive labour for continued operation of the production process, such factories may also continue to rely on exploitation of labour involved in the direct production process as illustrated in the examples drawn from our empirical data. If the capitalist production process continues to require the exploitation of human labour, the cybernetisation of production might include automated data collection and processing that directly tracks the location, movement, and activity of workers in the labour process, or indirectly by collecting data produced from the use of digitised machinery, thereby potentially deepening labour exploitation.

However, there are visions of the self-organization of industrial capital reaching a point where labour-power is replaced entirely with machine-power in fully automated smart factories. This would require either retrofitting, or replacing entirely, all pre-existing machines with cyberphysical control systems (Roblek et al., 2016: 4) as well as digitalising and integrating cyberphysical control over the flow of all raw materials, production processes and produced commodities. Such a fully automated production process would involve all raw materials wirelessly transmitting instructions to surrounding machines that automatically and flexibly produce each commodity on demand and to specification (Siemens, 2013). We suggest that if the design and implementation of fully autonomous smart factories becomes ubiquitous to the point of raising the organic composition of capital, this process would represent an advance of capital's real subsumption of the labour process toward a third and final stage of capital's autonomisation from labour-power[3], the realisation of which could theoretically lead to the dissolution of the labour-capital relation.

Discussion

As we have outlined in this article, Industrie 4.0 is both a technological vision and a broader ideological program of German industry and state actors. It has emerged with high performative power and may eventually translate to the development of a new production regime. The development of this regime through the integration of ICPS and the IIoT within the sphere of production is what we refer to as the *cybernetisation of production*. In our interviews with engineers and managers, the stated outcomes of Industrie 4.0 were *immediate feedback* and *self-organisation*. Immediate feedback is enabled by the ubiquity of sensor technology and rapid data processing while self-organisation of the labour process is envisioned to be an outcome of this feedback. Digital cybernetic control did not introduce feedback to industrial production. Rather, its advancement has reduced the time gap between action and feedback to the point of real-time feedback. Hence, cyberphysical feedback is generated at the very instance of the evaluated action itself. It therefore intervenes directly into the production process rather than through quality control at the end of a production cycle. The engineers and managers we interviewed envisioned this as a process of self-regulation, in which production is linked directly to market feedback. As a result, managers envision a delegation of responsibility to the lower levels of the organisation and, perhaps more importantly, they envision the near elimination of production failures due to human-driven management, planning and hierarchical order (Raffetseder et al., 2017).

From the perspective of labour process theory, the introduction of technology to the labour process is traditionally interpreted as a tool of management to increase control over the workforce – or, to put it differently, to increase the

3 See Marx's (1973) description of the development of automation at the point of production in the *Grundrisse*, 704-706.

autonomy of management by decreasing the autonomy of manual labour. This is partly still the case with respect to cybernetic control, as it still includes all three elements of direction, evaluation and discipline, which, according to Edwards (1979: 18) manifests in different proportions in every system of hierarchical control of the labour process. Can we conclude that replacing the relation of managers to workers with a relation of cyberphysical systems to workers increases the 'responsible autonomy' of the workforce (Friedman, 1977)? We suggest that if the concept of responsible autonomy was based on the relation of supervisors to workers, then the replacement of managers with automated machines develops capital's autonomous control, and thus, the self-organisation of production based on a relation of networked cyberphysical machines to workers. The introduction of ICPS and the IIoT to the sphere of production cannot, therefore, be understood as an attempt to couple the agency of the worker to the will of the manager. Rather, the cybernetisation of production connects the entire organisation to the 'will of capital', precisely by eliminating the error-prone will of human managers and by connecting the production process more directly to market fluctuations.

It is important to keep in mind that the development of Industrie 4.0 will by no means unfold as a frictionless process. As David Noble (2011: 324) maintains:

> ...machines are never themselves the decisive forces of production, only their reflection. At every point, these technological developments are mediated by social power and domination, by irrational fantasies of omnipotence, by legitimating notions of progress, and by the contradictions rooted in the technological projects themselves and the social relations of production.

Indeed, the current status of Industrie 4.0 must be analysed as an emerging ideology that is currently found primarily in the heads of industrial capitalists, managers and technocrats rather than in a fully realised regime of production. Industrie 4.0 is very likely to encounter a wide array of organisational industrial variability, advances and regressions, starts and stops, dysfunctionalities, and various forms of worker resistance that challenge the logic of the cybernetisation of production. Middle managers could also potentially lose either organisational power, or their jobs entirely with the ubiquitous development of smart factories. Therefore, managers could have an interest in using the digital technologies of process control for classical surveillance rather than for developing the autonomy of the labour process. Hence, as the cybernetisation of production could reduce the autonomy of both manual workers and managers, deviations from the optimistic visions that have been articulated in the interviews are to be expected from both sides.

