Human-Machine Interaction in Industry 4.0 and Beyond

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Abstract:
Manufacturing represents around 15% of the value-added and total employment in Europe. It is also of great importance to the EU and its R&D efforts, to which almost two thirds is contributed by manufacturing. Many of these efforts have so far been focused on automating manufacturing and the use of smart devices, which both experts and the general public have since named Industry 4.0.

While Industry 4.0 focuses mostly on connectivity and data analytics, the focus will shift more towards the human component in the future. The reason is, on one hand, in the growing complexity of the manufacturing processes. There is also growing awareness that in most industries the operators cannot be fully replaced by machines in spite of the growing power of automation supported by artificial intelligence. In the context of the fluctuating labour force and a need for new skills and knowledge, the question is how to include the operators in the control process in the most efficient manner. There are two important aspects of that problem. One is training the operators and shortening the learning process, which becomes essential for the overall productivity. The second aspect concerns the efficient interaction between the operators and machines.

The aim of this paper is to review the present position of the operators in manufacturing and the enabling technologies supporting their role in automation. A glimpse of new approaches to decrease the learning curve of the operators will be addressed, such as various potential training systems and required knowledge management methods in a paperless, more effective future. That is complemented by new ways of adapting human-machine interfaces and novel ways of implementing the user experience.

Keywords:
human machine interface, user experience, operator, training, Industry 4.0, Industry 5.0

1 Introduction

About one in seven jobs in the European Union is provided by industry. It provided 15% of total employment and value-added in 2017 [1]. Manufacturing accounts for two thirds of the total R&D activities and provides half of productivity growth. That represents around 65% of both exports and imports to and from the EU. It is reasonable to assume manufacturing will remain a vital sector in the EU for its innovation, productivity, and trade potential [1].

The collapse of global supply chains created by the COVID-19 pandemic has stressed the importance of keeping at least a part of every manufacturing sector in the region. This process has much to do with educating and managing human resources. Unlike manual labourers, operators of modern, automated manufacturing require higher skills and therefore command higher wages [2].

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After the recession following the 2008 financial crisis, low-skilled workers had a much harder time finding a new job compared to their medium or high-skilled counterparts, especially in manufacturing. There was a significant employment shift towards highly educated workers starting in 2011 [3]. Automation systems became more and more complex, so the demand for skilled workers went up with the complexity. As a result of advanced manufacturing, there was also an increase in quality control and standards [4].

Workers could be helped in the transition process by being enabled to acquire the necessary skills for employment. Skills and competences of the future are not even defined yet, so there is no syllabus that can teach people how to acquire them. Businesses could help their employees achieve the know-how in time by retraining them and considering multi-sector skilled partnerships. Hence, they can use the full potential of the same collaborative models that support many of the currently ongoing technology-driven business changes. This global industrial transformation is a reality and there is wide consensus that Europe should embrace this change while making sure it works for everyone. [5]

Plenty of institutions such as the McKinsey Global Institute (2018) [6] and PwC (2018) [7] have attempted to gauge the likely extent of automation over time. However, these studies mainly focus on the technical feasibility of substituting humans with machines. In fact, not all relevant technical and non-technical factors are considered, so that the impact of automation is overestimated in a sense of automation reducing the need for human participation in plant management and control. That means not all the predicted job losses will actually happen, but the character and the requirements of the jobs will change. Not every technologically feasible automation is economically rational. If all the jobs that could be automated were indeed automated, the required investment would be so extensive that it would be unrealistic from a macroeconomic perspective [4].

To better perceive the relationship between human operators and automated systems, Seymour Papert coined the very helpful concept of technocentrism. He considers technocentrism a combination of techno- and egocentrism, manifested as a "fallacy of referring all questions to the technology" [8]. *Anthropocentrism*, on the other hand, is a concept advocating that human beings are the most significant entities in the world [9]. After a period of belief that automation can entirely replace humans, soon followed by disappointment, industry shifted to focus more on "human-centred automation." An important step was the introduction of ISO standard 13407 in 1999. It is based on the philosophy that empowers people to design for people and address their core needs while doing so. In the context of man-machine interaction, technocentrism explores the limits on what technology can do, whereas anthropocentrism tries to centre the interaction around humans.

The aim of this paper is to present an ontology of the human position in automation from the point of view of ideas of technocentrism and anthropocentrism. The main concepts and categories will be reviewed in Section 2. Section 3 focuses on the particular issues related to the interaction between humans and machines. The conclusions section summarises the main highlights.

2 The ontology of the human-machine relationship in automation

2.1 Historical perspective

With each industrial revolution, the role of humans in the manufacturing process continually decreased. It all started by replacing the manual procedures with machines powered by steam and water (Industry 1.0), and later on with the widespread adoption of electrical power (Industry 2.0). In the next phase, In-

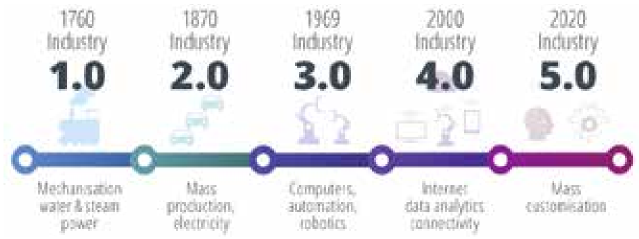

Figure 1 : *Evolution of manufacturing through industrial revolutions [12]*

dustry 3.0 came with a shift to digital electronics, which brought intensive automation especially on the physical level (e.g., controlling speed of the machines, movements of robots, etc.) [10].

