Augmenting the Production Operators for Continuous Improvement

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Abstract – **This paper discusses how continuous improvement activities can be supported by augmenting the operators in production. After a brief literature background, real life case examples from manufacturing companies are provided and discussed. Enabling technologies, specifically AR and embedded sensors, can guide the operators in execution of their tasks, quality verification of work done step by step, and data collection from both manual and automated operations in much higher levels of details. Collected data provides an empirical foundation for data-driven analysis and improvement potentials in production and quality operations. The paper contributes to theory and practice by providing research-based innovation experiences on this emerging topic of interest for manufacturing companies.**

Keywords – **Augmented operator, continuous improvement, manufacturing industry**

I. INTRODUCTION

Industry 4.0 is digitalizing and transforming the manufacturing companies through implementation of enabling technologies (e.g., sensorics, Augmented Reality) and methodologies (e.g., Big Data Analytics). The main objective of Industry 4.0 transformation is to create new values for manufacturing companies in the form of data-driven business models, and management and control of processes, factories, and value chains for increased efficiency [1].

Despite the digitalization and automation focus, operators will still be a critical driver for competitiveness of the manufacturing companies, taking the main role in performing activities that require flexibility, customization, and uniqueness [2]. Operators will handle unforeseen events and take more decision-making responsibilities in the increasingly digitalized and complex factories of the future [3]. Skilled and flexible workforce will remain critical to solve unforeseen events in production, identify the root causes [4], and drive continuous improvement efforts [5].

Accordingly, utilization of enabling technologies to establish operator-centric production management environments and activities is becoming more prominent over the past decade [6]. There are generic conceptual models that describe the augmented operator in literature [7]. Field-based studies and specific applications of augmenting the operators are rather scarce. This paper discusses how augmenting the operators can support the continuous improvement activities in production environments. The study is conducted as part of research-driven innovation projects that has focused on human augmentation, digitalization, and lean production in real life manufacturing companies. Accordingly, case studies are presented to illustrate the contribution of augmented operators for continuous improvement. In the remainder of the paper, firstly research design and a brief literature background on augmented operator is provided. The paper then presents a conceptual model for human augmentation and continuous improvement loop. In the end, case studies from HUMAN research project are illustrated and findings are discussed.

II. RESEARCH DESIGN

This study applied action research methodology, by researchers taking action in making a change in case companies, analysing and evaluating the change, and reporting the outcomes [8]. The case companies were part of an EU project that was coordinated by the researchers and aimed at implementing enabling technologies (e.g., AR, sensors, machine learning) to support production operators' tasks. During site visits, researchers were involved in implementation and evaluation of technologies, and collected data based on interviews and observations. Collected data was transcribed, analysed, and visualized through appropriate diagrams and flowcharts, and further validated by the use case partners.

III. AUGMENTED OPERATOR

"***The augmented operator***" is defined as one of the main paradigms of Industry 4.0, besides the smart product, and the smart machine [9]. Augmented operator or commonly referred as Operator 4.0 [7] or "Digitally enhanced operator" [10], utilizes the enabling technologies to improve the skills and capabilities of operators, and support their cognitive and physical tasks. Such enabling technologies can augment the production operators as discussed below.

A. Physical Augmentation

One of the main application areas of enabling technologies for operator augmentation addresses the physical activities of the operators [11]. The physical augmentation of operators aims to ensure their work safety, protect their health, while improving the productivity.

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The context of the task guides the suitable path for physical augmentation. For example, tasks that require heavy lifting and body stabilization can be supported by exoskeletons to minimize the physical stress on the operator, anticipate ergonomic issues, and avoid work injuries (e.g., sprain, fracture) [12].

Besides the task context, the environmental context of the operator should also be considered when implementing the exoskeletons. For example, workstations with limited areas prevents fully active usage of exoskeleton.

Nevertheless, the physical augmentation of operators is not merely limited to application of exoskeletons. In general, the physical augmentation contains implementation of enabling technologies to design and operate adaptable workstations that can sense and accommodate the requirements of the operator, facilitating the creation of human-centric workplace composed by people and collaborative robots [13]. As such, the work is performed ergonomically and efficiently.

