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Frédéric Vanderhaegen, Julian Nelson, Marion Wolff, Régis Mollard

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From Human-Systems Integration to Human-Systems Inclusion for use-centred inclusive manufacturing control systems

F. Vanderhaegen[1,2], J. Nelson[3], M. Wolff[3,4], R. Mollard[3,4]

[1]Université Polytechnique Hauts-de-France, LAMIH CNRS UMR 8201 59313 Valenciennes, France (e-mail: frederic.vanderhaegen@uphf.fr)

[2]INSA Hauts-de-France, Le Mont Houy, 59309, Valenciennes Cedex 9, France

[3]Univ. de Paris, UMR 9010 - Centre Giovanni Borelli, 45, rue des Saints-Pères - 75006 Paris, France (email: julien.nelson@u-paris.fr, marion.wolff@u-paris.fr, regis.mollard@u-paris.fr)

[4]ESTIA-PEPSS, Technopole Izarbel, 64210 Bidart, France (email: m.wolff@estia.fr, r.mollard@estia.fr,)

Abstract: The paper discusses about human-systems inclusion as a new way to take into account human factors on systems engineering. This process applies not only principles from human-supported by automation but also those on automation-supported by human to improve autonomy between humans and machines and autonomy between people. The main concern of human-systems integration is the consideration of a low number of future users in the design process or of the feedback of a majority of users in the evaluation process. Human-system inclusion considers that the system has to take into account and adapt to all users whatever their social, economic, physical or cognitive state, or disability. The concept of "human in the loop" or of "human touch" is usually limited to the definition of the role of humans and machines. It does not consider dynamic variability of users and systems abilities, and anticipate the feasible development of autonomous machines by reducing progressively human engagement in the control and supervisory loop. The paper presents both integration and inclusion concepts for Industry 4.0, and then suggests some challenging perspectives for use-centred inclusive manufacturing control systems in terms of opportunities and threats.

Keywords: human-systems integration, human-systems inclusion, human factors, Industry 4.0, inclusive design

1. INTRODUCTION

One of the main challenges of future smart manufacturing control system with supports as Enterprise Resources Planning (ERP), Supply Chain Management (SCM), or Supervisory Control and Data Acquisition (SCADA) is the application of the concept "human in the loop" or "human touch". These systems can then adapt themselves to the human state in order for example to share tasks between humans and machines and make the automation degrees variable in case of the temporary or permanent degradations of human abilities or machine limits. In human-machine shared control models as those presented on (Sheridan, 1992; Parasuraman et al., 2000; SAE, 2016; Powel et al., 2016), the entire autonomous system principle appears as a technical feasibility limit and reduces progressively tangible supports to interact with humans. The design of future systems as smart manufacturing control system may not depend on the definition of the degree of automation but on the interdependencies between human-machine system components (Johnson et al., 2017).

Cooperation between humans and machines is often seen as a solution for such a purpose. It aims to control possible interference between goals and to make the activities of the other easier (Millot, Hoc, 1997). However, it can also be required by decision-makers when they ask for supports to achieve their own activities and multilevel cooperation activities can occur (Vanderhaegen, 1997). Know-how-to-cooperate is a dedicated competence for making them cooperate (Millot, Lemoine, 1998; Millot, 2007). Human-systems integration process usually aims to define systems that cooperate with their users. However, learning and competition are two other ways to improve individual or collective activities (Vanderhaegen, 2019). Know-how-to-learn or learnability is then new features for system engineering in order to make systems more flexible and adapted to any users and any situations. This can improve the cooperation process between people and machines when skills are variable over time. Its implementation on future system will facilitate human-systems inclusion. Inclusion concept was developed by educative sciences and consists in adapting a given process by taking into account individual characteristics instead of collective or standard goals. The paper proposes a discussion about human-systems inclusion. Section 2 reminds the human in the loop concept for Industry 4.0. Section 3 discuss about the integration process versus the inclusion process for smart manufacturing control system. The last section proposes possible opportunities and threats about the implementation of inclusive manufacturing control system in the view of the learning from system uses.