Industry 4.0 arrived with the advancements in artificial intelligence, where decision-making has been visibly intruded by the machines, thus supporting the technocentric paradigm. It has its emphasis on interconnecting the existing technology through the Internet of Things (IoT), which has access to real-time data. Industry 4.0 allows business owners to better control and understand every aspect of their operations, as well as make full use of instant data to boost productivity, improve processes, and drive growth [11]. The question is: with such rapid and turbulent changes, what will the place and role of human operators in the future be?

The forthcoming Industry 5.0 is going to play a significant role in our society. It will complement the existing Industry 4.0 approach by focusing back on humans. It seeks to, in some respects, redefine industry by directing research and innovation towards the transition to a sustainable and resilient European industry. The concept itself was defined in July 2020. Its approaches are already a part of new policy initiatives by contributing to three of the European Commission's priorities for 2019-2024: "An economy that works for people," "the European Green Deal," and "Europe Fit for the Digital Age" [13].

A similar concept is Society 5.0, proposed by the government of Japan in 2016, that "will be able to balance economic advancement with the resolution of social problems by providing goods and services that granularly address manifold latent needs regardless of locale, age, sex, or language" [14].

Both Industry 4.0 and Society 5.0 emphasize the use of technology and entail a top-down, state-led approach with collaboration between industry, academia, and the governmental sector. The visions differ in the use of cyber-physical systems measuring the outcomes or scope of the intended future effects of technological innovations. While Industry 4.0 calls for a manufacturing-centric industrial revolution that does not account for its impact on the public, Society 5.0 focuses heavily on exactly the public impact of technology and the need to create a better society that caters to diverse needs and preferences [14]. One could therefore view Industry 5.0 as a logical continuation of Industry 4.0 with the human-centric ideals of Society 5.0 at its core.

2.2 The role of operators

Human operators are a fundamental component of the production process. Located on the factory floor, they are in charge of supervising the machinery used in the production process, as well as taking proper action whenever needed (especially in the presence of alarms and faults) [15]. Even with the increase in factory automation, they remain crucial for conducting manual assembly or maintenance procedures [16].

With Industry 5.0 being a turning point in how humans and automated systems interact, operators will be in a closer relationship with intelligent machines such as collaborative robots (cobots) [17]. Due to directly interacting with humans, human-machine interactive systems require safety certifications based on thorough risk analyses that introduce additional costs for the manufacturers in case of any change of the application. However, the adoption of cobots in manufacturing is a financially risky choice due to the lack of consistency and predictability of the market [18].

2.3 Operator-machine interaction

The operator-machine interaction is in fact a key point in automation systems. If not designed properly, a system requires an extended amount of time for being operated, and with the staff freedom to change employment at any time, it prevents the system from ever being used at its full potential [19].

Although there are no broadly available studies on how human operators manage and perceive their interaction with machines, equipment is getting more and more complex, resulting in an increased need for skilled workers [31]. The operations teams are rarely included in the design process of human-machine interfaces (HMIs), partly due to a significant increase of product variants that have shorter product life cycles [16]. That causes the operators to be disconnected from the process itself, leading to a high dependency on the system to signal any potential unexpected behaviour through alarms or process interlocks [19].

Humans tend to favour interacting with physical objects. Under real life circumstances, the use of both procedural and motor skills is crucial for the safety and efficiency of the manual procedures [16]. The AVEVA Group's situational awareness whitepaper of 2014 points out it is common to hear that it will take about two years for an operator to become proficient in the use of a system [19].

Following the example from the consumer electronics industry, automation system designers have turned to a more user-centric approach. It follows that in order for us to comprehend the experience of the operator-machine interaction, we need to understand the user first. We need to make sure that the user can answer the question "Who does what, when, and under which condition?" [20]. This is to ensure that the system they interact with is quick and intuitive, and that the system itself enables easy reversion of actions, or a simulation mode is implemented to motivate the operator to explore the system and reduce their stress when doing so [16].

2.4 Situational awareness (SA)

Situational awareness relies on the perception of information in the environment, interpretation of its meaning in context, and anticipation of its consequences for an appropriate response [21]. There are three distinct levels of SA. The transition between them is done through cognition, judgement, and decision-making, respectively [19], as seen in *Fig. 2*.

Situational awareness can complicate our work instead of simplifying it if not used adequately. In one study [22] that tasked users to explore the virtual environment and locate victims and fires within a short period of time, it was shown that sometimes more data means less understanding. In critical situations when a quick response is needed, the user might be overwhelmed by a big number of messages received and act on less critical information. If we add a complicated query in the background as well, usability of the system is reduced even further [22].

