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Smart production systems: a new type of industrial process innovation

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Abstract
This paper refers to change processes of production work under the conditions of smart produc-tion systems. These are technological concepts aiming at a new form of industrial automation and they are discussed in the engineering science and innovation policy debate especially in Germany under the label "Industry 4.0". Its central feature is the integration of the virtual computer world with the physical world of things through the creation of ?cyber-physical systems? (CPS). Pro-duction systems and technological components based on CPS should be able to configure, regu-late and optimize themselves in response to external demands largely autonomously. These tech-nological concepts can be regarded as a process-innovation. The assumption is that smart produc-tion systems represent a disruptive, structure-changing process innovation. To date, no systematic social science studies on the organizational and personnel consequences of these innovations are available Therefore, the present paper will attempt a first assessment of the possible perspectives for development and the organizational and personnel consequences of these process innovations. Additionally, the development prospects of the new technologies will be analyzed. Methodologi-cally the argumentation is highly explorative in character and based on a review and systematic résumé of the available literature in the area of social-science-oriented industrial and labor re-search that concerns itself more or less explicitly with the introduction of new technologies.

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1. Introduction

The topic of this paper is the development and diffusion of new automation technologies in industrial production, which has been discussed already for some time under the label of the "digital enterprise" (e.g. Marapoulos, 2003; Westkämper, 2007; Chryssolouris et al., 2009). The term is the general concept for the factory-spanning deployment of digital models and methods of production planning and control, and their application to real subsystems – production, assembly components and products. The concept refers to the planning, execution, monitoring and ongoing optimization of all essential shop processes und resources. The consequence is a fundamental transformation of the business process not only of single enterprises, but also of whole value chains. Actually, the concept of "digital manufacturing" up to today is a great collection of partial concepts and isolated approaches to solutions, the continual development of which has been carried on for some time in Europe and the US (e.g. Johnson and Bay, 1995; Lee, 2001; Terwisch and Ganz, 2009; White et al., 2010).

In recent years these developments have been resumed and taken further, especially in Germany. This perspective on industrial automation is being discussed in Germany under the label "Industry 4.0". This term means that currently a "4th Industrial Revolution" is beginning. Its central feature is the integration of the virtual computer world with the physical world of things through the creation of "cyber-physical systems" (CPS). Production systems and technological components based on CPS should be able to configure, regulate and optimize themselves in response to external demands largely autonomously (Lee and Seshia, 2011). In other words, this is a new form of process-innovation that can also be called, metaphorically, "swarm automation" (Lee and Seppelt, 2009). In this way a level of automation in industrial production heretofore unheard-of in earlier phases of industrial development is held to be achievable (Forschungsunion and achatech, 2013).

In this paper I ask what development perspectives this industrial process-innovation has and what consequences the new level of automation will have for the organization and the labor processes in industry. A significant number of authors stress that with this innovation the traditional forms of production organization and work will be totally changed (e.g. Lee, 2001; Cummings and

Bruni, 2009; Lee and Seppelt, 2009; Dworschak et al., 2011; Geisberger and Broy, 2012; BMWI, 2013; Spath et al., 2013).

The present paper will attempt a first assessment of the possible perspectives for development and the organizational and personnel consequences of these process innovations. The focus of the analysis is on change processes of production work in the context of smart production systems. The following argumentation presumes a *broad understanding of production work*, in order to grasp sufficiently the import of this transformation process. The concept includes all the directly and indirectly value-creating activities that occur in industrial operations. It relates to the operative and executive levels of the work organization, but also to the strategic levels of planning, regulation and monitoring, the areas of the lower and mid-level management of production processes, as well as to the activities of technical experts.

Empirical points of reference for the following analysis are the innovation efforts in Germany that, as "Industry 4.0" have reached a very advanced state by international comparison (Lee, 2014). These innovations will be in the following generally subsumed under the term of intelligent or "smart production systems". Methodologically the following argumentation is therefore highly explorative in character and based on a review and systematic résumé of the available literature in the area of social-science-oriented industrial and labor research that concerns itself more or less explicitly with the introduction of new technologies.[1] Because of the particularly intensive discussion in Germany over the perspectives of Industry 4.0, these resources are most often German-language studies. The argumentation is also based on the results of a series of semi-structured interviews with manufacturing experts in Germany.

2. Smart production: a new dimension of industrial automation

With the concept Industry 4.0 as discussed in Germany is referred to on the one hand existing production concepts, which in recent decades has been developed under the name "Computer Integrated Manufacturing" (CIM) and in the 1980s and 90s was realized at least in part (e.g. Harrington, 1973). One the other hand however the concept Industry 4.0 aims for a new dimension of industrial on the base of the highly flexible integration of the virtual world of dataprocessing with real manufacturing processes. The thereby attempted leap in automation

[1] Essentially these are studies from the sub-discipline industrial engineering, psychology of work, sociology of work and social-science research on innovation.

[power] can, to follow the innovation debate, be termed categorically as *disruptive process innovation*.[2]

The “disruptive” change in process structures is above all characterized by the dominant traditional models of production automation (based on sequential and ex ante optimized processes of pre-defined functional relations) being fundamentally transformed (Cummings and Bruni, 2009; Lee and Seppelt, 2009; Dworschak et al., 2011; Geisberger and Broy, 2012). The new automation level is based on a continuous self-optimization of intelligent, decentralized system components and their ability to self-regulate to dynamically changing external conditions, for example, to end-market conditions, production and delivery chains, or to real-time environmental demands. The aim of this conception is to manage by the new automation technologies the increasing flexibility demands of end-markets, an increasing individualization of products, ever-shorter product life-cycles, as well as the increasing complexity of process chains and the products themselves; in other words, the existing technological and economic limits of automation are to be broken and extended precisely in response to the new demands posed by flexibility (e.g. Scholz-Reiter et al., 2009; Forschungsunion and acatech, 2013).

