Contribution of Industry 4.0 to the emergence of a joint cognitive and physical production system

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Abstract

The digital and technological revolutions of Industry 4.0 aim at increasing the flexibility of companies, the mass customization of products and the improvement of working conditions. Thus, Internet of Things (IoT) and biofeedback sensors become new sources of information on the production context and the state of resources, big data and cloud computing offer increased processing capacity (for learning and simulation), virtual and augmented realities, as well as vocal or gestural commands, make the interactions more contextual, natural, and customized. The integration of these Industry 4.0 technologies must however reconsider the place of the operator in the production, to tend towards a joint cognitive and physical system. Interference between operators and the cyber-physical production system must be optimized, by fostering the emergence of a real know-how to cooperate on the different production management activities (line operations, supervision, planning). In this perspective, the paper provides an overview on the Industry 4.0 technologies and their impact on the human-systems cooperation. A synthesis model proposes to position these technologies around the processes of building common frame of reference and distributing functions between humans and the cyber-physical system. This model is finally illustrated by a conditioning activity, shared between a human operator and cyberphysical components (cobot, augmented reality, etc.).

Introduction

The term *Industry 4.0* emerged in the early 2010s and refers to the advent of a fourth industrial revolution (Drath & Horth, 2014) and the application of the Cyber-Physical Systems concept to the field of industrial production systems. For Wang, Wan and Zhang (2016), *Industry 4.0* is one type of industry which incorporates technological advances for addressing major societal challenges: improving the quality of life with high-quality customized products, participating in the sustainable development by reducing non-renewable energy consumption, and offering better working conditions to employees.

Rüssman et al. (2015, Boston Consulting Group report) identify nine technology pillars related to the digital revolution of industry.

On the one hand, *Internet of Things*, *horizontal and vertical integration of Information System*, *Big Data*, *Cloud computing*, *cybersecurity*, will facilitate

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management of companies' information by linking or decentralizing data, making data reliable, or also gave rise new knowledge becomes available (Hozdic, 2015). These technologies contribute to the advent of cyber-physical systems, defined as interactive networks of physical and computer components, characterized by their evolutionary and decentralized nature, and their properties of openness and context sensitivity (Fantini, Pinzone & Taisch, 2018). In addition, they offer enhanced capabilities in monitoring, modelling, analysis, and calculations, using data mining and machine learning techniques (Longo et al., 2017).

On the other hand, *simulation*, *virtual or augmented reality*, improves production verification and supervision capabilities. Longo et al. (2017) argue that the industry 4.0 will allow the emergence of the virtual enterprise, thanks to the constitution of digital twins. According to Rosen, Wichert & Bettenhausen (2015), this notion of 'digital copying' can be used to reduce design costs, to detect errors early in the preliminary design phase of products or production systems. Digital twins could also help for supervision, displaying in real time in virtual environments the state and behaviour of machines and production. This immersion of the digital twin in reality could be done using augmented reality. Augmented reality, today often dedicated to one or a few specific tasks, will become ubiquitous (Grubert, Langlotz, Zollmann & Regenbrecht, 2017). It will be adaptive depending on the context (location, type of activity, situation encountered), to project operational information on the immediate environment of the task to be performed, but also more tactical information on the general environment of production. Longo et al. (Ibid.) believe that this combination of virtual and real worlds is carrier and could bring interesting applications for maintenance (remote assistance) or training to operational situations.

Finally, *additive manufacturing* and *self-adjusting robotics* will support more flexible production. According Rüssmann et al. (2015), robotics becomes a more sustainable means of collaborative work. At the same time, additive manufacturing, now confined to prototyping, is becoming more industrial, and moving from mass production to "mass customization". All of this contributes to the emergence of autonomous and self-organized manufacturing systems (Longo et al., 2017), making production more agile.

These opportunities, brought by the implementation of new technologies in manufacturing systems, raise new challenges (Hozdic, 2015; NIST, 2016; Longo et al., 2017). In particular, the cyber-physical production system must be resilient, responsive and flexible in the face of critical situations. Manufacturing must become intelligent and holonic (NIST, Ibid.) and rely on artificial intelligence that can automatically adapt to the changing environments and demands of the process. Above all, we must move from the era of intelligent products (for example with RFID), to that of intelligent machines and the optimization of joint systems, combining operator and cyberphysical systems. The emergence of these joint systems (Hollnagel & Woods, 2005) also called "symbiosis" between operators and digital assistances (Romero, Bernus, Noran, Stahre, Fast, & Berglund, 2016), is a major challenge of the industry 4.0. It addresses key questions about the future place of human in industry 4.0 (Hozdic, 2015, Hirsch-Kreinsen, 2014, Longo, Nicoletti, & Padovano, 2017).