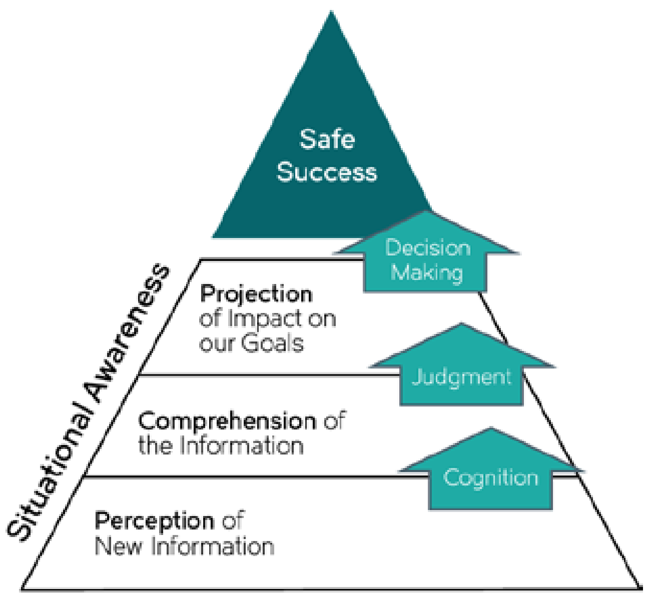

Figure 2 : *Levels of situational awareness [19]*

Situational awareness is an important concept that can enhance the overall interaction between operators and machines. The use of situational awareness has an important role in the design of HMIs.

There has been a lot of research done on situational awareness theory, design, training, and measurements since the 1990s. Although originally met with scepticism, interest in the topic grew quickly from its initial start in aviation into various other fields. It has since taken hold in the fields of cognitive psychology and human factors, becoming a part of the mainstream consensus despite not having an agreed-upon definition [23].

2.5 Manufacturing execution system (MES)

An MES is a platform where, based on information from the process and requirements imposed by the production, targets are transformed into decisions.

Manufacturing execution systems aim to increase the transparency of manufacturing systems by performing data acquisition from the manufacturing processes, reactive planning, and bi-directional communication to both enterprise resource planning (ERP) systems and shop floor systems, controlled by supervisory control and data acquisition (SCADA) systems [24].

Both ERP and SCADA systems are responsible for gathering and analysing real-time data [25]. SCADA does not enable us to track the detailed transformation of raw materials to finished goods through the entire production process. In fact, it provides specific information at individual stages, such as effectiveness, product quantity, and average production speed. ERP needs a system capable of dealing with both real-time data and transactions to make sense of the overwhelming amount of information at the production level. Here is where MES comes into play [26].

An MES integrates several applications that are already used on the factory floor with each other, as a part of a bespoke system, as well as with corporate information and process control systems [27]. These applications provide decision support to the production processes and create a consistent view of production data. They also bring more benefits with them, such as traceability and error prevention of production, increased overall equipment efficiency (OEE), and others [28].

An MES is purely a technical entity, becoming more and more powerful in terms of decision support but requires exchange of information with the operators. For an operator on the factory floor, the interaction with the MES should be intuitive, concise, and unambiguous; especially if they only see a partial picture of the processes running in the plant on the physical level, as well as of the processes related to data processing, information elicitation, and machine decision-making. It is important to understand where to focus our attention while designing MESs with the goal of maximising the efficiency of inclusion of the operators in the system control loop.

3 What matters for efficient inclusion of the operator in the loop?

As defined by the National Institute of Standards and Technology of the United States, a human-machine interface (HMI) is the hardware or software through which an operator interacts with a controller, that can range "from a physical control panel with buttons and indicator lights to an industrial PC with a colour graphics display running dedicated HMI software" [29].

The design of effective and easy to use human-machine interfaces is an important component of production efficiency [15]. As established in the previous section, the role of human operators remains crucial, so the design of new HMIs is considered to be a key challenge for the new industrial service solutions [30]. A well-designed human-machine interface provides support in a way that is effective and easy to understand, by addressing operators' needs and difficulties [31].

Aranburu et al. [32] suggest that new methods for evaluating the user experience when interacting with industrial HMIs are needed. These methods need to focus on increasing the efficiency and effectiveness of the task execution, while generating positive emotions in operators, so they are more motivated in their learning process [32].

3.1 User experience (UX)

User experience (UX) has its focus on "having a deep understanding of users, what they need, what they value, their abilities, and also their limitations" [33]. It goes beyond system functionality and usability, but there is a different perception of it between the scientific and academic fields. In the scientific community, there is a bigger emphasis on experience-related factors, whereas in the industry, the efforts focus on practical and functional aspects of the experience, such as usability, novelty, or the life cycle [32]. In *Fig. 3*, created by Peter Morville, we can see one interpretation of the several aspects of UX.