The technological basis for this is the above-mentioned “Cyber-Physical Systems” (CPS) (e.g. Gill,2006; Lee and Seshia, 2011; Geisenberger and Broy, 2012; Kagermann et al., 2012; Sendler, 2013). Concretely, these are networked products and process technologies as well as transport technologies which autonomously organize and steer their own operations, the course of finishing processes and the corresponding logistical functions, and regulate themselves to external demands such as varying demand and unexpected process disturbances. The technological preconditions for this are the availability over new sensory technologies and embedded mechatronic components functioning on the basis of decentralized IT intelligence. A further central requirement is the linkage of these intelligent components and subsystems through the wide-area availability of an information infrastructure in the form of industrially applicable internet connections (e.g. Weiss, 2000; Uhlmann et al., 2013), oriented conceptually on the long-proposed “internet of things” (e.g. Bullinger and ten Hompel, 2007; Uckelmann et al., 2011).[3] In that way the integration of the real and virtual world is to be made possible with products,

[2] In contrast to disruptive innovation, in innovation research the notion “sustaining innovation” means only the improvement of existing technologies and the resulting market advantages (Christensen, 1997).
[3] In a more general perspective beyond the industrial area, also the concept “ambient intelligence” is used for intelligent networks in the most various areas of work and the objects used; further concepts in a similar sense are “ubiquitous computing” and “pervasive computing” (Kinkel et al., 2008: 229f.).

machines and objects all with embedded software growing together into distributed and at the same time integrated systems.

The concept of CPS has been propagated for several years internationally and especially in Germany by computer scientists, engineers, influential economic federations and politicians. As already mentioned, in this discourse the specifically new dimension of this automation innovation is stressed. Its advantages are held to be robust self-regulation to variable demands from the environment, and broad applications, particularly in industry (Lee and Seppelt, 2009: pp.430).[4]

It can be assumed that with this process innovation, permanently sustainable transformative processes in industrial production will be initiated that in their consequences have been until now unfathomable. What is more, from a macroeconomic perspective the hypothesis has been variously formulated that the developed societies are just at the beginning of a “highly disruptive period of economic growth”.[5] The main driver of this development is the constantly expanding functional and economic potential of ICT applications that in industry until recently have hardly been exploited on a wide scale. Components and subsystems will diffuse ever more rapidly in industry because of sinking costs and continual improvement of their applicability. For many German system developers and manufacturers this approach is a chance to maintain and strengthen their already frontrunning technological position in process innovation and manufacturing automation on the world market.

In order to limit problems in the introductory phases, at first mostly only subsystems as partial solutions will probably appear on the market with, each with different degrees of automation. Currently are being reported a number of development- and introductory-phase processes for such systems in German technology-intensive enterprises of the metal products industry, which are particularly concentrated on the production functions of logistics, planning and control, as well as assembling (e.g. Forschungsunion and acatech, 2013; Reinhart et al., 2013; wt-online, 2013).

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[4] Another concept used for this is that of the “multi-agent system”. Such systems are found already in many areas, such as the sorting of great amounts of data or as autonomous robots in land-mine clearing (Lee and Seppelt, 2009: 429).

[5] Thus The Economist in regard to a book Brynjolfson and McAfee, with the title “The Second Machine Age” (The Economist, 2014).

3. Smart production as sociotechnical systems

An analysis of the interaction of the new technology with the changes of industrial organization and labor requires a fundamental look at the total system of production and their interdependencies with organization and labor. For only that way can the consequences of long-term disruptive innovation be adequately captured and their effects sufficiently examined. An analytic-conceptual investigation informed by social science on the automation tendencies sketched is offered by the recent sociological research on the interaction between autonomous technologies on the one hand and human behavior on the other, as well as into the question discussed by it of what forms of interaction are worked out between them. Theoretically inspired above all by Bruno Latour's "Actor-Network Theory", which posits an extensive equality of human and non-human actants (Latour, 1996) in contrast to the traditional perspective on technology as passive object, technology is here attributed the role of a behaviorally capable actor. Thus also "hybrid" systems are spoken of, in which the relation between technology and humans is sorted out continually anew for specific tasks and behavior (Rammert and Schulz-Schaeffer, 2002; Rammert, 2003).

Rammert argues with a concept of "distributed action", which in regard to the functional distribution of tasks internally in a technical system, as well as between a technical system and human action, is characterized by the following features: *Parallelism* instead of sequentiality in problem elaboration, *self-organization* within an existing framework instead of given hierarchical structure, *loose coupling* of integrated elements instead of the stiff cogs of a progression of steps, *situative distribution of activities* among action, technology and programs and human action, as well as an *interactively steered* human-machine-environment relationship instead of the programming of hard parameters. Therefore, thus Rammert further, we must speak of a fragmental and interactive distributiveness of action, in contrast to the traditional functional and hierarchical distribution of actions. Fragmental means thereby, that the processes often run parallel and separately to each other, but in relation to the total system, concurrently; interactive means thereby, that the paths and solutions to reaching goals are not set ex ante like a program, but are determined in the context of negotiation and harmonization processes between the various technical and non-technical elements of the total system. With that – thus the conclusion – only from a hybrid perspective comprising technology and humans in socio-technical constellations can be made visible the distribution of activities and levels of autonomy (Rammert, 2003: pp.309). In research therefore the traditional view of the dualism of technology and the nontechnological or social elements is abandoned, and instead their reciprocal context and connection is elevated to a complex sociotechnical system. With the concept of the sociotechnical system in this debate is meant the ongoing interdependence of technical and social components (e.g. Ropohl, 2009).