The purpose of the paper is to contribute to the understanding and modelling of this joint industry 4.0 production system. The first part presents a review of the literature on the place of human in industry 4.0 and develops the concept of operator 4.0. A state of the art on human-machine cooperation models is also conducted in this section, in order to better understand the emergence of the joint, cognitive and physical system of production. The second part then presents a synthesis framework, to model the possibilities of man-machine cooperation between the operator and these new assistances of industry 4.0. This framework is applied to a use case (the activity of order picking). Finally, these proposals are discussed, in terms of the prospects for the design and adaptation of Industry 4.0 to future operators.

I. Related works

I.1. Towards operator 4.0, a joint cognitive and physical system of production

The place of operators in future smart factory

Several authors identify various issues related to the role of operators within these new sociotechnical systems. Hirsch-Kreinsen (2014) describes the impact of this new “industrial revolution” on the skills and qualifications of operators as well as the evolution of the organization of work

- *Skills and knowledge*. Operators will be required to demonstrate high adaptive capacity. They will act on complex, interconnected and autonomous technical systems that they will have to understand and control. Operators will manipulate more abstract information and will often be more “remote” from the process to be controlled, with an increased scope of supervision (Hoc, 1996).
- *Qualification*. Industry 4.0 will employ fewer unskilled workers than the traditional factory. Indeed, as Fantini, Pinzone and Taisch (2018) recall, it is the routine activities, characterized by a low level of requirements of manual dexterity or social interaction, which are most likely to be replaced by the technology. On the other hand, it will need qualified and well-trained workers (Lorentz, Russmann, Strack, Lueth, & Bolle, 2015).
- *Work organization*. Hirsch-Kreinsen identifies two extreme forms of organization and division of work between humans: a “polarized” organization with few disqualified tasks and a large group of highly qualified experts and specialists versus a “distributed” organization aiming for flexibility and based on a high level of qualification which enables operators to face unanticipated situations.

The place of human in the productive systems is thus to rethink in depth. It is in this sense that Hozdic (2015) calls for the updating of the operator model. The author specifies that it is necessary to reflect on new human activities, taking into account the new possibilities of the mixed reality combining the physical world and the digital / cybernetic world (through interfaces, techniques of representation of knowledge, augmented reality, etc.). In this perspective, Hozdic (Ibid.) also emphasizes the need to model new architectures of cyber-physical production systems (CPS), ranging from sensors to the presentation and contextualization of decision support, and that keep the human in the loop, or even increase its capabilities.

In order to better define the place of the human in the context of Industry 4.0, some authors have recently sought to build typologies of the operator, qualified as "operator 4.0" (Romero et al., 2016), to from the new technological revolutions (see §I.1). They have formalized in a detailed way the interactions with the cyber-physical system of production (Romero et al., 2016, Romero, Wuest, Stahre, & Gorecky, 2017), or proposed a framework to design and evaluate these interactions (Fantini et al., 2018).

Operator 4.0: a symbiosis between human and machines

Romero, Bernus, Noran, Stahre and Fast Berglund (2016) explain that the operator 4.0 is part of a new approach to designing adaptive production systems. Automation is considered as a means to increase human capacities at the physical, sensory and cognitive levels. The "symbiosis" between the human and the cyber-physical system, will allow emerging a new intelligent hybrid agent (human and artificial). This vision proposed by Romero et al. (2016) somehow joins the current of cognitive systems (Hollnagel & Woods, 2005). This approach follows and extends the concept of "Balanced Automation System" (Romero et al., 2016, Fantini et al., 2018): it is no longer only a question of finding a balance between manual tasks and automated tasks, but to design an adaptive and dynamic automation, based on a dynamic allocation of functions between the man and the machine.

According to Fantini et al. (2018), robots and algorithms are not intended to replace the human in industry 4.0, but are instead intended to become assistance that allows the operator to continue working, despite age, disabilities or inexperience, which favour the maintenance of human "in the control loop", and which improve the performance and comfort of workers.