Currently, the human-machine interfaces focus on providing the operator with control over the production processes and access to relevant information [35]. Usability studies can show us how easy

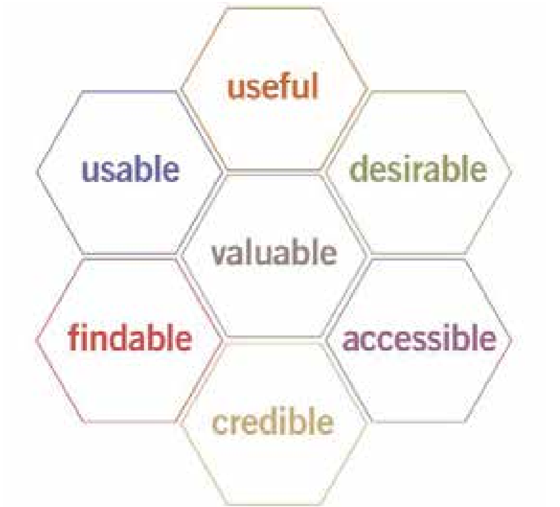

Figure 3 : *User experience honeycomb [34]*

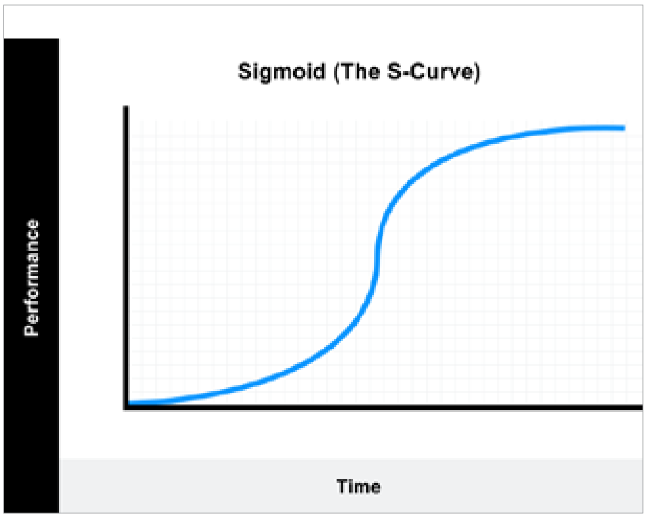

Figure 4 : *The model of learning curve [36]*

or complicated using an interface for an operator is [15]. Sometimes products that directly affect the user's experience, such as a computer mouse or a keyboard, might be omitted when creating the interface [30].

Recent technological advancements raise the question of what can be improved and how to increase the interaction capabilities of the operator with the human-machine interfaces. In one paper [35], the authors propose a workstation-operator interaction that has the capability to adapt the ongoing interaction with the user, to improve performance, safety, well-being, satisfaction, and production measures [35]. Another study [30] proposes the implementation of an experience context capturer (ECC). That is a "user centred tool that analyses the user experience context within the industrial HMI environments and its influence on the development of positive experiences" [30].

3.2 Learning curve

A learning curve is defined as "a correlation between a learner's performance on a task and the number of attempts or time required to complete the task," and it can be represented by an injective function on a graph. The theory proposes that the more the learner repeats the task, the better their performance gets. In industry, the learning curve can be used to track the manufacturing costs related to workers' performance. Due to the varying speed with which the user learns throughout the process of achieving proficiency, the sigmoid curve model is most representative [36].

Most current human-machine interfaces come with a major disadvantage: they need to be operated by an expert who has to complete their tasks and set up the machine through the user interface. These interfaces tend to be too complex for the less specialised operators. A simple, structured HMI would allow less training to manage the entire process effectively while avoiding wrong decisions and improving operator response [31].

There is a high lack of standardisation of production systems. This implies a higher learning curve, because no common principles and methods are assimilated by the user over time [31]. The standard that defines the key performance indicators used in manufacturing operations management, ISO 22400, specifies a selected number of KPIs in current practice [37]. However, it does not yet cover human-machine collaboration, and it is questionable whether it will in the future [38].

3.3 Training

An important aid in training and getting an operator accustomed to a system are user manuals. They contain detailed, comprehensive procedures about how to operate the HMI. In theory, that means that no other human personnel are required to teach a newly employed operator. In reality, the beginners are still being supervised or shadowing a more experienced operator and require weeks, if not months, to achieve full proficiency, as mentioned by Krajewski [19].

Complex production systems require complex human-machine interfaces that result in complex user manuals. This phenomenon makes inexperienced operators unable to interact with and more experienced operators feel uncomfortable to operate the system. User manuals are the most widespread tool supporting operators in handling critical scenarios, but they are insufficient on shop floors [39]. They cannot predict all possible corner cases of a system's operation, especially for a complicated system with multiple potential fail points. Even proper training cannot cover all possible scenarios.

Many training systems have been proposed for manual procedures (e.g., assembly, maintenance, setup) [40]. However, these systems focus on what the user can remember about the sequence of work steps. Currently, many of the existing virtual training systems focus on providing visual information presentation. For a manual procedure, the acquisition of precise motor skills is a key component that should be present. The operator should receive real-time feedback on their performance for self-assessment. Mistakes in production are not acceptable, but no alternative is provided to learn in most cases [16].