In regard to the question posed here, the analytic perspective can be broadened by relating it to a well-known concept of social science work research on the relation of technology, organization and work. This is the concept of the sociotechnical system that at the end of the 1940s was developed for the analysis of the automation of mining processes (Trist and Bamforth, 1951). Since then it has proven its analytical power in many studies of the organizational and personnel consequences of automation. Though in research it is not always uniformly defined, a sociotechnical system can be understood, in a first approach based on Rice (1963), as a production unit that consists of interdependent technological, organizational and personnel subsystems. Though the technological subsystem limits the developmental possibilities of the two other subsystems, these display autonomous social and work-psychological characteristics that in turn influence the functioning of the technological subsystem. In addition the total system is always in a close reciprocal relation with the conditions in its environment.

With this concept, asking only about the functioning of individual and separated technical and non-technical elements is avoided, but the analysis comes to focus instead on the reciprocal effects and the combination of elements, that is, the *sociotechnical configurations*. Connected with this is the fundamental assumption of the concept, as precisely stated by Chris W. Clegg: “Sociotechnical theory has at its core the notion that the design and performance of new systems can be improved, and indeed can only work satisfactorily, if the ‘social’ and the ‘technical’ are brought together and treated as interdependent aspects of a work system.” (Clegg, 2000: 464)

As, not least importantly, the first basic considerations in the context of the debate over smart production systems also show, this analytical comprehension of the total system alone sufficiently permits statements about the developmental perspectives and consequences for work. Methodologically this concept also permits the inclusion of different levels and segments of production processes in a comparative analysis. For these reasons the sociotechnical system concept is also programmatically included in the current discussion about Industry 4.0 (Forschungsunion and acatech, 2013: pp.40). Conceptually attention is drawn – above all in technically dominated discourses – to the often overlooked circumstance that automation affects not only single jobs, activities and the qualifications of individual persons, but beyond that, has consequences for the entire socio-organizational structure of a production system. For its part, this sociotechnical system is in turn connected with higher-level strategic targets and is an element in the total process of a value-creation chain. With this concept is also opened a dynamic perspective on the technologically induced transformation of productive work, since it addresses the reciprocal contexts between the technological and the social subsystems.

4. On the transformation of organization and work

If one asks about the possible and conceivable tendencies towards change in factory organization and industrial work in the context of the new forms of automation, it is indisputable in the relevant computer-science and technology-centered debate that the diffusion of such systems will permanently change the heretofore usual forms of factory organization, in particular also today's well-known patterns of the organization of work and employment of personnel (e.g. Lee, 2001; Cummings and Bruni, 2009; Lee and Seppelt, 2009; Dworschak et al., 2011; Geisberger and Broy, 2012; BMWI, 2013; Spath et al., 2013). Indisputable is of course here also, that in contrast to the CIM discussion of the 1980s, the perspective of a complete automation and "factories without people", for technological and economic reasons, is not and cannot be a realistic one (see also: Kinkel et al., 2008: 241). Following the concept of the sociotechnical system and the broad conception of production work sketched here, the fundamental transformative tendencies can be formulated in the following dimensions:

4.1 Human-machine interaction and the importance of experiential knowledge

Central is the dimension of "human-machine interaction" and the related qualification requirements for the workers who interact with the machines. Here abound above all research findings of the work sciences and industrial psychology, which traditionally are concerned with the forms of interaction between humans and computer-based mechanical processes (Hacker, 1987; Ulich, 2005). In this context several studies point to the problem, considered central, of production work in automated systems, namely in how far the workforce involved is at all able to monitor autonomous systems and, with that, take responsibility for the system functioning (e.g. Grote, 2009). For the assumption is that the overseeing persons will not always be able to check all functions, because the functional and informational distance to what is happening in the system is too great. A good illustration of this are given monitoring activities that are no longer directly connected with the physical and material processes taking place on the shop-floor lines, but rather are “mediatized” by the use of measurement stations. The consequence is that “the informal feedback associated with vibrations, sounds, and smells that many operators relied upon” is eliminated, and therefore personnel cannot assess accurately conditions on the production line and sometimes make faulty decisions in respect to interventions in the automated process (Lee and Seppelt, 2009: 419). It is therefore fundamentally important for such workers to avoid “complacency and loss of situation awareness” in production-line work (Cummings and Bruni, 2009: 442).

Sociological studies on the particular demands of work with automation have come to similar findings and conclusions. Prominent from the 1980s until now has been a research thread that has determined the great importance of “subjective qualification elements” such as experiential knowledge in the context of the increasing automation of production processes. The authors within this research direction, in particular Böhle, Pfeiffer et al., thus stress (summarizing e.g. Pfeiffer, 2013) the growing complexity and the inherent incalculabilities of automated processes always exhibit the limitations of their technical controllability. In their findings, a work situation often emerges that Bainbridge (1983) instructively describes as one of the “ironies of automation”, where automated processes, because of their extreme routine character, make it very difficult to manage disruptions. In such situations, qualifications are needed that cannot be developed in automated routines (Windelbrand et al., 2011). The relevance of these aspects was instructively demonstrated within the framework of studies about work at complex, highly automated production lines (Böhle and Rose, 1992; Schumann et al., 1994). Notable here is in particular the worker type of the “system regulator”, whose behavioral requirements are a “qualification-amalgam” of theoretical knowledge and practical experience. This specific qualification pattern is seen as the central condition for a competent management of production-lines, which includes improvisational-experimental work behavior in case of unavoidable disturbances (Schumann et al., 1990), though certainly these authors also stress that a suitable system setup should ensure that the qualified work personnel are able to carry out effectively their monitoring tasks (ibid.).

4.2 Heterogeneous task- and activity-structures

A further central dimension of sociotechnical analysis involves the task- and activity-structures in the context of the new technological systems. For this dimension, the findings of social-science investigations into production work in the context of smart systems – similar to the results of earlier studies on automation[6] – underline the assertion of heterogenous task- and activity-structures onto the new production systems. Here the focus in particular is on the operational and organizational levels of the systems.