Given these considerations, we suggest that in the short-term, the cybernetisation of production will continue to require a relative mix of the human agency of cybernetic work and human managerial forms of hierarchical control. In the long-term, however, a gradual realisation of full automation at the point of production would affect the rate of unemployment and therefore the domestic effective demand needed by industry to sustain revenues, a consequence that not only affects the social conditions of the working class but the very self-interests and sustainability of industrial and financial capital. Considering the scale of the digital transformation of industry, its subsequent effect on the transformation of class composition could be significant and far-reaching. It is for this reason that the broader effect of Industrie 4.0 on class conditions should be given broad and significant research attention.

When we asked a manager of a German automobile producer whether he sees any risk in the current digital transformation of their industry, he replied:

> I don’t see any problems for the company. These are rather societal problems. With all of this automation we might have to think about a basic income at some point.

When asked if there were any discussions about these issues within their company, he said there were not. Rather, he suggested these discussions would, ‘only start when people can't afford our cars anymore’. However, there is still no empirical evidence for technological unemployment, at least in the German labour market. What can be proven empirically are drastic changes in working conditions, especially with respect to the intensification of work and further employee polarisation in terms of qualifications (Butollo et al., 2017). Thus, while the idea of a universal basic income has been put forward mostly from the side of employers, employees and unions may instead demand a reduction in working hours to counterbalance the digital intensification of work.

On this front, future research might direct its attention to the relation between smart factory automation and the reduction or elimination of working hours, the effects of changes in employment on class composition and the growing political movement for a universal basic income. Finally, while this article has presented a preliminary examination of the cybernetisation of production, this is only a recent development that has been preceded historically by the digitalisation of the circulation and consumption sphere as the other two 'moments of capital' (Fuchs, 2013; Manzerolle and Kjøsen, 2012). Further research into the cybernetisation of these other 'moments of capital' could yield critical insight into conceptualising the motion of the circuits of capital in relation to the motion of the circuits of big data, or the formation that has been referred to as a globally-interconnected 'cybernetic capitalism' (Diab, 2017; Dyer-Witheford, 2015; Schaupp, 2017b).

references

Beer, S. (1959) *Cybernetics and management*. London: The English Universities Press.

Braverman, H. (1974) *Labor and monopoly capital*. New York: Free Press.

Burawoy, M. (1985) *The politics of production: Factory regimes under capitalism and socialism*. London: Verso Books.

Butollo, F., M. Ehrlich and T. Engel (2017) 'Amazonisierung der Industriearbeit?: Industrie 4.0, Intralogistik und die Veränderung der Arbeitsverhältnisse in einem Montageunternehmen der Automobilindustrie', *Arbeit: Zeitschrift für Arbeitsforschung, Arbeitsgestaltung und Arbeitspolitik,* 26(1): 33-59.

Diab, R. S. (2017) 'Becoming-infrastructure: Datafication, deactivation and the social credit system', *Journal of Critical Library and Information Studies,* 1(1): 1-23.

Dyer-Witheford, N. (2015) *Cyber-Proletariat: Global labour in the digital vortex*. London: Pluto Press.

Edwards, R. (1979) *Contested terrain: The transformation of the workplace in the twentieth century*. New York: Basic Books.

Friedman, A. L. (1977) *Industry and labour: Class struggle at work and monopoly capitalism*. London: Palgrave.

Fuchs, C. (2013) 'Political economy and surveillance theory', *Critical Sociology,* 39(5): 671-687.

Fuchs, C. (2018) 'Industry 4.0: The digital German ideology', *tripleC: Communication, Capitalism & Critique,* 16(1): 280-289.

Gilbreth, F. B. and R. T. Kent (1921) *Motion study: A method for increasing the efficiency of the workman*. New York: D. Van Nostrand Company.

Hajek, S. (2016) 'Profiteure der neuen Datenflut', *Wirtschaftswoche* (35): 75-77.

Hirsch-Kreinsen, H. (2016) 'Digitization of industrial work: development paths and prospects', *Journal for Labour Market Research* 49(1): 1-14.

Jeschke, S., C. Brecher, T. Meisen, D. Özdemir and T. Eschert (2017) 'Industrial internet of things and cyber manufacturing systems', in S. Jeschke, C. Brecher, H. Song and D. B. Rawat, (eds.) *Industrial internet of things: Cybermanufacturing systems*. London: Springer International Publishing.