Operators' training is a low-documented topic in both the industry and the scientific communities, which is the same as many other aspects; but this should change. It teaches us how to reduce the learning curve of operators, increase machinery usage efficiency, and reduce potential accidents in the workplace, so there could be more knowledge shared on the topic to help the industry improve.

4 Knowledge Management

Learning is at the heart of problem-solving and decision-making [20]. Whenever one is given an unfamiliar task, time and resources are spent to learn the task before being able to perform it productively. To avoid duplicate work and to enable others to learn from our experience, the knowledge we have gained should be documented. Knowledge management (KM) is the process of creating, using, sharing, and maintaining information and knowledge [41]. After a number of years and new situations, people tend to forget the original solution, so here is where KM comes in handy.

As mentioned in section 3, a common way to keep the knowledge of operating machinery still relies on user manuals that are usually both ineffective and insufficient to allow an operator to gain full confidence in operating the system [16].

There are ways of reducing the need for written materials though, and that is by assessing and improving the usability of the current human-machine interfaces. One proposed way to do that is through subjective usability assessment, more exactly cognitive walkthrough, which uses the following four questions in its process [15]:

1. Does the user (of the interface) understand what one should do?
2. Is the user able to identify the interaction tool?
3. If the user is able to identify the interaction tool, can they understand what they should do to achieve the goal?
4. After the action has been performed, can the user understand the answer?

The previous questions are meant to check all the unconscious phases that a user goes through when using an interactive system, because in the mentioned process, at first, they are given a task, and then are asked to map a list of actions required to complete the given goal. The questions give a good insight into how the task is planned, approached, and later on, how the response received is perceived by the user [15].

Another proposed idea in the literature is to have a social network for sharing knowledge that enables asking questions to other operators, aiming to help especially when faced with unexpected events such as troubleshooting or unscheduled maintenance [39].

The core of user manuals covers basic usage of the system. A way to reduce the necessity of that can be implementing a real-time feedback training, as explained in section 3. However, this kind of a system can only be applied to manual procedures. They have been noticed to be more effective than video-based training systems exactly because of the feedback component that is a crucial key in manual operations in both teaching the user and giving them the required confidence to perform the respective actions in the future [16].

An idea that might help reduce the need for user manuals is a training system for human-machine interfaces. More exactly, in a similar way that some video games are doing it—by not just presenting the information on screen and having you click through it, but instead having a demo/simulation mode. That makes the user actually interact with the system and gives feedback on their behaviour in a similar way to what the active feedback training is doing for manual procedures. This way, we would allow the operator to understand the needed sequence of steps required to perform an operation and allow them to try it out without impacting production. No data would be recorded in the production system, and it would allow them to do a short refreshment course at any moment they feel they need it just to regain their confidence or refresh their memory.

The world is moving to smart devices and appliances. Very few people still read user manuals cover to cover, and that should make us decide carefully what needs to be included in them. For example, the most useful part in the user manual of a coffee machine is the cleaning cycle—a frequent but not daily procedure that, if not done properly, can damage the machine. Because of this, the user needs guidance in completely and correctly executing all the steps for it. Similarly, for HMIs, the most important parts to be covered in a user manual should not be those for regular usage, but rather for troubleshooting. However, it is impossible to cover all potential situations in a classic document type user manual, so there is a need for a more flexible approach, and the end result should be widely available for all operators.

4.1 Workflow

One way to help maintain an operation's defined sequence of steps is with the use of workflow management software. It is a good way to enable knowledge management, since it helps with keeping track of standard operational procedures (SOPs) and improving process efficiency by 40%. It also helps with creating and monitoring KPIs while reducing costs by approximately 30% [42].

Some common functionalities of a workflow management software are prompt notification systems along with detailed reporting, task assignment, controlled access to specific parts of the system, and graphical process modelling. A good workflow-based system can omit errors and replace the user manual by automating all the required procedures. This way, it shortens the learning curve while improving quality and providing good decision support if configured accordingly.

Workflow application is a hot topic in computer application science [43] and has attracted great attention in China amongst other countries, in context of their re-industrialisation strategy [13].

4.2 Digital twins

One way to help workers get more easily accustomed to the interfaces would be to bring the demo/simulation mode from the testing environment, where a digital twin is used to simulate the system [44], all the way to human-machine interfaces. From the operator's perspective, adding a simulation mode with some virtual reality capabilities and a platform to exchange knowledge with their colleagues would both be very beneficial, since operators are located mostly at their workstations, therefore having a harder time to reach other people directly. Such an additional app would however require the management to contact a third-party company that could develop such a mobile software, which would increase the initial costs.

User experience has hardly been studied with regard to human-machine interfaces. However, several methods to evaluate the UX when interacting with HMIs have been proposed, and they are based on the context of the interaction [30].