The thesis of the heterogenization of work is explicitly formulated in studies on technology consequences in the use of intelligent IT systems in industrial production (TAB, 2008; Kinkel et al., 2008). The authors assume first of all that low-qualification jobs and simple, repetitive tasks will be replaced by intelligent automated systems. Examples are simple logistics tasks, machine operation and the – until now manual – gathering and entry of data. The extent of these replacement processes is however currently hard to estimate (ibid.: pp.242). As to the middle range of job qualifications, i.e. skilled workers and technicians in areas of finishing processes, the authors assume somewhat contradictory tendencies of change (ibid.: p.243 ff.):

For one thing, for the previously "qualified skilled worker" level a "de-qualification and partial substitution" of activity content is feared. Their existing tasks such as simpler machine operation, handling materials and materials-linked machine settings, as well as various monitoring and regulating functions, will be automated in the future. Also disposition decisions in production logistics could be partially automated with the new systems. Desired goods and merchandise could be largely autonomously ordered from production installations, so that the corresponding logistical tasks of the employees on finishing lines could be eliminated. These would intervene in production procedures thus only in occasional exceptional cases. The authors speak therefore of a "residual category" of qualified workers in production, with activities and functions that are not automated (or could only be automated at excessive expense). Among these are for example demanding maintenance and preparatory tasks, feeding materials or partly finished products or certain manual production skills, all of which require expert knowledge and experience (ibid.: p.244).

On the other hand these authors also assume that an enrichment of job activities will take place. This is the consequence of a greater complexity of processes and in the IT decentralization of decision-making, control and coordination functions. Therefore, it is argued, the specialists involved will be increasingly challenged to independently plan and coordinate procedures. That entails a broader understanding of the coordination of the entire production process, logistics and delivery requirements. Besides the increasing need for "overview knowledge", also the social

[6] Cf. Schultz-Wild et al., 1986; Hirsch-Kreinsen et al., 1990; Moldaschl, 1991; Schumann et al., 1994.

competencies of workers take on greater value, since, with intensified integration of previously separate functional areas, the need grows for [effective] interaction – real or computer-based – with distant groups of persons and functional areas. In this connection is mentioned the term “specialist engineer” (*Facharbeiteringenieur*), which is thought to express that manual skills will become less important, while other abilities – some programming knowledge as well as the regulation and servicing of complex systems – will gain.

Similarly Spath et al. (2013) argue in a recent study: Also under the conditions of smart production systems human work will remain an important part of production. However, it will change considerably in the face of the demand for complexity, innovative ability and flexibility (ibid.: pp.20). Direct production activities will diminish considerably in favor of indirect work tasks, and traditional production work and modern knowledge work will converge. The focus on creative, value-creating activities presumes the progressive automation of employees’ routine tasks and continual reductions in low-skill, repetitive jobs. Standardized, long-term planable tasks will be performed techno-mechanically, while only certain necessary single or unforeseen procedures will remain for human workers to perform. At the same time it is admitted that some existing areas of human work, i.e. those requiring bodily and manual effort, because of specific and scarcely standardizable production parameters, must remain (ibid.: p.101).

Comparable theses are also posited in a study by Windelband et al. (2011) based on an investigation of work in the context of intelligently networked logistic systems (see also: Düll, 2013: pp.178), from which result contradictory development trends: On the one hand with the new technology processes are automated, with the obvious effect that human tasks and activities are simplified. The consequence is that companies can now hire low-skilled personnel cheaply and without long job-learning periods. The freedom of action of this employee group are naturally very few in view of the strictly set characteristics of the system. On the other hand however, such logistic systems are exploited to optimize procedures on condition of employees’ having suitable qualifications. The authors emphasize that therefore qualified employees gain in various ways in significance, for they must be able to “enter the necessary data in disciplined and error-free work, and at the same time demonstrate a good understanding of the entire process” (ibid.: p.5).

4.3 Management levels

To the question, how work is changing in the hierarchic dimension, up to now only a few clear research results have emerged. The levels of planning and management, findings have shown to date, are potentially hardly directly affected by the introduction of smart systems; at the most one can speak of quite contradictory “collateral effects” of a system introduction on the upper levels of hierarchy:

For one thing the evidence suggests that with the decentralized self-organization of systems and correspondingly flexible work organization on the operative level, a part of the planning and control functions previously executed on the management level by technical experts and production management have been “knocked down” to lower levels. That means that with smart systems there is a decentralization shift and dismantling of hierarchy, often within factory organizations with an already relatively “flat” structure. For another thing, complexity-related broadened and/or new planning tasks will also fall within the responsibility of these areas. Some authors say that in view of the system complexity, “trouble-shooting” tasks will gain dramatically in importance (Uhlmann et al., 2013). It can also be assumed that on planning and management levels, previously separate tasks and competencies, for example IT and production competencies, will merge (Spath et al., 2013: 123).

This unclear situation may be intensified by an equally contradictorily changing surveillance potential of higher-level positions: From the investigation by Kinkel et al. (2008: 242) results that the new systems and their information-technical image of real process runs will open to production management new possibilities for monitoring processes and diagnosing disturbances. Of course with that is also indicated that, at the same time, new kinds of problems are expected to arise in managing and appropriately filtering the huge amounts of system data (ibid.). It is also assumed that the production runs of autonomous systems, because of their complexity, will have to remain for planners and production management largely opaque. Therefore the earlier decision-making competencies of this management group will move down to the operative level and there, as part of the system, will be either automated or taken over there by the qualified operators. As consequence of this, a potential lack of acceptance of the new technologies among [industry] management is now feared (Spath et al., 2013: p.100).

Although up to now far from explicit, these indications however permit us to foresee that planning and management areas, with the introduction of smart production systems, will be just as much permanently affected as the operative levels. Moreover, it is presumable that the corresponding transformation of management levels will be an unavoidable requirement for the mastery of the new technologies.