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2. HUMAN IN THE LOOP CONCEPT OF INDUSTRY 4.0

Regarding human factor viewpoint, Industry 4.0 requires the development of cognitive, sensorial and physical supports to assure the workers' wellbeing or safety, to improve the human control and supervisory of more complex factories, to avoid high physical or cognitive workload, and to take into account human behaviors, satisfactions or expectations (Pfeiffer, 2016; Romero et al., 2016a; Peruzzini et al., 2017; Rauch et al., 2019). To do so, Operator 4.0 concepts, i.e. human factor engineering for Industry 4.0 are concerned by involving such cognitive, sensorial or physical interactions (Romero et al., 2016a; Ruppert et al., 2018; Segura et al., 2018):

- The Virtual Operator concept takes benefits of virtual reality technologies to develop virtual dummy or digital human models. The development of such digital models based on anthropometric or physical criteria for instance aims at assessing workplace ergonomics, human performance or product use in a virtual environment (Poirson, Delangle, 2013; Zülch, 2014; Laudante, 2017).
- With the Healthy Operator concept, wearable supports monitor human health in real-time. However, these supports can also monitor on-line user behavior by assessing stress, workload, attention or emotion with eye-trackers for gaze and pupil activity analysis or connected watch for heart activity analysis for instance (Peruzzini et al., 2017; Vanderhaegen et al., 2020; Rauch et al., 2019). They can be useful for self-monitoring of health care management or for adaptive automation to implement shared control between human and machine.
- The Smarter Operator concept increases human abilities by supporting them with smart devices as intelligent conversational supports.
- The Collaborative Operator concept makes collaboration between humans and smart and cooperative devices possible.
- The Social Operator concept is linked with the use of social networking services.
- The Augmented Operator concept uses augmented reality technologies based on visual computer technologies or physical support technologies as exoskeleton to assist human physical activities or system to support human decisions or actions.
- The Analytical Operator concept includes Big Data collection, organization and analysis for a better understanding or forecasting of the digital system state by human operators. However, Analytical Operator cannot be limited to the control or monitoring of a large set of data related to the Big Data concept, but also to weak signals associated to a low number of useful data

These concepts are then suitable for studying the "human in the loop" or "human touch" in term of engaging human contribution of future smart manufacturing control systems in terms of benefits, costs or deficits. Human-automation symbiosis will increase or support human capabilities and system flexibility (Romero et al., 2016b). In this context, human work is usually supported by machines or Cyber-Physical Systems (Ruppert et al., 2018). Nevertheless, a very high level of such a symbiosis can also became an obstacle for performance achievement when a symbiotic component fails or is missing (Vanderhaegen et al., 2019). Two main ways can prevent or recover such a problem: human-systems integration processes or human-systems inclusion ones.

3. INTEGRATIVE VERSUS INCLUSIVE MANUFACTURING CONTROL PROCESS

Literature about manufacturing systems of the future is not stingy with the definition of their operational features by increasing the role of autonomous systems. Indeed, future factories require being smart, resilient, green, safe, reliable, efficient, interoperable, connected, autonomous, digital or sustainable for instance. The design of such systems can applied principles from human-systems integration that combines both human-centred design and systems engineering processes to define shared control between users and autonomous systems. It rather defines systems that correspond to classical requirements from standards and that make satisfaction to a majority of persons. Human-machine systems are designed by taking into account feedback from few users and are usually validated when positive results about criteria like acceptability, performance, or usability are obtained by an important number of users, Figure 1. As a matter of fact, people who consider a system as unsuitable must adapt to it because it has been validated by a majority.

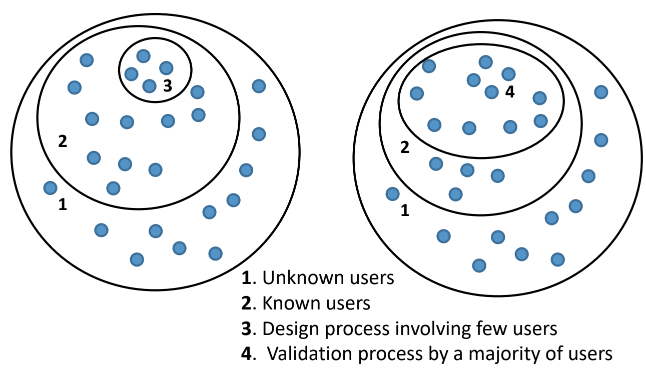

Fig. 1. User-centred design and validation on the human-systems integration process.

Some human-systems integration approaches focus on team work based design involving interdisciplinary process from social and engineering sciences to make system capable to cooperate and coordinate operations with humans and to control economical, social, and maturity factors (Tvaryanas, 2006; Boy et al., 2013; Kozlowski et al., 2015; Boy, 2000).