A typology of operator 4.0, based on digital revolutions

Romero, Bernus, Noran, Stahre, Fast and Berglund (2016) detail the different "increase" of the operator 4.0. They propose a typology based on the technological pillars of industry 4.0 listed by Rüssmann et al. (2015), and secondly on the nature of the assistance (physical, sensory or cognitive) provided to the operator (Figure 1).

The operator 4.0 can be physically increased ("super-strength operator" and "collaborative operator"), using cobots and exoskeletons. This will contribute to the increase in performance and the reduction of musculoskeletal disorders (the physical load can be shared between the man and the robot) and will also allow the insertion of disabled workers.

The operator 4.0 can also be increased on the cognitive level (to better treat and interpret the information, and to solve in a more optimal way the problems met) and on the sensory level (to better perceive the environment and to detect new signs):

- Biofeedback sensors will bring a sensory increase ("healthy operator"). Like the IoT sensors, they will allow a reflexive evaluation of the operator on the physical and mental effort that he provides, and thus contribute to the detection of risk situations, when the man is physically overloaded or cognitive
- New visualization interfaces, such as virtual reality and augmented reality, will contribute to sensory and cognitive enhancement of the operator ("augmented

operator” and “virtual operator”). The diagnosis of the situation can indeed be enriched, through the display of information from the cyber-physical system, and this contextualized (depending on the location, the role of the operators, the situation encountered). The perception of the environment will also be increased, thanks to the subjective vision proposed by these visualization means, and to the display of visual alerts or indexes highlighting the important elements of the environment.

Figure 1. A typology of operator 4.0 (from Romero et al., 2016)

Enterprise social networks will participate in a cognitive increase of the operator (“social operator”). They will notably improve the diagnosis of the real situation and help the problem solving thanks to the knowledge of other experts accessible online, synchronously (chat, video), or asynchronous (with the information “traces” left on the platforms of wiki type, forum). The analysis of big data and cloud computing will lead to a cognitive increase of the operator (“analytical operator”). They will extend the capabilities of calculation, classification, analysis and synthesis of information of the company, and thus enrich the analysis of the situation by the operator, whether at the strategic, tactical or operational level.

Finally, the operator 4.0 will benefit from increased interactions with the cyber-physical system (“smarter operator”), in support of the various increases of the operator listed above. Human-machine interactions will be improved by the use of personal assistants and artificial intelligence. The queries and commands can then be transmitted in natural language between the man and the machine, and the understanding of the needs of the operator will be contextualized and enriched (through a learning process where the personal assistant will consolidate a model of the operator).

Operator 4.0, a social agent
In addition to this vision based on the "symbiotic" assistance and increases of the operator, we must also approach human-machine cooperation with a perspective of social interactions (Fantini et al., 2018). In this sense, Romero, Wuest, Stahre and Gorecky (2017) refine their vision of the operator 4.0, placing it at the centre of a social network, made up of other social operators, but also of machines and software qualified them also of "social". These authors propose a multi-agent architecture of the social factory to better formalize these social interactions and this holonic production system. This is based in particular on the introduction of two types of agents:

- The *interface agents* correspond to a set of rules and interaction conditions that support interactions between human or technical agents and the rest of the system. These interface agents are qualified as active, in the sense that they evolve continuously, by learning (based on observation, imitation, return of other agents or programming). They thus make it possible to personalize the assistance provided to the agent, making it dynamic and adaptive, and thus contributes to keeping the social operator or the social machine in the loop when they encounter difficulties. These agents correspond to the intelligence that drives the adaptive HMIs and manage the dialogue, adapting to the context or the operator. An example is the personalization and the customization in google maps, where trips can be proposed to a driver depending on the schedule, the driver's location, and his/her travel history, and where the states of heaters or lights in driver's home can be modified according to this trip.
- The *broker agents* correspond to the rules of allocation of functions and sharing or delegation of authority. They thus make it possible to adapt the level of automation to optimize man-machine cooperation.

Optimization of joint production systems: a human-machine cooperation perspective
Attempts to model the place of the operator in Industry 4.0 and its "social" interactions with other agents of the organisation highlight the emergence of a joint cognitive system, symbiosis of human and of the cyber-physical system. Obtaining a "symbiotic" system must go through an optimization of man-machine cooperation. This optimization is conditioned by:

- The creation of a common frame of reference (Clark, 1996, Hoc, 2001), including both a shared awareness of the environment, but also a representation of each agent and the team, seen as resources. It is in this sense that the interface agents allow adaptive assistance. This common frame of reference must also be constructed taking into account the questions of transparency, which will refine and guide the dialogue between the different agents (Chen, Procci, Boyce, Wright, Garcia & Barnes, 2014).
- The design of a dynamic allocation of functions, allowing a sharing of work between the man and the machine that responds to the hazards and keeps the operator in the loop.