4.4 Interim résumé: divergent patterns of work organization

If we now subsume the above findings on the changes in work organization and qualification structures, it becomes clear that there is no "one best way" of forms of work in smart production systems. Rather, the assumption is of a broad spectrum of diverging patterns of work organization that ranges between two poles:[7]

One pole corresponds to a formative pattern of the tendencies outlined of the internal workplace heterogenization of tasks, qualifications and personnel implementation. In these production systems, on the one hand, a probably only low number of simple activities (with little or no room for independent action) is still needed which carry out ongoing standardized monitoring and regulation or control tasks. On the other hand is found an extended or also newly created group of highly qualified experts and technical specialists whose qualification level lies noticeably higher than that of the earlier specialist worker level. These employees are in charge of not only dispositional tasks such as disruption management, but they also take over variously the work of production management. These employees are, in contrast to the lower-level workers, without a doubt the winners in the coming technological shift. This pattern of work organization corresponds largely to the currently already in many high-tech operations dominant forms of work that can be characterized as a contradictory mix of the formative principles of decentralization and responsibility-widening on the one hand, and structuring and standardization on the other (e.g. Kinkel et al., 2008; Hirsch-Kreinsen, 2009; Abel et al., 2013). Thus companies already burdened by expensive technological innovations may avoid high-risk and uncertain organizational innovations if they follow this established path of work-organizational configuration. This work-organizational pattern shall therefore be called here the *polarized organization*.

The other pole on the spectrum is the organization model that can be metaphorically called a *swarm organization* (Neef and Burmeister, 2005; also: Lee and Seppelt, 2009; Cummings and

[7] Similar findings were established by earlier sociological studies on CIM systems (e.g. Hirsch-Kreinsen et al., 1990: p.79).

Bruni, 2009). The goal of this organization pattern is, by the greatest possible openness and flexibility on the basis of high employee qualifications, to be able at all times to deal with unforeseeable disruptions and exceptional situations through competent, experienced and work-based repertoire of actions. This pattern of work organization is characterized by a loose network of highly qualified employees who are fully empowered to act. Simple, low-skilled jobs are simply not found here, for they will have been largely replaced by automation. Central characteristic of this organization model is that there are no defined tasks for individual employees; rather, the "work collective" is self-organized, situation-driven, and acts flexibly on problems that present in and around the technological system. However there exist frameworks of action prepared by management levels: fundamental rules of action, strategic goals and collective orientations and guiding images, essentially with the aim of a disturbance-free, optimal technological process (ibid.: pp.569). Formulated otherwise, this model of work organization aims for the explicit exploitation of informal social processes of communication and cooperation and connected with it, the extra-functional competencies and the accumulated specific process-knowledge of employees.

In sociological work research some of the reasons for the possible relevance of swarm organizations in the context of intelligent production systems have been emphasized: An effective system mastery by skilled personnel is held to be particularly ensured above all in but little regulated, informal and cooperative forms of work processes (Lee and Seppelt, 2009; Cummings and Bruni, 2009). Furthermore, within the framework of such a pattern of work organization it is quite possible to master the processes of decision-making and communication taking place in real time (Spath et al., 2013: pp.115). In addition it is stressed that the state of complex systems changes "spontaneously" and has opaque and unpredictable effects (Weyer and Grote, 2012) that in turn require highly flexible actions in the course of work that are scarcely projectable or amenable to rules.

5. Determining factors

Because apparently in the case of smart production systems there are very different developmental paths of production work, the question is understandable what determinants influence the development of organization and qualifications. An answer is provided by a glance at the interdependence relations between the technical and non-technical elements of a sociotechnical system, in particular the design of the technical subsystem and the associated room for organization and work. If one looks at the older literature on the introduction of CIM systems (Schultz-Wild et al., 1986; Hirsch-Kreinsen et al., 1990), the automation concept followed by each of the user companies and associated with that, the and introduction processes of the new systems play a central role.

5.1 Alternative automation concepts

The design of the technical subsystem has to be regarded as one of the main influencing factors for the development possibilities organization and work. Following the literature, one can speak of "alternative automation concepts". Here two fundamentally different of system design can be distinguished (e.g. Hollnager and Bye, 2000; Kaber and Endsley, 2004; Cummings and Bruni, 2009; Lee and Seppelt, 2009; Grote, 2005):

- One is a *technology-centered automation concept*. This conception goes in the direction of a far-going replacement of work functions by automatic installations. The role of human intervention in the work has then only a compensatory character. The remaining tasks for workers are those that can be automated only with difficulty or not at all, and are generally surveillance tasks. Otherwise formulated, human action in the work has now a temporary function and the conceivable final state of such a system conception is its complete automation. Unquestionably, with this system concept there are progressively narrower limits on the place for human creativity in the work.
- On the other hand a *complementary automation concept* can be posited. This design concept goes in the direction of developing a distribution of tasks between humans and machines, which makes possible a satisfactory functional capability of the total system. This requires a holistic or collaborative perspective on the human-machine interaction and which identifies the specific strengths and weaknesses of both human labor and technical automation. For the development of work in this conception, a technological framework is established that can serve in different ways.

In the relevant social-science literature it is unanimously assumed that only a complementary system interpretation is sufficient for the optimal exploitation of the technological and economic potential of smart production systems, for it doesn't relegate human intervention in work systems to only a few fragmentary functional remains, as does the technology-centered automation concept. Instead, the complementary conception opens design possibilities of work that minimize the above-named awareness and feedback problems of acting on complex installations, make possible informal [manipulative] action and ongoing learning processes, and thereby permit a sufficient regulative capacity of the total system.

To follow Grote's formulation, with such an approach the specific strengths and weaknesses of humans and technology will not be regarded "…in the sense of an *either-or*, human or technology, …but rather merged into a new quality of the total system by means of a thorough elaboration of the human-technology interaction." For this the three dimensions of the sociotechnical system concept are equally involved in the system development, in order to make it able to deal with variations and disruptions (Grote, 2005: 67). As essential formative criteria are mentioned for example (ibid.): the possibilities to monitor the technology, a motivation-oriented task structure, as well as an organizationally enabled self-regulation of activities.