The three questions posed make us better understand what the user needs to know to feel comfortable when using an interface. The base is, of course, understanding what to operate and how, but it is equally important to understand why that procedure is even needed in the first place, and how it makes the operator feel when they are doing it. People's emotions are often overlooked, but it is important to know how a user feels about their environment and the results of their work. In the end, if we want to fully improve the user experience, we need to be aware of the entire context of the interaction.

Context can be divided into micro and macro user experiences. The first one is analysed from the user's perspective gained while interacting with the system, while the latter one is wider and covers more intrinsic aspects such as their employer and its values, social environment, and culture [30].

5 Conclusions

The paper reviews the potential changes in HMI design to ensure a better user experience for the operator, by both reducing the time needed to master the interface and removing the necessity of a user

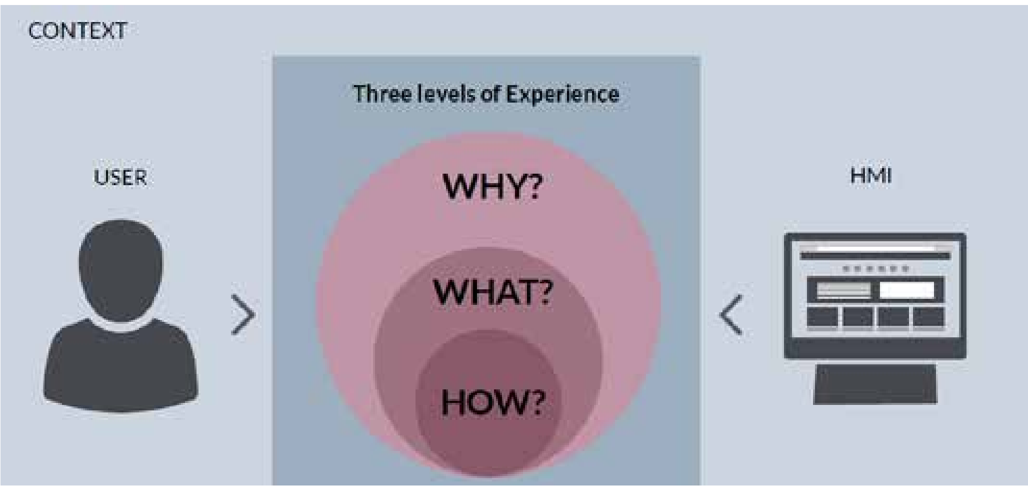

Figure 5 : *User experience in industrial workspaces, in context [30]*

manual. Several training methods and their benefits are presented, as well as how close HMIs currently are to the core tenet of Industry 5.0: being human-centric.

The position of the human operator in the age of rising complexity of manufacturing is discussed in this paper. The main entities which affect the performance of the operator and consequently the performance of the entire manufacturing process are reviewed, and some observations are deduced.

A good human-machine interface allows anyone to know how to react in common usage situations. A really good user experience is tailored to the operator, which makes its development even harder considering that opinions can be linked to one's personality and even in the same context, two assessments of it might have completely different results [30].

Various improvement possibilities were reviewed: what sort of training methods are and can be used, how to handle knowledge management inside the plant, and why to introduce situational awareness and workflow in the automation systems.

We want to raise awareness among designers of industrial automation systems on re-defining the role of the operator in the emerging manufacturing automation paradigms. This work will serve as one of the bases for INEA to continue conceptualising a new generation of HMIs for complex large-scale manufacturing processes.

It seems the future of manufacturing is expected to lead to safer jobs, requiring new and higher skills. Those are already needed, however, due to the existing complex systems that sometimes make even the most experienced operators feel uncomfortable using them, especially when it comes to undocumented scenarios that might appear during usage.

With the fifth industrial revolution, the focus shifts to placing the added-value and well-being of the workers at the centre of the production process, while respecting the production limits of the planet. We should give value back to the people, and with the help of Industry 5.0 guidelines we can do exactly that: promote talent, diversity, and human empowerment.

Literature

[1] bruegel.org/2017/09/remaking-europe (Last accessed 22.03.2021)

[2] europarl.europa.eu/EPRS/140791REV1-Reshoring-of-EU-manufacturing-FINAL.pdf (Last accessed 22.03.2021)

[3] Overview of the EU Industrial Sector ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupMeetingDoc&docid=111A81 (Last accessed 26.01.2021)

[4] Eurofound (2019), The Future of Manufacturing in Europe, Publications Office of the European Union, Luxembourg. doi.org/10.2806/44491. epma.com/dm-industry-news/833-eurofound-report-future-of-manufacturing-in-europe-april-2019/file (Last accessed 26.01.2021)

[5] European Commission (2017). Industry in Europe. Facts & figures on competitiveness & innovation. Luxembourg: Publications Office of the European Union. doi.org/10.2777/899824 (Last accessed 26.01.2021)

[6] mckinsey.com/featured-insights/artificial-intelligence/notes-from-the-ai-frontier-modeling-the-impact-of-ai-on-the-world-economy (Last accessed 09.04.2021)

[7] pwc.fr/fr/assets/files/pdf/2018/02/impact-of-automation-on-jobs-international-analysis-final%20report-feb-2018.pdf (Last accessed 09.04.2021)