However, the ambitious objective for future factories is reminiscent of the "all inclusive" concept developed in the tourism industries which aim to optimize the occupancy rate of their means of production of services (Bilgili et al., 2016). The "all inclusive" principle was also used on (Vanderhaegen, 2019, 2021) to develop systems capable to adapt themselves to human demands whatever the social, cognitive or physical facilities of their users. Such system plasticity is inspired on the inclusion process by proposing advanced supports that adapt themselves to any levels of autonomy without any discrimination. Regarding educative programs, integration process consists in focusing on collective purpose and interest whereas the inclusion one puts the individual needs and capacity as a priority (Vislie, 2003; Plaisance et al., 2007). Inclusion views the limits and abilities of a system as an added-value for inclusive design process. It considers that any experience from any individual can be beneficial for the others. Concepts as inclusive design, inclusive transport or inclusive manufacturing were developed for such purpose and can be another way to include human factors in system engineering.

Human Factors / Ergonomics (HFE) has long been concerned with optimizing the fit between system design and user characteristics (Karwowski, 2005). Most often, this implies providing a clear definition of the system's intended end users and carrying out user research to identify their characteristics, goals, and the system's intended context of use (ISO 9241-210, 2019). Optimal design from a human-centred perspective thus implies that the system's design allows task goals to be met regardless of this variability. Inclusive design takes the point of view that failure to take into account this variability may exclude some of the system's end users, and that it is a worthwhile goal to design systems that are usable by a broad variety of users and use cases (Clarkson et al., 2003; Waller et al., 2015). Although this concept is primarily used in the context of designing systems and environments that are suited to disabled users, it is also relevant to HFE goals as a whole.

"Autonomation" or "Jidoka" principles are mainly related to integration of system learning ability when machines are capable to learn from human touch (Romero et al., 201; Sarkar, Sakar, 2020). Inclusive design principles focus mainly on the autonomisation or empowerment to design learning technical supports to increase the autonomy of workers, or of users as disabled or ederly people (Newel et al., 2000; Politis et al., 2018; Kildal et al., 2019). Both autonomation and autonomisation concepts require learning ability of systems in order to make adaptation to any users, any use and any situation possible.

4. CHALLENGES FOR USE-CENTRED INCLUSIVE MANUFACTURING CONTROL SYSTEMS

Table 1 lists the challenging opportunities and the possible threats for the use-centred manufacturing control system process when applying the inclusion concept.

Computer-based systems are obviously useful to support human activities, to limit risk occurrence, avoid accidents, to protect people by activating active or passive safety barriers, or to assist disabled or elderly people. When pandemic situation as COVID19 occurs, it can be interesting to make manufacturing control system autonomous and supervised remotely by human supervisors to limit risks of contamination for instance.

Reconfiguration of human-systems organization is then required not only at the functional level but also at the structural one by transforming them into high flexible system. From an HFE perspective, such a reconfiguration will likely lead to a reconfiguration of human activities. Therefore, successful implementation of smart manufacturing will require not just simulating future activity, but constructing future scenarios in order to structure such simulations. This anticipation of future use can be supported by creativity techniques (Nelson, Buisine & Aoussat, 2013; Nelson, Buisine, Aoussat & Gazo, 2014).

Table 1. Opportunities and threats for use-centred inclusive manufacturing control systems.

Opportunities	**threats**
Mutual recovery of lack of skills	Shortage of skill workers in case of machine failure
Training and education for every skill levels of workers	High dependency on technology
Machines supported by humans and humans supported by machines	Reduction of human work engagement (robotization of humans, lack of human creativity
Creation of employment for everybody	Long-term unethical impact
System plasticity	Increasing of social divide
Pedagogical abilities on machines	Erroneous conditioned learning
Respect of human rights	Contaminated learning

One of the main multimodal interaction supports for such functional and structural dynamic configurations will be built around computer or smartphone screen, and more precisely touchscreens (Gorecky et al., 2014). Nevertheless, despite the interest for maintaining human in the control and supervisory loop, the long-term use of screen can transform people into "digital idiot" and generate serious consequences on health, behavior or intellectual abilities (Desmurget, 2019). Indeed, on current young generation, this use can facilitate obesity, cardiovascular problem, reduced life expectancy, aggressiveness, depression, risky behavior, language problem, concentration problem or learning capacity reduction for instance.