5.2 Implementation process

In total, these considerations and findings indicate the great influence not only of the fundamental development of and formative processes in the new production systems, but also on the actual implementation process of a new system at each end-user plant. For only in the course of that does in the rule the configuration of the total sociotechnical system become concrete, also for what regards the specific technical, work-organizational and personnel issues. The significance of the implementation process for the ultimate system design and model of production work realized is grounded above all in the fact that the new smart systems normally cannot be implemented at all as "turnkey solutions" or as it were, "plug-and-play-ready" in workplaces. And it is only seldom the case that an intelligent factory is put up on the "greenfield" as a total concept. Rather, most autonomous systems will probably be integrated first as "island solutions" within certain production segments in existing technical-organizational structures of user companies. Therefore in the concrete introduction phase will be required an under certain circumstances long and drawn-out, costly and reciprocal process of coordination between the new system and the existing plant's conditions. Here attention should be drawn particularly to the extremely costly harmonization of the new system with existing databases and systems (Spath et al., 2013: 123; also: Schuh and Stich, 2013: pp.229). Overall are therefore to be assumed exhaustive introductory and startup phases in smart systems, in the course of which activities and the work organization will have to demonstrate high flexibility and problem-solution capabilities, and which can hardly be expected reach a definable end-state. Variously is mentioned the "life-cycle" of such complex installations which can cause continuously new and difficult system conditions that permanently require newer forms of work organization and personnel engagement (BMWI, 2013).

Whether and how these challenges are managed depends in turn on many additional company and management-structural factors. Earlier studies on the introduction of computer-integrated systems thus point to the often overloaded factory resources of planning capacity, know-how and available financial leeway. The restrictive influence of a lack of resources is particularly evident when smaller and scarcely technology-intensive firms decide to adopt smart production systems. Furthermore the course of the implementation process is affected by labor- and company-political issues. As relevant is to be considered the internal-plant constellation of actors participating in the introduction, as for example the way key promoters in management, or in project group-formation commit themselves in decision-making processes. Which automation concept ensues in separate cases and how the work organization is structured, could be decisively influenced by which actors are especially influential.

6. Development prospects

To the question of the perspectives for smart production systems, it must be emphasized that the possibilities of realization have by far not been definitively made out. This is because the industrial diffusion of these systems, with their disruptive and structure-changing character, is confronted by technical, economic and social barriers that are hard to overcome. In other words, it must be assumed that the innovation of smart production systems has an exceptionally *paradoxical character*.[8] Its structure-changing effects provoke all at once opposition, limitations and barriers to its realization. This can be due to the following factors:

- First, there are the above-mentioned problems of data migration and the integration of the new systems the new systems in the existing production structures and databases, the costs and complexities of which presently seem scarcely fathomable.
- Second, indications of acceptance problems of the new concept on the part of management and among industry practitioners cannot be overlooked. A substantial role has here quite evidently a widespread skeptical attitude towards the automation and the efficiency promised by the smart systems, based on their long years of practical and contradictory experiences

[8] In innovation research an “innovation paradox” is referred to when a technological innovation carries within itself reasons for its failure (e.g. Andriopoulos and Lewis, 2009).

with automation. Beyond that, smart systems with their technological principles of decentralized, automated self-organization collides with widespread organizational concepts of standardization and lean production, by which often sustainable efficiency gains and increases in the steerability potential of processes is realized. In this regard the concept contradicts in several ways the dominant guiding wisdom how to structure an efficient factory. Besides, there is often reserve out of very comprehensible fears for the data security of the complex databases that must be elaborated in highly networked intelligent production systems.

- Third, organizational inertia should be taken into account. This is probably the particular consequence of the necessary restructuring of company planning and control levels, and a changed distribution of duties between IT and production technology. For generally, IT competencies and duties should increase massively in importance and be merged with the other existing production-technical competencies. Concerned by this are in particular technical experts who could use their existing influential position to slow down rapid change or even block it. Possibly such a defensive stance towards a loss of competence could be strengthened by the fear of the surveillance potential of the digital systems.

It can be assumed therefore that in the industrial sector in total, in the medium term a differentiated landscape of the diffusion and application of smart production systems will be observed. Above all such enterprises will seize the opportunity of the new systems who because of high flexibility requirements are permanently under pressure to innovate and rationalize, and in the new systems see a chance to achieve robust productivity increases. Typical of these are technology-intensive, strong mid-scale firms who above all have the necessary qualified personnel and capabilities and which are famous for the German industrial structure. Examples are medium sized technology intensive and highly innovative firms of mechanical engineering and metal industry. Also, the area of logistics, because of its standardized processes and rapid growth, should become in the mid-term a promising user of smart systems.

Rather reserved by contrast towards smart systems will be such enterprises who as large scale producers have already progressed very far in highly automated production technologies and organization. For the specific and new – i.e. disruptive – automation logic of smart systems would probably endanger their achievement of high productivity and with that, their existing competitive advantage. Examples are flexible large scale producer of the automotive and the electro-technical sector. Presumably these systems will also scarcely interest the wide area of technologically low-intensity small and middle-size enterprises (SMEs). The reasons for this lie, for one thing, in the limited resources and capabilities of most SMEs, who therefore aren't usually willing to go for technological experiments with uncertain results. For another thing, many SMEs are in sectors that are traditionally successful producing relatively standardized goods at a modest level of automated technology. These enterprises, for example in nutrition products, the furniture industry or metal goods, are subjected to only low flexibility demands, so that costly and risky automation measures for them will probably not need to be seriously considered. These forms of low-qualification, straightforward industry jobs should therefore remain in the foreseeable future.

