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# Human-Centered Manufacturing Challenges Affecting European Industry 4.0 Enabling Technologies

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**Abstract.** Industry 4.0 implies the digitization of the shopfloor combining technologies such as sensors, augmented reality, and wearable robots that transform the manufacturing environment into a workplace where human-machine interactive symbiosis. As manufacturing companies develop strategies to innovate and engage with the digital transformation, the reality of the enabling technologies demonstrate serious challenges to the wider organizational adoption beyond the pilot phase albeit the promising evaluation results. This paper presents two cases based on two European research projects encompassing representatives of different industrial sectors and distils the challenges encountered that raise barriers to wider adoption.

**Keywords:** Digital Enhanced Operator, Enabling Technologies, Smart Manufacturing, In-dustry 4.0.

## 1 Introduction

The digital transformation of the manufacturing environments is accelerating significantly with the recent introduction and promotion of the Industry 4.0 technologies (e.g. internet of things, data analytics, wearable technologies, artificial intelligence, mixed reality) all around the world. Although automation and digital transformation is touted as the innovation driver for establishing manufacturing competitiveness in the global marketplace, workers will remain as a critical resource for manufacturers [1], especially in complex, high-tech, and customized manufacturing industries. Highly skilled, independent, and flexible workforce is foundational to solve problems, address root causes, drive continuous improvement efforts, and innovate towards short-term and long-term changes [2].

The previous work conducted in the manufacturing planning and control literature [3][4] have shown the importance of human factors in the performance of manufacturing operations and the interdependent relations between HTO (human, technological, and organizational) factors. It is now well-recognized in literature that successful utilization and implementation of the digitalization and automation technologies largely rely on the compatibility of the technological support with human factors. The integrity of the technological support to the tasks of human [3], the interaction of the human with the digitalized support system [5], and cognitive abilities (e.g. attention, perception) of humans [6], make them a critical component of the decision-making process together with the digital systems. It is therefore critical to digitalize the manufacturing environments in synergy with the human factors of workers.

This paper gives an overview of existing Operator 4.0 frameworks and taxonomies (Section 2), followed by an analysis of two relevant European research projects pertaining successful digitalization of Industry 4.0 manufacturing environments (Section 3), distilling and characterizing the relevant limitations (Section 4) that affect human-centered manufacturing work environments, which limit the effective deployment and use of the associated enabling technologies.

## 2 Operator 4.0 frameworks and taxonomies

There is an overall consensus in Europe on naming Fourth Industrial revolution the current process of transformation undergone by the manufacturing sector, following to the first one consisting on mechanization of processes, based on water and steam power; the second one consisting on mass production, based on division of work and electricity; the third one consisting in automation, based on information and communication technologies [7]. The fourth industrial revolution consists in integrating the vertical layers of the traditional automation hierarchy; the horizontal nodes of the supply chain; the phases of the design and engineering process; based on cyber-physical-systems (CPS) [8]. These systems consists of material entities empowered by sensorial, computational, actuating and communication capabilities that collaborate with each other [9] and enable the integration between manufacturing machines and equipment on the shop-floor with the manufacturing execution, enterprise information systems, and with the digital world in general.

The integration of the cyber and physical world is pursued through the implementation of a set of different technological solutions or enabling technologies, such as Additive Manufacturing, Augmented Reality, Big Data and Analytics, Autonomous Robots, Simulation, Industrial Internet [10].

The deployment of the Industry 4.0 solutions has been limited so far to narrow scopes within manufacturing enterprises and a full integration of a manufacturing system has not been achieved, so far. Therefore, there is not a large base of evidence concerning what the implications of the fourth industrial revolution are for the organization of work when considering the augmentation of the operator.