Short-term, medium and long-term consequences of systems and recovery control processes have to be studied for any smart manufacturing control system to face any situation with any physical or mental levels of workers. The concept of weak signal is an interesting way of investigation to identify improbable scenarios of dangers of automated systems. They are for instance border-line tolerated conditions of use when hazardous operational situations of use exist and are accepted by users in order to achieve production goals (Polet et al., 2003). They are also dangerous interferences between humans and machines in the course of shared control or hazardous affordances when an interface designed for a given goal is used for another one (Vanderhaegen, 2014, 2016).

The development of more complex manufacturing control system will confront two main interdependent issues:

- The continuous learning and education requirement to empower workers (Bonekamp, Sure, 2015; Faller, Feldmüller, 2015). Intensive automation of manufacturing system may decrease low skilled job demands but increase high-skilled ones with new missions that have to be covered by adapted learning and training programs.
- The continuous redefinition of the role of human factors facing potential lack or shortage of qualified workers (Kagermann, 2015; Benešová, Tupa, 2017).

To do so, it is urgent to study the engagement of the workers in the manufacturing system design process by personalizing competence development and learning (Kadir et al., 2019; Kaasinen et al., 2020). Several learning methods can be implemented (Vanderhaegen, 2012; Vanderhaegen, Zieba, 2014; Enjalbert, Vanderhaegen, 2017; Chen et al., 2019; Zhang, Li, 2019; Vanderhaegen, 2019). However, the resulting system are not free of problems as erroneous conditioned learning due to a wrong use of similarity functions or as contaminated learning by adversarial data, data poisoning, fake data, data loss or information withholding. Plasticity of systems relates to their ability to cooperate, to learn or to compete in order to optimize individual or collective goals by implementing pedagogical features in order to explain or justify any decision and to identify as soon as possible any wrong process (Vanderhaegen, 2017, 2019). Another opportunity for the implementation of human-systems integration to future smart factories is the respect of ethics on several factors as mobility, accessibility or intervention on systems (Gallez et al., 2018; Habibovic et al., 2019, Kanellopoulou et al., 2019; Stramondo, 2019; Vanderhaegen, 2021). Feedback analysis of experience from a minority of users is valuable to improve system design and reduce social discrimination (Vanderhaegen, 2021). Figure 2 gives an example of the application of the concepts of use-centred inclusive manufacturing control systems in case of industrial failures.

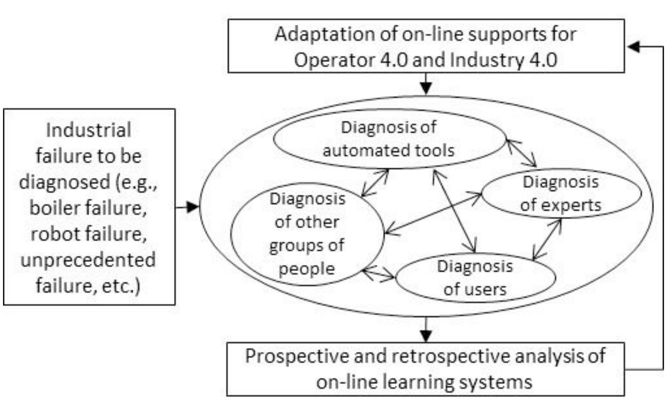

Fig. 2. Example of application to industrial failure diagnosis.

It implements concepts from Industry 4.0 and Operators 4.0, and analyses convergent and divergent feedback from different networks of decision-makers, including viewpoints from minorities and majorities. On-line learning process can then be developed to improve user's training programs, interaction devices, knowledge of decision-support systems, etc. The possible opportunities and threats of system uses have to be studied regarding short-term, medium-term and long-term impacts and to adapt the learning processes accordingly. Prospective and retrospective analyses during the design and the use processes have to consider any experience as worth being learned and implemented if necessary.

5. CONCLUSION

The paper proposed a review of questions related to systems engineering and user-centred design applied to smart manufacturing control systems. The inclusion process was compared to the integration one. It takes advantages of the individual quality in order to improve the collective interest. Abilities for co-learning and self-learning are then required and can improve activities as cooperation, competition or explanation between humans and machines. The discussion focused then on the use-centred inclusive manufacturing control system. The paper concluded the discussion by listing challenging opportunities and possible threats related to such system. Future works will study the feasibility of the application of these opportunities or of the control of these possible threats in a simulated or field industrial process.

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