I.2. Human-machine cooperation models to understand operator 4.0

Human-machine cooperation can be understood by structural approaches that define the structure of the relationships between cooperating agents, or functional approaches that describe the cooperative activities that develop between agents (Chauvin & Hoc, 2014)

Human-machine cooperation models

Millot and Mandiau (1995) defined two generic organizational structures for cooperation:

- Vertical cooperation in which an agent at a higher level supervises and has authority. The lower level agent can provide advice;
- Horizontal cooperation where the agents are at the same hierarchical level and the tasks are shared by allocation, the sharing being defined by the higher hierarchical level.

Schmidt (1991) takes a functional-structural approach by distinguishing three types of cooperation, which can be observed when agents are mutually dependent to carry out their task (their individual activities must then be articulated in order to achieve the work objectives):

- Augmentative cooperation that aims to increase physical or intellectual abilities since additional agents with identical skills perform the task when the workload increases and cannot be managed by a single agent;
- Debating cooperation makes it possible to confront points of view between agents in order to make the solutions more reliable and reduce the errors. This type of cooperation requires some agents to check and control other agents;
- Integrative cooperation joins complementary skilled agents.

According to Hoc's (2001) functional approach, two autonomous agents are in a cooperative situation if two minimum conditions are met. First, each agent pursues goals, and each may interfere with goals, resources, or procedures. Secondly, each agent strives to deal with these interferences in order to facilitate the accomplishment of the individual activities of each or the accomplishment of the common task if it exists. This interference management can be observed at three levels, defining three levels of cooperation:

- L1: cooperation in action (or execution). This level distinguishes between different operational cooperative real-time and short-term goal and procedure management activities: local interference creation (e.g. disagreement), local interference detection (e.g. redundancy), anticipation, and interference resolution.
- L2: cooperation in planning. This level is characterized by cooperative activities for developing or maintaining a common reference system: maintaining and developing a common objective, a common plan, a distribution of functions
- L3: metacooperation. It facilitates the two previous levels by developing a common code of communication and models of oneself and the partner

The central concept of common ground in human-machine cooperation

To move towards joint cognitive systems based on a symbiosis between operator 4.0 and technologies of industry, shared representations of situations, adapted to the contexts, must be supported (Salas, Prince, Baker, & Shrestha, 1995, Kaber & Endsley, 1998). Millot and Pacaux (2013) propose to extend the work of human-machine cooperation from framework of collective situation awareness (team-SA, shared-SA and distributed-SA) defined as the shared understanding of a situation between agents. Although each individual has an individual representation of a given situation, one can identify a level of “recovery” of individual SA whose key elements facilitating the construction of the team-SA are to share the goals and future states of the system. (Salmon et al., 2008). The 4.0 technologies will thus facilitate a level of mutual transparency between the partner agents, by making it possible to build, feed, update and adapt the common repository of agents. The common frame of reference becomes the “linchpin” of cooperating agents since it allows: (a) cooperation in action and planning (Hoc, 2001) through effective coordination mechanisms (Schmidt, 1991). By generalizing the joint activity concepts developed by Clark (1996), Klein, Feltovich, Bradshaw, & Woods (2005) indicate that this coordination is facilitated when team members are inter-predictable (they can predict the actions of others) and have a sufficient common frame of reference; (b) enrichment of self and partner models. This enrichment of models helps to develop the “know-cooperate” component of cooperation (Rogalski, 1996).

Know-How to Cooperate and processes for building common ground

Millot and Pacaux (2013) propose a model of human-machine cooperation that articulates the coordination mechanism to the concept of knowing how to cooperate. Their model of cooperation is based on two principles: (1) the agents have know-how in the control of processes or the accomplishment of tasks (2) the agents have knowledge to cooperate with other agents. From the definition of cooperation proposed by Hoc (2001), the authors consider two processes contributing to the know-how to cooperate: (a) the coordination which makes it possible to manage the interferences between the aims pursued by the agents (detect, create, solve); (b) facilitating the goals of other agents. Their common reference concept, the Common Work Space (Pacaux-Lemoine & Debernard, 2002, Millot & Pacaux-Lemoine, 2013) then makes it possible to support cooperative activities.