Scholars, while waiting for richer and more mature empirical studies, have developed a conceptual reference, based on two opposite scenarios [11]. The first one assumes that the power and autonomy of artificial systems will be so high to allow for a tight control on the workers exerted through the technologies: technologies master humans. The second scenario speculates that workers will be in control of the processes and technologies will be used for support: technologies as tools for humans. From the human-centric perspective of this last scenario the concept of the Operator 4.0, a "Smart and skilled operator who performs work aided by machines if and as needed" [1] developed as an emerging paradigm. According to this view, the Operator plays the key role on the shop-floor and various technologies enhance his/her capabilities and support his/her activities. Examples of technologies to augment operators are exo-skeletons to increase strength; augmented reality to transfer knowledge and increase cognitive capabilities; wearable technologies improve health through monitoring of physiological conditions.

Indeed the Operator is a fundamental resource for manufacturing, especially if he/she focuses on activities in which the uniqueness of human contribution is valued [12] and not for mere execution of routine tasks either physical or cognitive. Indeed the human worker represents an extraordinary driver for flexibility in manufacturing environment with high levels of automation, no matter how flexible and advanced these systems are [13]. The Operator 4.0 is mainly a decision maker and a problem-shooter, his/her intervention develops by leveraging and collaborating with the artificial systems along all the phases, from the initial understanding of the situation to the final decision and performance [14]. Most of the effectiveness of human actions depends on situation aware-ness, that is on the perception and comprehension of the current status of a system, and on the projection of future status [15].

## 3 Enabling Technologies Case Studies

### 3.1 Case 1: HUman MANufacturing Project

The HUMAN project [16] is a H2020 research project aiming to digitally enhance the operator on the shop-floor to support them in their work, augmenting their physical and cognitive capabilities, thus avoiding loss of productivity and poor quality due to errors done in their work, whilst contributing to greater well-being.

An overview of the conceptual framework of HUMAN, illustrated in Fig.1, is composed of two distinct cycles:

- Short-term. The operator is sensorized by the use of wearable devices (eg: smart watches, depth cameras, HMD, thermo-graphic cameras, etc) capturing a wide range of signals that are complemented with sensors in the work environment to generate a the digital representation of the workplace environment by the existence of multiple models. Based on the contextual understanding of reality, the system reasons about any anomalies and discrepancies that represent a fallacy in the situation awareness of the operator. As a result, the system determines whether assistance is required and what would be the appropriate level of assistance. When appropriate an intervention is triggered that is tailored to the particular needs of the operator, who may always decide to over-rule the system;

- Long-term. All the data from sensors and events generated from the system are captured for secondary usage by additional services used for learning, supporting decision making and workplace optimization. Unlike with short-term where the system reasons and determines the best course of action to support the operator, in the case of long-term, an engineer needs to be involved and makes decisions based on the generated insights.