B. *Cognitive Augmentation*

With digital transformation of workplaces, operators' responsibilities and skill requirements are changing. Operators are empowered to take more autonomous decision-making roles on the shop floor, leading to higher degree of authority on their physical and cognitive tasks [11]. Their cognitive tasks will be extended by taking more responsibility on planning and scheduling of shop floor orders, management of product and process quality, maintenance operations, and taking reactive actions against disturbances and disruptions in uncertain production systems [10].

The extended cognitive tasks of operators requires perception and comprehension of various types of information (e.g., work order status, maintenance information, quality assessment, work instructions), and hence interaction with various types of information sources (e.g., Manufacturing Execution Systems, Enterprise Resource Planning systems, Maintenance systems) in order to make appropriate and timely decisions [4]. Information collection and processing activities of humans are aimed to acquire a situation awareness from the initial perception and comprehension of the situation to making the final decision in an effective manner [14]

Information and communication technologies (e.g., Manufacturing Execution Systems, dashboards) can guide the operators in performing their cognitive tasks by visual decision support, enhancing the problem-solving capabilities. Enabling technologies such as Augmented Reality (AR) can be utilized for augmenting the work instructions and automated quality verification in combination with machine learning tools, aiding operators in the high-quality performance of their tasks [15]. AR tools can also aid operators in learning and training activities for accelerated skill development and reduced time-to-competence [15].

C. *Interaction Augmentation*

Interaction of operators with the enabling technologies should also be enhanced in factories of the future [11]. Production operators perform their work in a different context than the managers of whose work context were mainly considered in the design of the enabling technologies. For example, operators require mobility to control multiple machines assigned to them on the shop floor and hand-free solutions to perform their physical tasks efficiently. The design and implementation of enabling technologies for augmented operators should consider such contextual requirements in a way that operators can utilize the solutions without compromising from efficiency in performance of their tasks. Some examples of such interaction augmentation technologies for providing hand-free and mobile support to operators include, but not limited to, speech recognition, muscle recognition, gesture recognition, and smartwatches. Especially in production environments where multiple machines controlled by one operator, mobile technologies enable the operators with the ability to coordinate their workload, and identify and handle unforeseen events in unattended machines before the productivity of the machines. This reduces time-to-discovery, avoids the loss of productivity, and aids the operator in self-planning [14].

IV AUGMENTED OPERATOR for CONTINUOUS IMPROVEMENT

The successful realization of continuous improvement in production environments largely depends on the involvement and contribution of employees from all organizational levels in a manufacturing company, including of course the production operators, with everybody making incremental improvements [5].

A combination of above technologies can enable the augmented operator significantly contributing to continuous improvement activities and loops in production. Such continuous improvement loops can be classified into operational, tactical, and strategic level improvements, based on well-being-centric and quality-centric analysis of the production performance by augmented operators. Well-being-centric improvements focus on capturing the health-related measures such as cognitive (mental) stress, and physical stress of operators. Quality-centric improvements focus on production processes and operations step by step when the augmented operator executes the operations. Figure 1 illustrates a conceptual model for such continuous improvement loop through augmented operators.

For example, exoskeletons combined with data capture technologies, can sense important biometric data that can define operators physical stress while performing the physical tasks. AI algorithms can exploit such biometric data to analyse and evaluate the ergonomic problems that the operator might encounter as well as provide early warning alerts to take operational actions (e.g., adjustment of posture, giving a break). Analysis of such operational data can be utilized further to take strategic decisions and actions for ergonomic re-design of the workstations to enhance well-being and productivity of the operators.

Application of AR will support operators through the provision of detailed work instructions / knowledge points when performing their complex tasks, ensuring the most efficient transfer of design information to physical products. AR tools with embedded motion sensors also aid sensing and receiving data from operators, completing the missing links in captured data from processes, identifying the operators' physical and cognitive situation, and enabling a full and detailed digital view of process steps together with information systems and machine control systems [16].