Industry 4.0, a support for the enhancement of human-machine cooperation

Technologies of Industry 4.0 will help to build and adapt the common frame of reference of cooperating agents by supporting the processes of coordination and facilitation of goals. These adaptive mechanisms of the joint human-machine systems may vary according to spatial and temporal parameters, making it possible to define different modes of cooperation (Schmidt, 1991): close or distant cooperation, synchronous or asynchronous cooperation, collective or distributed cooperation, direct or indirect cooperation. The “state” or “quality” of the common frame of reference could then be a criterion allowing to favour real-time flexible human-machine cooperation (Hoc, 2001) and thus “activate”, according to the paradigm of the dynamic allocation of functions, modes of assistance to optimize resources or recover a degraded situation.

II. A framework for modelling joint cognitive and physical production systems

II.1. Development of a human-machine cooperation framework for operator 4.0

The functions of production to model

Operators perform functions of different natures to perform their tasks. In the current definition of jobs of operators, there is indeed a combination of several aspects of production management that an operator must manage. We can find for example:

- The scheduler, which does both short-term planning and supervision, possibly correcting the planning of the manufacturing orders of the day according to the encountered hazards (related to the demand, or the shortcomings of the production system provoked by machine breakdowns or the absence of employees);
- In empowering organizations (e.g. in Michelin or French Post Office), flow facilitators do both production operations and supervision. They will carry out support activities (quality control, training) or managerial activities (point 5 minutes, transmission of directives and feedback of field problems) in addition to their implementation tasks.

Rather than focusing on roles, we will discuss in terms of production functions, by distinguishing operational, planning and supervisory functions. These different functions can be analysed according to the level of control that operators can have on operations. This control can be characterized following two axes (cf. figure 2):
- Control can be reactive (during production) or anticipatory (before production),
- The control level depends on the margins that operators can have on production load and capacity (in other words, on the trade-off that an operator will be able to find between the demand of production and the implementation of the human and technical resources).

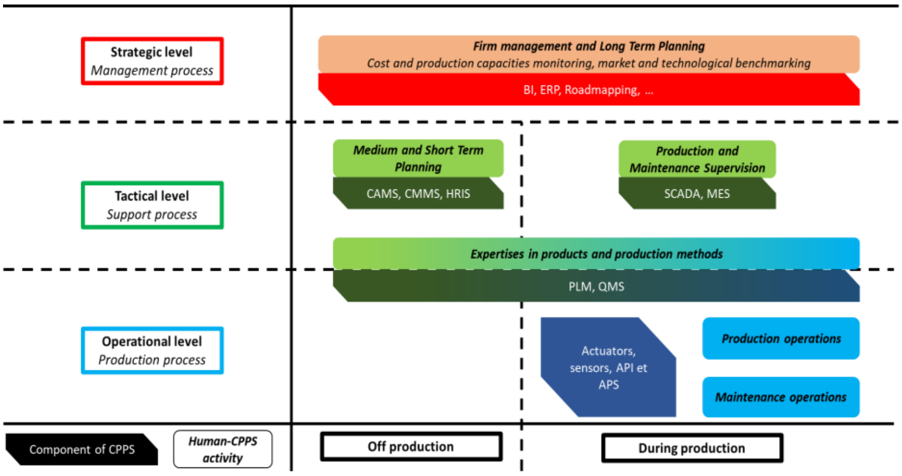

Figure 2. Mapping of functions of production and existing cyberphysical components

During production (reactive control), we will therefore distinguish two kinds of function: (a) production operations (product manufacturing, maintenance, etc.) consist in implementing resources to meet the demand. Production capacity and load are fixed, and the operator must remain in this constraint field, with a reflexive control of the action in progress; (b) production supervision consists of monitoring and reconfiguring the production system, if necessary, to ensure that the resources (capacity) can adequately meet the demand for production (load). Capacity can therefore be redefined (redistribution of tasks, prioritization of manufacturing or intervention orders), but demand is a constraint.

Before production (anticipatory control), planning tasks aim at monitoring and adjusting the load / capacity ratio in the management of production operations. Operator plays on load AND capacity, with a more or less distant horizon (at the level of Industrial and Commercial Planning or Master Production Scheduling).