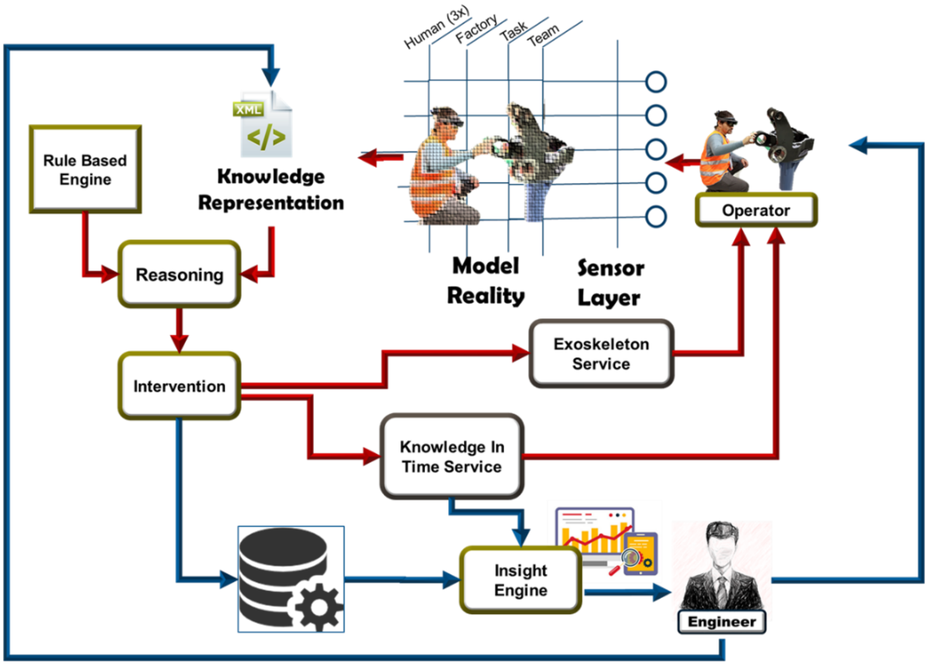

**Fig. 1.** The HUMAN conceptual framework with short-term reasoning (red track) and long-term reasoning (blue)

Two of the short-term services are:

- Knowledge In Time (KIT) service [17], which uses augmented reality combined with machine learning to address the detrimental effect of cognitive overburden of the operator that ultimately affects their productivity and quality of the work output. The understanding of the operator’s context permits a tailored delivery of support;
- Exoskeleton service, where the operators don a semi-passive exoskeleton along with wearable device to measure real-time physiological data. The service determines the probable level of physical fatigue experienced by the operator and adjusts the level of physical assistance.

**Fig. 2.** Use of the HUMAN short-term services at the end-user organizations

Taking the KIT service in more detail, it has been deployed at all three of the end-users organisations, covering a range of different industries, namely aeronautics, robot manufacturing and furniture manufacturing. Each of the end-users has differing production rates and product/process complexities, which have their own challenges:

- Furniture Manufacturing. The primary use of the KIT service is for training purpose to reduce the time to competence of operators. However, the system is also used by the experienced operator by bringing to their attention intricacies of the assembly operation based on their past performance and evidence of retention concerning process. The secondary use of the system is to verify the quality of the training and decide on potential workplace optimisation.
- Robot Manufacturing. The system provides step-by-step instruction support, whilst monitoring the operator's activities to assess the quality of their work and capturing evidence of the work. The secondary use of the captured data is to support quality auditing of the production process.
- Aeronautics. The system is used to support the operator in their process, indicating the mistakes that were incurred in the recent past. The system in this case monitors the operator's actions, indicating the probability of error in the task, thereby bringing to the attention of the operator. The secondary use of the system is to improve the process optimisation.

The operators have appreciated the use of augmented reality with machine learning to increase their cognitive capabilities tailored to the particular context of work being carried out. However, the secondary use of the system to support long-term cycle provides the means to augment and improve existing company knowledge.

### 3.2 Case 2: MAN-MADE worker-centric adaptive workplace

The MAN-MADE (MANufacturing through ergonoMic and safe Anthropocentric aDaptive workplacEs for context aware factories in EUROPE) project aims at defining new socially sustainable workplaces where workers are foreseen at the centre of the factory [18], especially in terms of workplace adaptation. The worker-centric manufacturing model is, then, demonstrated in a pilot implementation at the training assembly line of an Italian producer of white-goods.

According to the MAN-MADE approach, in order to build a personalized workplace that fits each individual worker, specific anthropometric data of each worker are gathered to build a detailed 3D digital mannequin characterized by significant dimensions of the human body (e.g., standing height, elbow height). The anthropometric characterization of the worker is also enriched with information on her capacities, skills and needs [19]. As a result, a comprehensive, consistent and evolving knowledge base is created to enabling the digital design and configuration of the worker-centric workplace and its physical adaptation, so that it can sustain workers' performance and wellbeing at best [21].