Overall however, hardly any definitive and sure assumptions about the future dispersion of smart production systems can be formulated. The arguments made here are therefore highly hypothetical. But with that a wide field of future social-science research on innovation and work is laid out, which will concern itself with changes in the work of production in the context of the introduction of smart production systems. Such an agenda could take in analytically oriented basic research as well as projects in applied research, for example on technologically oriented development and application attempts. In any case however, the newness and complexity of this area only make still more obvious the need for an interdisciplinary approach between the technical and social sciences. All in all the burning question – and one in no way yet even approaching a definitive answer – is whether this economic and social development, as the German discussion surrounding Industry 4.0 suggests, indeed is the threshold of a "4th Industrial Revolution".

References

Abel, J./Ittermann, P./Steffen, M. 2013: *Wandel von Industriearbeit. Herausforderung und Folgen neuer Produktionssysteme in der Industrie.* Soziologisches Arbeitspapier TU Dortmund, Nr. 32, 03/2013

acatech (ed.) 2011: *Cyber-Physical Systems. Innovationsmotor für Mobilität, Gesundheit, Energie und Produktion*. Berlin

Andriopoulos, C./Lewis, M.W. 2009: Exploitation-Exploration Tensions and Organizational Ambidexterity:Managing Paradoxes of Innovation, *Organization Science*, 20(4), 696-717

Bainbridge, L. 1983: Ironies of automation, *Automatica*, 19(6), 775-779

BMWI – Bundesministerium für Wirtschaft und Technologie 2013: *Mensch-Technik-Interaktion*, Berlin

Boes, A./Kämpf, T. 2013: Informations- und Wissensarbeit. In: Hirsch-Kreinsen, H., Minssen, H. (ed.): *Lexikon der Arbeits- und Industriesoziologie*, Berlin, 280-284

Böhle, F./Rose, H. (ed.) 1992: *Technik und Erfahrung. Arbeit in hochautomatisierten Systemen*, Frankfurt am Main/New York

Bullinger, H.-J./ten Hompel, M. (ed.) 2007: *Internet der Dinge*, Berlin

Clegg, Chris W. 2000: Sociotechnical principles for system design. *Applied Ergonomics* 31, 463-477

Chryssolouris,G.; D Mavrikios, N Papakostas, D Mourtzis*, G Michalos, and K Georgoulias 2009: Digital manufacturing: history,perspectives, and outlook. *Proc. IMechE 223*, 451-462

Cummings, M./Bruni, S. 2009: Collaborative Human-Automation Decision Making. In: Nof, S. (ed..), *Handbook of Automation*, Berlin, 437-447

Düll, N. (Hg.) 2013: *Arbeitsmarkt 2030 Fachexpertisen und Szenarien. Trendanalyse und qualitative Vorausschau*, http://www.wbv.de/openaccess/artikel/6004384w (01/05/2014)

Dworschak, B./Zaiser, H./Achtenhagen, C. 2011: *Zukünftige Qualifikationserfordernisse durch das Internet der Dinge in der industriellen Produktion*, Nürnberg

Forschungsunion/acatech (ed.) 2013: *Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industry 4.0 working group*, Frankfurt/M

Geisberger, E./Broy, M. 2012: *agendaCPS. Integrierte Forschungsagenda Cyber-Physical Systems*, Heidelberg

Gill, H. 2006: *NSF Perspective and Status on Cyber-Physical Systems*, Austin

Grote, G. 2005: Menschliche Kontrolle über technische Systeme – Ein irreführendes Postulat. In: Karrer, K./Gauss, B./Steffens, C. (ed.): *Beiträge der Forschung zur Mensch-Maschine-Systemtechnik aus Forschung und Praxis*, Düsseldorf, 65-78

Grote, G. 2009: Die Grenzen der Kontrollierbarkeit komplexer Systeme. In: Weyer, J. (ed.), *Management komplexer Systeme*, München, 149-168

Hacker, W. 1987: Software-Ergonomie: Gestaltung rechnergestützter geistiger Arbeit. In: Schönpflug, W./Wittstock, M. (ed.): *Software Ergonomie 1987. Berichte des German Chapter of the AMC, 29*, Stuttgart, 31-45

Harrington, J. 1973: *Computer Integrated Manufacturing*, New York

Hirsch-Kreinsen, H. 2009: *Innovative Arbeitsgestaltung im Maschinenbau*? Soziologisches Arbeitspapier, Nr. 27, Dortmund

Hirsch-Kreinsen, H./Schultz-Wild, R./Köhler, C./Behr, M. von 1990: *Einstieg in die rechnerintegrierte Produktion: alternative Entwicklungspfade der Industriearbeit im Maschinenbau*, Frankfurt am Main/New York

Hollnagel, E./Bye, A. 2000: Principles for modelling function allocation. *International Journal of Human-Computer Studies*, 52(2), 253-265

Johnson, P./Bay, J. 1995: Distributed control of simulated autonomous mobile robot collectives in payload transportation. *Autonomous Robots*, 2 (1), 43-63

Kaber, D./Endsley, M. 2004: The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. *Theoretical Issues in Ergonomics Sciences*, 5 (2), 113-153

Kagermann, H./Wahlster, W./Helbig, J. (ed.) 2012: *Bericht der Promotorengruppe Kommunikation. Im Fokus: Das Zukunftsprojekt Industrie 4.0*, Berlin

Kinkel, S./Friedewald, M./Hüsing, B./Lay, G.; Lindner, R. 2008: *Arbeiten in der Zukunft: Strukturen und Trends der Industriearbeit*, Berlin

Latour, B. 1996: On Actor-network Theory. A few Clarifications. *Soziale Welt*, 47(4), 369–382

Lee, J. D. 2001: Emerging challenges in cognitive ergonomics: Managing swarms of self-organizing agent-based automation. *Theoretical Issues in Ergonomics Science*, 2(3), 238-250

Lee, J. 2014: Industrie 4.0 – ein deutscher Begriff. *VDI-nachrichten*, 68(5), 2

Lee, J. D./Seppelt, B. 2009: Human Factors in Automation Design. In: Nof, S. (Hg.), *Handbook of Automation*, Berlin, S. 417-436