Categorization of industry 4.0 technologies

The technologies for industry 4.0 can be grouped into four categories (Tech1 to Tech4), according to their impact on information processing or implementation of the action (Table 1).

Table 1. Characterization of industry 4.0 technologies

Technologies 4.0		**Impact for industry 4.0**	
Internet of Things & biofeedback sensors *« conncected & healthy operator »*	***Tech1***	Information processing	Raw information collected by new sensors
Bigdata, Cloud computing, Machine Learning *« analytical operator »* Enterprise social network *« social operator »*	***Tech2***		Information enriched by models enabling simulation and prediction
Augmented reality *« augmented operator »* Virtual reality *« virtual operator »* Personal Digital Assistant *« smart operator »*	***Tech3***		Situated information, adapted to context
Cobot *« super-strength operator »*	***Tech4***	Implementation of action	Assistance for repeated actions (Norm NF EN 1005)
Exoskeleton *« collaborative operator »*			Assitance for constraining action (lift, carry, push-pull / Norm NFX35-109)

A framework for modelling operator 4.0

The figure 3 below synthesizes the human-machine cooperation mechanisms that should be developed for designing future operator 4.0, by positioning the different industry 4.0 technologies and the different levels of functions of production. The four categories of technology 4.0 in Table 1 (Tech1 to Tech 4) can be positioned according to the two main levels of industrial activity (Figure 3): at the upper level, with tactical activities of planning and supervision, and at the lower level, the operational activities of product manufacturing.

Industrial activities at the operational level are performed by a combination of human agents and machines (H or M or H-M or M-M). At this level, sensor technologies (Tech1) can dynamically collect information related to the state of material resources (IoT: temperature, hydrometry, presence, etc.), to the operator functional states (biofeedback: heart rate variation) or to the characteristics of the production processes. At this level too, the human can be assisted in performing physical tasks (Tech4).

The collected data of the situation of production are treated at the tactical level by human or artificial agents, which manage the diagnosis and the adaptation of the operational level. This process is performed by comparison with models (individual’s long-term memory, organizational memory and computer database). This comparison process, supported and enriched by big data and machine learning (Tech2), allows:

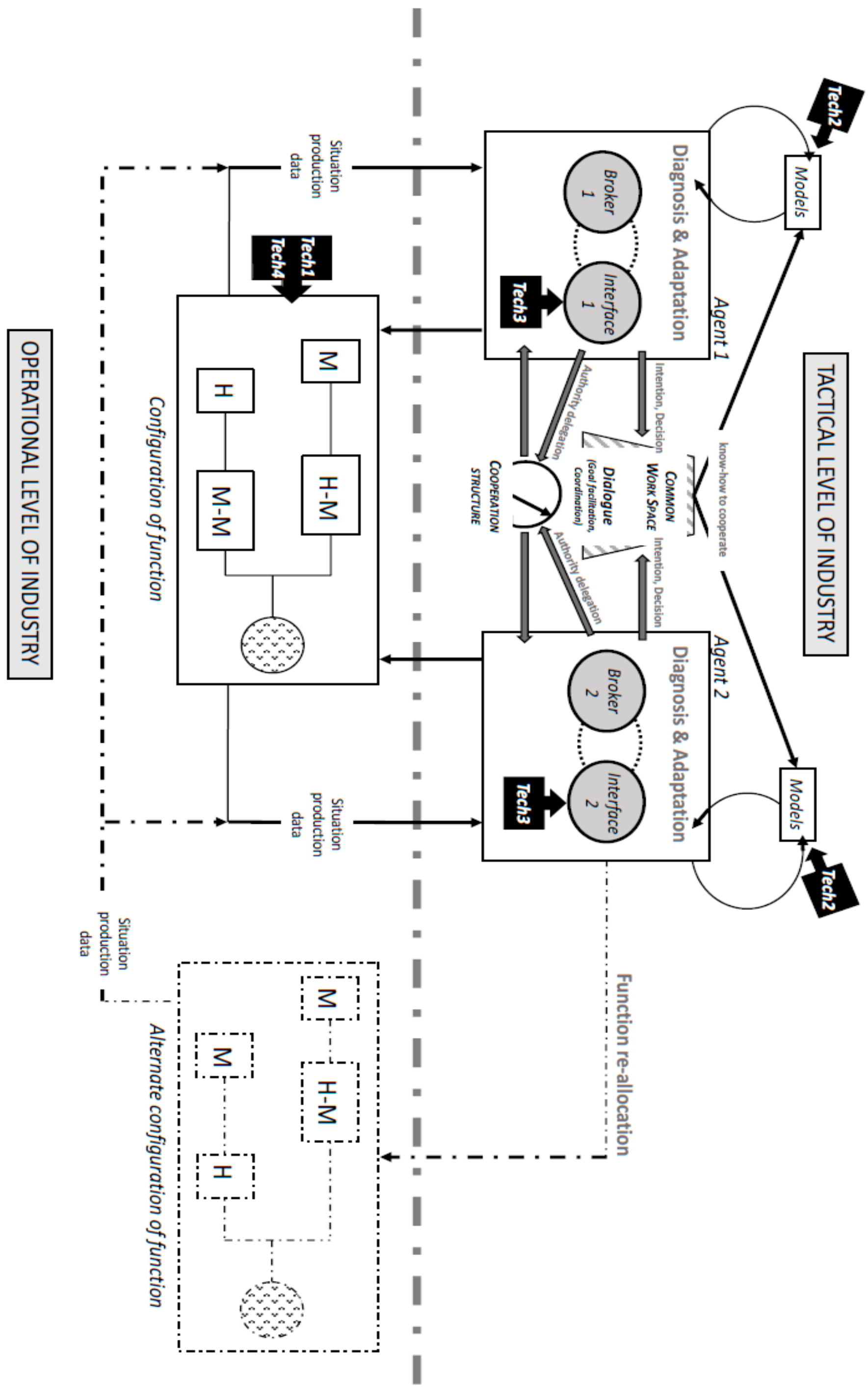

Figure 3. Framework for modelling operator 4.0 with a human-machine cooperation perspective, according to industry 4.0 technologies and functions of production

- To evaluate the current situation (diagnosis), by measuring the quality of the COFOR ("interface" property of supervisory agents 1 and 2) and the relevance in the distribution of the functions at the operational level ("broker" property of supervision agents 1 and 2). The diagnosis is based on the mutual understanding of goals and the compliance with procedures, and focused on short term operational activities of production (corresponding to cooperation in action of Hoc, 2001);
- To generate system adaptations from the results of these assessments. The adaptation criteria must satisfy the maintenance of a common reference system (Hoc's cooperation in planning, 2001) and may lead to re-allocations of functions at the operational level (broker property of supervisory agents);
- To infer new rules to improve models and the know-how to cooperate (Hoc's meta-cooperation, 2001) through a learning process.

At this tactical level, decision-making on adaptations of the industrial system also involve a dialogue between supervisory agents, which feeds a Common Work Space or CWS (for more details on the construction dynamics of the CWS, see Millot & Pacaux-Lemoine, 2013, Fig. 11). This dialogue between supervisory agents then makes it possible to determine the cooperation structure, horizontal or vertical (see Millot & Mendiaux, 1995, Millot & Pacaux-Lemoine, 2013), which will define the role and authority of each agent for the operational regulation of the industrial system (information sharing, task sharing). The results of this "horizontal" dialogue, resulting in the delegation of authority to one or the other of the supervisory agents, will then be transmitted "vertically" at the operational level, in order to:

- Coordinate the operating agents with each other according to a mode of cooperation adapted to the situation (augmentative, debatable or integrative, see the Schmidt taxonomy);
- Maintain COFOR by facilitating perception, understanding and projection of future states of the situation, including the context of the task in which the information can be transmitted (Tech 3), based on the same information transparency rules.

This model of operator 4.0, with a human-machine cooperation perspective, replaces the new technologies of industry 4.0 as input or assistance for managing the dialogue between agents and coordinating the joint activity. It aims at supporting the definition and the analysis of new activities of operators 4.0. The next section will notably study the order picking activity. This specific activity will include both planning and organization tasks for the different production batches to be performed, as well as physical production tasks related to batch packaging.

II.2. Application of the framework to the specific activity of order picking

We consider the activity of an order picker, who can be assisted by all the different kind of technologies presented in table 1. Tech 1 will be composed of biofeedback sensors (smart watch on operator) and IoT sensors (RFID, smart sensors for detecting the presence of empty parcel boxes in storage). Tech 2 consists in calculation capabilities provided by the digital twin (predicting breakdown of production agents from Tech 1 sensors) and the integration of other data (related to customer demand). Tech 3 will support dialogue and communication with augmented reality glasses, pick-to-light and voice-to-pick technologies. Finally, Tech 4 corresponds to a cobot, able to interact with a human agent in a parallel or a sequential process.