[8] A Critique of Technocentrism in Thinking about the School of the Future (1987) http://www.papert.org/articles/ACritiqueofTechnocentrism.html (Last accessed 27.01.2021)

[9] britannica.com/topic/anthropocentrism (Last accessed 27.01.2021)

[10] ied.eu/project-updates/the-4-industrial-revolutions/ (Last accessed 12.04.2021)

[11] epicor.com/en-in/resource-center/articles/what-is-industry-4-0 (Last accessed 27.01.2021)

[12] nickelinstitute.org/blog/2020/november/customising-the-future-the-next-industrial-revolution (Last accessed 24.02.2021)

[13] ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en (Last accessed 24.02.2021)

[14] Deguchi A. et al. (2020) What Is Society 5.0? In: Hitachi-UTokyo Laboratory (H-UTokyo Lab.) (eds) Society 5.0. Springer, Singapore. doi.org/10.1007/978-981-15-2989-4_1

[15] Valeria Villani, Giulia Lotti, Nicola Battilani, Cesare Fantuzzi, Survey on Usability Assessment for Industrial User Interfaces, IFAC-PapersOnLine, Volume 52, Issue 19, 2019, Pages 25–30, ISSN 2405-8963, doi.org/10.1016/j.ifacol.2019.12.078.

[16] Frieder Loch, Ulrich Ziegler, Birgit Vogel-Heuser, Using Real-time Feedback in a Training System for Manual Procedures, IFAC-PapersOnLine, Volume 52, Issue 19, 2019, Pages 241–246, ISSN 2405-8963, doi.org/10.1016/j.ifacol.2019.12.089.

[17] allaboutcircuits.com/industry-articles/a-look-at-industry-5.0-cobots-and-hmi (Last accessed 22.03.2021)

[18] Ionescu, Tudor & Fröhlich, Joachim & Lachenmayr, Markus. (2020). Improving Safeguards

and Functionality in Industrial Collaborative Robot HMIs through GUI Automation. doi.org/10.1109/ETFA46521.2020.9211886
[19] Situational Awareness – The Next Leap in Industrial Human Machine Interface Design, J. Krajewski, 2015 semanticscholar.org/paper/Situational-Awareness-%E2%80%93-The-Next-Leap-in-Industrial-Krajewski/8e13f3cdbae15e41607f85f5d7d33b83a74ca53d (Last accessed 04.02.2021)
[20] Fazel Ansari, Knowledge Management 4.0: Theoretical and Practical Considerations in Cyber Physical Production Systems, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, Pages 1597-1602, ISSN 2405-8963, doi.org/10.1016/j.ifacol.2019.11.428.
[21] National Research Council. 1998. Modeling Human and Organizational Behavior: Application to Military Simulations. Washington, DC: The National Academies Press. doi.org/10.17226/6173
[22] Pahlke, Norbert & Rohlf, Benedikt & Behrendts, Alisa & Smets, Nanja & Mioch, Tina & Neerincx, Mark & Greeff, Joachim & Jonker, Catholijn & Baberg, Fredrik & Sengupta, Sohini & Nabizadeh, Nima & Kruijff-Korbayova, Ivana & Fddo, Dortmund. (2020). Tailored Shared Situation Awareness Interfaces.
[23] journals.sagepub.com/doi/full/10.1177/1555343415572631 (Last accessed 22.03.2021)
[24] Schmidt, Alexander; Otto, Boris & Kussmaul, Alfrid: Integrated Manufacturing Execution – Functional Architecture, Costs and Benefits, 2009, BE HSG/ CC CDQ2 / 17. alexandria.unisg.ch/68002
[25] toolbox.com/tech/erp/blogs/the-role-of-scada-systems-in-your-erp-solution-041015 (Last accessed 22.03.2021)
[26] 8sigma.eu/why-do-we-need-mes-when-we-already-have-scada (Last accessed 22.03.2021)
[27] MES: Manufacturing's Missing Link is a Tool for Change services.mesa.org/ResourceLibrary/ShowResource/4c118e85-3655-454a-95bd-c6f54467bb47 (Last accessed 27.01.2021)
[28] http://mescenter.org/en/articles/108-mes-manufacturing-execution-system (Last accessed 27.01.2021)
[29] csrc.nist.gov/glossary/term/Human_Machine_Interface (Last accessed 04.02.2021)
[30] Aranburu, Erik & Lasa, Ganix & Mazmela, Maitane & Gerrikagoitia, Jon. (2017). EXPERIENCE CONTEXT CAPTURER (ECC): NEW APPROACH TO ANALYSE THE USER EXPERIENCE CONTEXT WITHIN THE INDUSTRIAL HMI ENVIRONMENTS.
[31] Giulia Lotti, Valeria Villani, Nicola Battilani, Cesare Fantuzzi, New Trends in the Design of Human-Machine Interaction for CNC machines, IFAC-PapersOnLine, Volume 52, Issue 19, 2019, Pages 31–36, ISSN 2405-8963, doi.org/10.1016/j.ifacol.2019.12.080.
[32] Aranburu, Erik & Lasa, Ganix & Gerrikagoitia, Jon & Mazmela, Maitane. (2020). Case Study of the Experience Capturer Evaluation Tool in the Design Process of an Industrial HMI. Sustainability. 12. 6228. 10.3390/su12156228.
[33] usability.gov/what-and-why/user-experience.html (Last accessed 04.02.2021)
[34] http://semanticstudios.com/user_experience_design (Last accessed 04.02.2021)
[35] Yuval Cohen, Maya Golan, Gonen Singer, Maurizio Faccio, Workstation–Operator Interaction in 4.0 Era: WOI 4.0, IFAC-PapersOnLine, Volume 51, Issue 11, 2018, Pages 399-404, ISSN 2405-8963, doi.org/10.1016/j.ifacol.2018.08.327.
[36] valamis.com/hub/learning-curve (Last accessed 04.02.2021)
[37] iso.org/standard/54497.html (Last accessed 04.02.2021)
[38] Andrea Bonci, Sauro Longhi, Massimiliano Pirani, Prospective ISO 22400 for the challenges of human-centered manufacturing, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, Pages 2537-2543, ISSN 2405-8963, doi.org/10.1016/j.ifacol.2019.11.588.
[39] Valeria Villani, Lorenzo Sabattini, Alessio Levratti, Cesare Fantuzzi, An Industrial Social Network for Sharing Knowledge Among Operators**The research has been carried out within the "Smart and adaptive interfaces for INCLUSIVE work environment" project (INCLUSIVE) funded by the European Union's Horizon 2020 Research and Innovation Programme (H2020-FoF-04-2016) under grant agreement N. 723373., IFAC-PapersOnLine, Volume 51, Issue 11, 2018, Pages 48-53, ISSN 2405-8963, doi.org/10.1016/j.ifacol.2018.08.233.
[40] Loch, Frieder & Koltun, Gennadiy & Karaseva, Victoria & Pantfoerder, Dorothea & Vogel-Heuser, Birgit. (2018). Model-based training of manual procedures in automated production systems. Mechatronics. 55. 10.1016/j.mechatronics.2018.05.010.
[41] omnisci.com/technical-glossary/knowledge-management (Last accessed 21.03.2021)
[42] industrial-software.com/solutions/aveva-workflow-management (Last accessed 15.02.2021)
[43] Jiao Wang, Jarvis N. Jiang, Meilin Wang, Yinhao Ye, Yangshuai Wang, Yi Zhou, Qing Liu, Implementation of a Message-driven Manufacturing Execution Workflow System, Procedia CIRP, Volume 83, 2019, Pages 655-660, ISSN 2212-8271, doi.org/10.1016/j.procir.2019.04.125.
[44] networkworld.com/article/3280225 (Last accessed 22.03.2021)