Kaufmann, J.-C. (2015) *Das verstehende Interview. Theorie und Praxis*. Konstanz München: UVK Verlagsgesellschaft.

Kirazli, A., R. Hormann, S. Cetinkaya and J. J. Ryan, (2015) 'A conceptual approach for identifying Industrie 4.0 application scenarios – ProQuest', *Proceedings of the 2015 Industrial and Systems Engineering Research Conference.* [https://www.lib.uwo.ca/cgi-bin/ezpauthn.cgi?url=http://search.proquest.com/docview/1791989039?accountid=15115]

Kline, R. R. (2015) *The cybernetics moment: Or why we call our age the information age*. Baltimore: Johns Hopkins University Press.

Kuckartz, U. (2016) *Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunterstützung*. Weinheim Basel: Beltz Juventa.

Levine, Y. (2018) Surveillance valley: The secret military history of the Internet. New York: Public Affairs. Kindle.

Manzerolle, V. R. and A. M. Kjøsen (2012) 'The communication of capital: Digital media and the logic of acceleration', *tripleC: Communication, Capitalism & Critique,* 10(2): 214-229.

Marwedel, P. (2011) *Embedded system design: Embedded systems foundations of cyber-physical systems*. Amsterdam: Springer Netherlands.

Marx, K. (2005) *Grundrisse: Foundations of the critique of political economy*. Penguin Books. Kindle.

McKinsey Digital. (2015) 'Industry 4.0: How to navigate digitization of the manufacturing sector'. [https://www.mckinsey.de/files/mck_industry_40_report.pdf]

Noble, D. F. (2011) *Forces of production: A social history of industrial Automation*. New Brunswick: Taylor & Francis Inc.

Oks, S. J., A. Fritzsche and K. M. Möslein (2017) 'An application map for industrial cyber-physical systems', in S. Jeschke, C., Brecher, H. Song and D. B. Rawat (eds.) *Industrial internet of things: Cybermanufacturing systems*. London: Springer International Publishing.

Pfeiffer, S. (2015) 'Warum reden wir eigentlich über Industrie 4.0? Auf dem Weg zum digitalen Despotismus', *Mittelweg,* 36(24): 14-36.

Raffetseder, E.-M., S. Schaupp and P. Staab (2017) 'Kybernetik und Kontrolle. Algorithmische Arbeitssteuerung und betriebliche Herrschaft', *Prokla,* 187: 229-247.

Roblek, V., M., Meško and A. Krapež (2016) 'A complex view of industry 4.0', *Sage Open* 6(2): 1-11.

Sanders, A., C., Elangeswaran and J. P. Wulfsberg (2016) 'Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing', *Journal of Industrial Engineering and Management,* 9(3): 811-833.

Schaupp, S. (2017a) 'Digital self-evaluation and the cybernetic regime: A sketch for a materialist apparatus analysis', *tripleC: Communication, Capitalism & Critique,* 15(2): 872-886.

Schaupp, S. (2017b) 'Vergessene Horizonte: Der kybernetische Kapitalismus und seine Alternativen', in P. Buckermann, A. Koppenburger, S. Schaupp (eds.) *Kybernetik, Kapitalismus, Revolutionen. Emanzipatorische Perspektiven Im Technologischen Wandel*. Münster: Unrast.

Seibt, D., S. Schaupp, and U. Meyer (2019) 'Towards an analytical understanding of domination and emancipation in digitalizing industries' in U. Meyer, S. Schaupp, D. Seibt: *Digitalization in industry: Between domination and emancipation*. New York: Palgrave Macmillan.

Siemens (2013) 'Industrie 4.0 - The fourth industrial revolution'. [https://www.youtube.com/watch?v=HPRURtORnis]

Steiner, W. and S. Poledna, (2016) 'Fog computing as enabler for the Industrial Internet of Things', *Elektrotechnik & Informationstechnik,* 133(7): 310-314.

Taylor, F. W. (1913) *The principles of scientific management*. New York: Harper & Brothers.

Wang, S., J. Wan, D. Zhang, D. Li and C. Zhang (2016) 'Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination', *Computer Networks,* 101(4): 158-168.

Wiener, N. (1948) *Cybernetics or control and communication in the animal and the machine*. Massachusetts: MIT Press.

Zuboff, S. (1988) *In the age of the smart machine: The future of work and power*. New York: Basic Books.

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