Lee, E.A./Seshia, S.A. 2011: *Introduction to Embedded Systems - A Cyber-Physical Systems Approach*, http://LeeSeshia.org, 2011. (2/25/2014)

Marapoulos, P.G. 2003: Digital Enterprise Technology. *International Journal of Integrated Manufacturing*, 16(7-8), 467-478

Moldaschl, M. 1991: *Frauenarbeit oder Facharbeit?* Frankfurt/New York

Neef, A./Burmeister, K. 2005: Die Schwarm-Organisation — Ein neues Paradigma für das e-Unternehmen der Zukunft. In: Kuhlin, B./Thielmann, H. (ed.): *Real-Time Enterprise in der Praxis*, Berlin et al., 563-572

Pfeiffer, S. 2013: Arbeit und Technik. In: Hirsch-Kreinsen, H., Minssen, H. (ed.): *Lexikon der Arbeits- und Industriesoziologie*. Berlin, 48-53

Rammert, W. 2003: Technik in Aktion: Verteiltes Handeln in soziotechnischen Konstellationen. In: Christaller, T./Wehner, J. (ed.): *Autonome Maschinen*, Wiesbaden, 289-315

Rammert, W./Schulz-Schäffer, I. 2002: Technik und Handeln. Wenn soziales Handeln sich auf menschliches Verhalten und technische Abläufe verteilt. In: Rammert, W./Schulz-Schäffer, I. (ed.): *Können Maschinen handeln?* Frankfurt am Main/New York, 11-64

Reinhart, G./Engelhardt, P./Geiger, F./Philipp, T./Wahlster, W./Zühlke, D./Schlick, J./Becker, T./Löckelt, M./Pirvu, B./Stephan, P./Hodek, S./Scholz-Reiter, B./Thoben, K./Gorldt, C./Hribernik, K./Lappe, D./Veigt, M. 2013: Cyber-Physische Produktionssysteme. Produktivitäts- und Flexibilitätssteigerung durch die Vernetzung intelligenter Systeme in der Fabrik. *wt-online*, 103(2), 84-89

Rice, A. 1963: *The enterprise and its environment*, London

Ropohl 2009: *Allgemeine Technologie. Eine Systemtheorie der Technik*, Karlsruhe

Scholz-Reiter, B./Böse, F./Lampe, W./Virnich, A. 2009: Auf dem Weg zur Selbststeuerung der Prozesse. *Industrie Management*, 25(6), 21-26

Schuh, G./Stich, V. (ed.) 2013: *Produktion am Standort Deutschland. Ergebnisse der Untersuchung 2013,* Aachen

Schultz-Wild, R./Asendorf, I./Behr, M. von/Köhler, C./Lutz, B./Nuber, C. 1986: *Flexible Fertigung und Industriearbeit*, Frankfurt am Main/New York

Schumann, M./Baethge-Kinsky V./Neumann U./Springer, R. 1990: Breite Diffusion der neuen Produktionskonzepte – zögerlicher Wandel der Arbeitsstrukturen. *Soziale Welt*, 41(1), 49-69

Schumann, M./Baethge-Kinsky, V./Kuhlmann, M./Kurz, C./Neumann, U. 1994: *Trendreport Rationalisierung. Automobilindustrie, Werkzeugmaschinenbau, Chemische Industrie,* Berlin

Sendler, U. (ed.) 2013: *Industrie 4.0*, Berlin/Heidelberg

Spath, D./Ganschar, O./Gerlach, S./Hämmerle, M./Krause, T./Schlund, S. 2013: *Produktionsarbeit der Zukunft – Industrie 4.0.* Stuttgart

TAB 2008: Zukunftsreport: *Arbeiten in der Zukunft – Strukturen und Trends der Industriearbeit.* Bericht des Ausschusses für Bildung, Forschung und Technikfolgenabschätzung (18. Ausschuss) gemäß § 56a der Geschäftsordnung, Deutscher Bundestag Drucksache 16/7959

Terwisch, P./Ganz, C. 2009: Emerging Trends and Challenges in Automation. In: Nof, S. (ed.): *Handbook of Automation*, Berlin, 127-143

The Economist 2014: *The on rushing wave, January* 18th, 18-21

Trist, E./Bamforth, K. 1951: Some social and psychological consequences of the long wall method of coal-getting. *Human Relations,* 4(1), 3-38

Uckelmann, D./Harrison, M/Michaelles, F. (ed.) 2011: *Architecting the Internet of Things*, Berlin

Uhlmann, E./Hohwieler, E./Kraft, M. 2013: Selbstorganisierende Produktion mit verteilter Intelligenz. *wt-online,* 103(2), 114-117

Ulich, E. 2005: *Arbeitspsychologie*. 6th ed., Stuttgart

Weiss, G. (ed.) 2000*: Multiagent Systems. A Modern Approach to Distributed Artifical Intelligence*, 2. Ed.. Cambridge MA

Westkämper, E. 2007: *Digital enterprise technology: digital manufacturing in the global era,* New York

Weyer, J./Grote, G. 2012: Die Grenzen der Beherrschbarkeit technischer Systeme. In: Böhle, F., Busch, S. (ed.), *Management von Ungewissheit*. Bielefeld, 189-212

White, J./Clarke, S./Groba, C./Dougherty, B./Thompson, C./Schmidt, D. C. 2010: R&D challenges and solutions for mobile cyber-physical applications and supporting Internet services. *Journal of Internet Services and Applications*, 1(1), 45-56

Windelband, L. et al. 2011: Zukünftige Qualifikationsanforderungen durch das „Internet der Dinge“ in der Logistik“. In: FreQueNz (ed.): *Zukünftige Qualifikationserfordernisse durch das Internet der Dinge in der Logistik, Zusammenfassung der Studienergebnisse*, Berlin, 5-9

wt-online 2013: *Sonderausgabe Industrie 4.0*, 103(2), 83- 162