Industrijski uporabniški vmesniki v industriji 4.0 in pogled naprej

Razširjeni povzetek:
Proizvodna dejavnost predstavlja približno 15 % dodane vrednosti in tudi 15 % vseh delovnih mest v Evropi. S takšnim obsegom je torej kritičnega pomena za EU in njeno raziskovalno-razvojno dejavnost, saj skoraj dve tretjini vseh investicij pride prav s tega naslova. Velik delež raziskav se osredotoča na avtomatizacijo proizvodnje in uporabo pametnih naprav, kar strokovnjaki kot tudi splošna javnost opredeljujejo z oznako industrija 4.0.

Industrija 4.0 se trenutno osredotoča predvsem na povezljivost in analizo podatkov, v prihodnje pa se bo nekoliko bolj usmerila na uporabnika in človeško komponento nasploh. Razlogov za to je več: naraščajoča kompleksnost proizvodnih procesov na eni strani, na drugi pa vse večje zavedanje, da delo operaterja – kljub vse večjim zmožnostim umetne inteligence – v popolnosti nikoli ne bo moglo biti zadovoljivo nadomeščeno s tehnologijo. Ob teh dejstvih se odpirajo nova vprašanja učinkovitega vključevanja delovne sile v proizvodne procese, saj vse večja kompleksnost sistemov narekuje nova znanja in spretnosti, te pa je ob naraščajoči fluktuaciji delovne sile vse težje zagotoviti. Ta izziv lahko rešimo s krajšim časom učenja in uvajanja operaterjev ter z učinkovitejšo interakcijo med operaterjem in napravo oz. procesom, ki ga upravlja.

Namen tega prispevka je pregled trenutnega položaja operaterjev in tehnologij, ki omogočajo in podpirajo njihovo vlogo v avtomatiziranih proizvodnih procesih. Dotaknili se bomo nekaterih novih pristopov za hitrejše učenje in potrebnih metod za (brezpapirno) upravljanje z bazami znanj, vse to v povezavi z novimi načini prilagoditve industrijskih uporabniških vmesnikov in celostne uporabniške izkušnje.

Ključne besede:
industrijski uporabniški vmesnik, HMI, uporabniška izkušnja, operater, učenje, industrija 4.0, industrija 5.0