Such data allow analysis and evaluation of well-being (e.g., satisfaction, engagement, stress levels) and productivity (e.g., work performance, skills match) of operators both in real-time and longer-terms [16]. Examples of motion data that can be captured by AR tools and can define the psycho-physiological status of operators are: breath/heart rate, skin conductance and movement of relevant body segments [16].

Combined with data analytics and machine learning, captured motion data can be analyzed and the AR platform can provide guidance, early warning signs that can avoid possible harm or injury to the operator (safety risks) and error prevention to the product, contributing to greater safety and quality performance in the work environment. This can be considered as short-term operational improvement.

Having data collected from the entire process, the system will also provide analytics for production insights supporting tactical engineering and strategic managerial decisions (e.g., re-designing the workplace) for improved flow, efficiency, delivery, and not least well-being. As such, it will enable continuous improvement by supporting the cycle of knowledge creation, application, control and learning.

V. CASE STUDY – HUMAN PROJECT

HUman MANufacturing (HUMAN), a European H2020 project, investigated how enabling technologies can enhance the well-being and productivity of production operators to achieve best possible combination of the abilities of human and technology in manufacturing environments. The focus was on facilitating the symbiotic relationship between the factory and the human operators, thereby supporting:

1) Adaptability and flexibility of humans to automation: The growing level of automation in manufacturing requires operators to be more flexible. They require interaction with machines and robots and need to acquire new working practices, movements, gestures, and speeds that simply were not required in the past.

2) Synchronization of tasks with individual capabilities: Although human capital is the main asset for industry, the increase of automation and task complexity is not always matched with the necessary skills of operators that are cognitively impaired or/and physically non-able, thus resulting in a misuse (non-optimal use) of operators' capabilities and potential, leading to inefficiency. Consequently, it is necessary to monitor the physical and mental stress, which varies according to the natural capabilities of each individual operator, thus requiring personalized support to enable task productivity levels are reached without humans becoming too tired, frustrated, or being put in danger.

3) Synchronization of enterprise goals (advancements) with individual expectations: Motivation and participatory attitude in employees is commonly detached from enterprise goals, more so the operators on the shopfloor. As a result, corporate culture should have a new participatory approach in which all workers – from high-level management down to the shopfloor operators – should be able to contribute ideas.

As a result, the HUMAN project provided a platform that take into consideration the factory context, the