From a technological viewpoint, the characterisation of the worker is realised with the support of a non-invasive data capture systems meant to collect relevant anthropometric dimensions of each worker (Fig. 3). Specifically, a stereo camera-based imaging system is used. It consists of two cameras, landmarks to place on the worker's body, a data analysis software, and a screen to visualize the data capture process. The system has low costs due to non-complex hardware; it is accurate with measurements performed in 3D, and easy-to-use, as all measurements are performed automatically from the acquired images, and the measurement procedure requires less than 5 minutes.

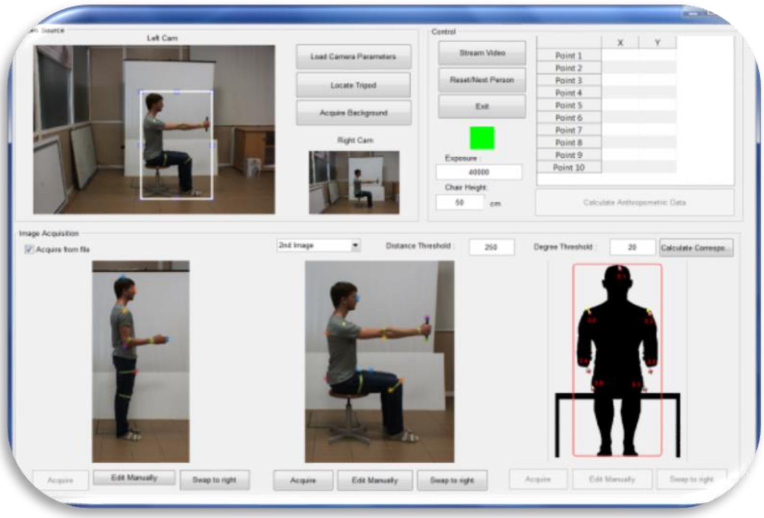

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**Fig. 3.** User interface of the stereo camera-based imaging system

The captured data and information enable the creation of a digital 3D mannequin. Then, an ad-hoc CAD plug-in is used to transfer the data to/from a Computer Aided Design software to define a new adaptable workplace, and to configure its parameters so that it ergonomically fits the worker as well as production objectives.

Finally, from the physical point of view, the workplace adaptability is realized by introducing a collaborative robot instead of complex automation alternatives (Figure 3). Collaborative robots enable direct interaction between operators and cobots, thus overcoming the classical division of labour, which requires industrial robots to be confined in safety cages [21]. As an example, in one of the MAN-MADE scenarios, the worker approaching the workstation is recognized and the worker’s parameters are directly transferred to the motors to automatically adjust the workstation plan. The cobot hands the worker a part in the most ergonomic way or adjust the position of the bins where the worker fetches components, taking into account the specific traits of the individual worker (e.g., if the worker is right- or left- handed). Equipping the workplace with a collaborative robot to implement adaptability leads to a more flexible, scalable, and economic system than other traditional electromechanical approaches, which usually lack in flexibility and cannot efficiently adapt to frequent changes and dynamic working environments.

**Fig. 4.** Training assembly line and Collaborative Robot

# 4 Challenges

In both projects, different technologies were used in researching solutions to address human-centred manufacturing work environments, whether by changing the workplace (MAN-MADE) or by digitally enhancing the operator on the shopfloor (HUMAN). The results from the research projects were promising, but there remains a significant gap between the research results and the industrial uptake, which are briefly described in the subsequent subsections.

## 4.1 HUMAN

In the HUMAN project, the focus on digitally enhancing the operator on the shopfloor is faced with several challenges associated to the enabling technologies that are used in the digital transformation of the workplace, namely:

- Production readiness. The devices used for the different services were afflicted with shortcomings that make their adoption harder when considering a factory roll-out. In the case of wearables, the level of accuracy of the readings in terms of time synchronization raises difficulties in construing an accurate context from the different sources; in the case of the exoskeleton, one requires certification for deployment in the factory; in the case of hololens (device used in KIT), the overheating presented

itself as a problem due to passive dissipation of the heat, the battery lifetime was limited, the reduced field of view (FOV) caused concerns with some operators when trying to gauge the big picture and the accuracy of the holograms invalidated some processes due to quality constraints.
- Privacy and Trust. A fundamental premise of the HUMAN project was for the system to build a context of the work environment, the operator and the task being carried out. In addition to the traditional digital information originating from production systems and the environment, the operator themselves was sensorized with wearable devices, depth cameras, video and audio. Whilst this richer data sets provided the means of creating more accurate understanding of the work context at hand, serious concerns regarding privacy were raised [22][23], which consequently had an impact on the trust operators would have in the service and affecting their acceptance.
- Integration with the Work Practice. The use of new solutions with innovative work practices have an impact on existing processes that need change. The use of process analytics and mining contribute to a measured approach to improving the workplace.
- Training and Reasoning. The advent of machine learning is transforming the opportunities in the workplace, but approaches such as deep learning, require inordinate amounts of data for training purposes. However, within manufacturing environments, access to data is in most cases sparse and difficult to acquire taking into account the practical constraints of production schedules, environment conditions (eg: lighting, noise, etc), intellectual property involved and the requirement of contextual knowledge for labelling. Therefore, one needs to create proprietary data sets that benefit from contextual information that make learning transfer difficult to achieve.

## 4.2 MAN-MADE

The approach proposed by MAN-MADE for workplace adaptation is considered as promising by the main company stakeholders. However, some challenges must be addressed to guarantee its successful implementation in real factories. The main ones are briefly described:

- Contextual Knowledge. Health professionals of the company medical service are needed to perform the acquisition of the measurements, with standardized protocols to be followed with instructions for preparation (kind of clothing to be worn, calibration method of the system, anatomical land markers), the correct positioning of the worker, and taking the images.
- Privacy and Trust. Data privacy and protection concerns regard how workers' personal data are being stored, protected and re-used. These concerns may be also amplified when a dynamic worker profile is created and updated by monitoring the worker status trough wearable devices to enable the adaptation of the workplace in real-time [24].
- Environmental Constraints. Industrial environments are often complicated and may not have optimal lighting conditions. Therefore, it is crucial to select carefully hardware and software components that are suitable for use in real-life industrial environments.

- Safety. safety and trust in the cobot are essential. Additional certification for the cobot's tools is required to guarantee the physical safety of operators. Similarly, issues related to mental stress and anxiety induced by close interaction with the cobot must be considered to ensure that the worker feels comfortable and safe when cooperating with the cobot.
- Training and Reasoning. Operators and maintenance technicians must be trained to develop the skills needed not only to perform new tasks together with the cobot but also to re-programming the cobot in case of adjustments, minor product changes, or stoppages [25].

## 5 Conclusions

The industry 4.0 digital transformation of the manufacturing landscape is promising [26] but unlike many proponents, it will not deliver the vision of a fully automated manufacturing site, as the human operator remains necessary due to the nature of tasks, in particular when creativity and problem solving is required. Therefore, the emphasis has been of exploiting the synergies between the human operator and technology, to cognitively and physically enhance the operator whilst making the work environment adaptive to the needs of the operator.

This paper has presented some of the research results from two European projects, involving end-users organizations from different industrial sectors. The cases demonstrate the potential of adopting enabling technologies to digitally enhance the operator and the work environment, but the paper delved into the challenges that raise barriers concerning the wider deployment of the devised solutions albeit the pilots yielded promising results with attractive performance indicators.

Some of the challenges are related to the maturity and production readiness of the enabling technologies, which gradually will improve over time (eg: the hololens 2 provides a wider FoV, more sophisticated sensors and an ergonomically much improved design that offsets the heavy load from the front). However, there are many of the limitations are rooted in non-functional features, namely the concerns over trust and privacy as significant amounts of data from the operators are captured so a digital solution may understand the context and determine the best way to support the operator. It becomes essential to consider privacy by design from the onset and adopting engagement strategies that involve the operator in the designing and deploying the solution in their work environment.

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