The activity of an order picker 4.0, considered as an agent in symbiosis with the four technologies, could be described through the following scenario, designed with the aid of the framework proposed in Figure 3:

- Let consider that the customer demand is increasing. The activity of conditioning (filling and closing parcel boxes according to the customer orders) could be therefore shared between human and cobot (Tech 4) with a parallel organization (in the augmentative mode of Schmidt's cooperation taxonomy, where each agent is making a complete box at the same time).
- The detection of production problems is enhanced with the aid of Tech 1 sensors. A Problem can be related to operator overload, or wrong cobot behaviour for specific production to fill in the boxes.
- Based on the history of incidental situations experienced at this picking workstation, machine learning and simulation capabilities (Tech3) will help for deciding between different improvement strategies. Considering a problem of wrong cobot behaviour on the filling of specific products into boxes, a choice could be proposed between:
    - Switching to a sequential organization (the human agent, in addition to his/her own parcel boxes, will also fill the boxes of cobot with the specific products, transforming this task into an integrative cooperation),
    - Stopping the production, to teach the cobot with the correct behaviour

  The data mining achieved of the factory database thus help for enrich situation knowledge, and it can be therefore considered a component of the metacooperation level of Hoc's HMC model.
- Finally, the operator can be alerted with augmented reality (smart glasses) that there is a performance decrease of the cobot, or that a new function allocation is proposed between agents. It is also assisted in his/her manual actions by voice or by light to choose the correct products or the rightsized parcel box.

Discussion

The conceptual proposals in this paper aim at complementing the rather technocentric approach of recent research works (Romero et al., 2016 and 2017, Fantini et al., 2018) on the place of humans in future smart, connected and agile factories. The proposed modelling framework aims to better position, or even design, the new activities of operators 4.0, seen as a joint physical and cognitive production system. This notion of symbiosis is crucial in the emergence of smart factories: the new technologies should not replace human operators but help the transformation of workstation to allow operators to gain higher flexibility and power of decision.

However, we could go further in this approach, by analysing in more detail the cognitive dimension of the joint activity. The question of the "social" organization of the operator 4.0 (Romero et al., 2017) could thus be deepened with methods such as the CWA of Rasmussen, and in particular the phase of socio-organizational analysis.

The management of human-machine dialogue should also be further explored, so that the common ground can be optimized between the two agents, thus guaranteeing the performance of the joint system and the quality of decision-making. In this sense, it would be interested to work on an enrichment of the model presented here with the concept of informational transparency, developed in particular around 2 models (Lyons, 2013, Chen et al., 2014):

- The first model concerns the transparency of the autonomous and intelligent agent towards the operator ("robot-to-human transparency") and can be detailed using the SAT of Chen et al. (2014). Situational Awareness-Based Transparency (SAT), uses Endsley's Situation Awareness model to define three levels of agent-to-human transparency, ranging from disclosure of basic information (reporting of actions and goals), sharing of explanations on the reasoning used (constraints considered, methods chosen), until the transmission of elements on the consequences of actions in progress (projection, uncertainty, risk);
- The second model concerns the level of information that the agent has and can communicate about the state and the behaviour of the human operator ("robot-of-human transparency"). It must include modelling and assessment of the operator's or team's condition (stress, fatigue), goals and behaviour (social purpose), and must also be based on an understanding of environment and the structure of the performed tasks.

The level of transparency would also influence the trust that humans would place in the machine; the higher the level of transparency, the higher the trust level would increase (Chen, 2014). On the contrary, a lack of access to data can lead to forms of "circumvention" of cooperation and a decline of trust that built up gradually by observation of the behaviour of the agent can lead to misuses. The design of future work must consider these drifts by proposing adjustments of the interface/broker agents according to the use (on the degree of transparency to bring, on the degree of automation, etc.).

Conclusion

Ultimately, the reflection on the industry of the future is in full swing. It mobilizes a lot of research, to address both the technical challenges of implementing new technologies in the plant, but also to consider the sociological, cognitive and ergonomic aspects of this transformation. While some authors have recently reflected on the place of the man in the industry 4.0, the existing frameworks however remain rather technocentric. This is why the current paper attempts to combine these recent works on operator 4.0 with more cognitive approaches, by especially using well-known models of human-machine cooperation.

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