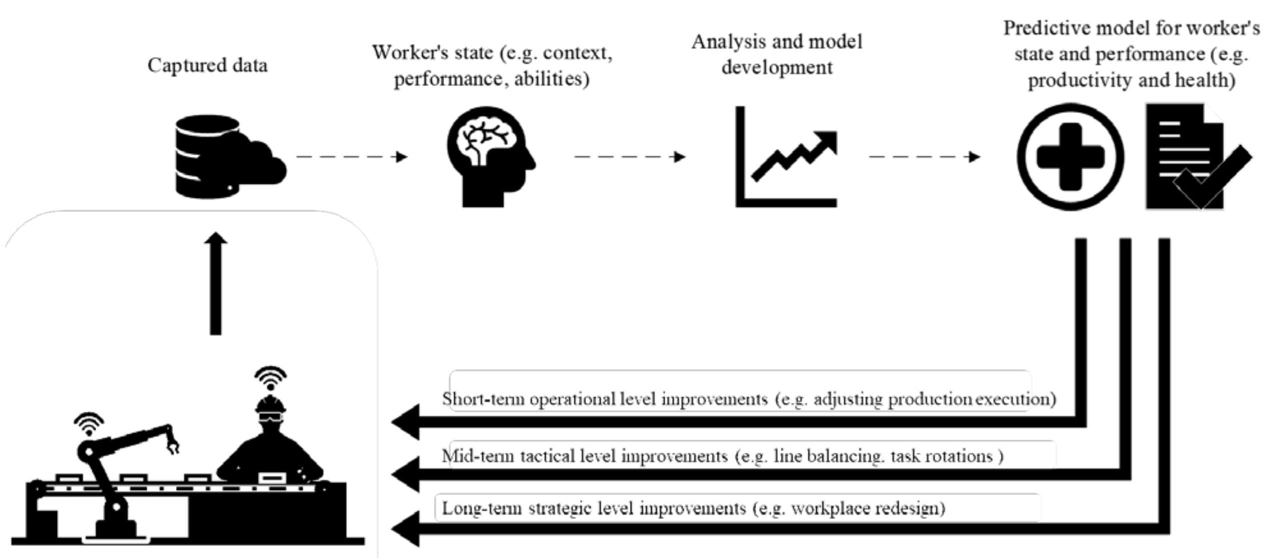

Figure 1. A conceptual model for continuous improvement loop through augmented operator

operator's context, and the context of the operator's task. Such context-aware platform enables analysis, evaluation, identification, and notification of corrective actions to ensure that the operator carries out his/ her tasks with expected quality and productivity, while safeguarding the well-being of the operator. The platform was further industrialized into an AR system, called Knowledge-in-Time AR (KIT-AR), that combines the AR, sensors, and machine learning technologies to support operators in performing their work efficiently and safely. Additionally, the platform includes process mining and data analytics tools to analyse the production process steps in great details, generate detailed performance evaluation reports, and guide the longer-term continuous improvement activities. The platform was tested and demonstrated in three industrial use cases with varying production characteristics and requirements for augmentation of operators:

Airbus (Airplane manufacturer): The Airbus case targeted the operator in the assembly of electrical harness within the fan cowl of the A320 neo engine. The operator is required to assemble multiple clamps, which due to repetitive tasks may cause mistakes and rework downstream thereby reducing the production rate. KIT-AR guided the operator with detailed work instructions on assembly tasks in the right sequence, which standardised the assembly process across the different shifts. This guidance was complemented by automated quality assurance of the correct assembly, reducing production errors. When compared to the quality gateway downstream based on fixed cameras, the use of KIT-AR allowed to detect and correct mistakes at the point of assembly, thus improving the productivity and reducing the overall cost.

Comau (Robot manufacturer): The supported case was the assembly of a robot forearm, where due to the rich customisation increase the probability of assembly mistakes. Another challenge was ensuring the correct application of sealant upon the body ridges before the covering of the robot body, which would make the area inaccessible for quality inspection and a problem would only manifest through long usage, requiring either product recall or dispatching engineering team to the customer. KIT-AR provided stepwise instructions facilitating the mapping of the tasks onto the product with high precision holograms. Additionally, the system would have quality steps where the worker would look at the surface where the sealant was applied and the system would capture sequence of images and machine learning to validate the correct application of the sealant before allowing the operator to proceed with the assembly. KIT-AR would not only capture the timings and sequence of steps undertaken with each product assembled, but also select the best image from the quality checkpoint to support quality traceability.

Royo Group (Furniture manufacturer): In furniture manufacturing, the daily production rate is of a few hundred units with multiple different designs. Due to the nature of this industry, seasonal variations require employment of new operators who can supplement the capacity shortage. Such additional operators may be skilled but lack the necessary experience thus their training result in a throttle in productivity as more experienced operators are required to spend part of their capacity to help learning and competence development of new trainees. With KIT-AR, the aim was to setup a dedicated training process where the seasonal worker would learn the different furniture units, along with their configurations, and the system would monitor their progress determining when they achieved the median competence level to progress to the shopfloor. With KIT-AR, the company was able to reduce training by an estimated 25%, but additionally, there was reduced costs by reducing the need of involving experienced operators to shadow the trainee.

V. DISCUSSION AND CONCLUSION

Augmenting the operators aims to safeguard the well-being of the operators while increasing their productivity. European industry is now coining a new industrial revolution, Industry 5.0, that places the augmented operator at the center, and utilizes enabling technologies to ensure work safety, industrial growth, and economic and environmental sustainability [17].

Augmenting the operators can support the continuous improvement loops in production as discussed and illustrated above. The improvements that can be identified by augmented operators can device context dependent, operational, tactical, and strategic interventions through redesigning the product, process or workplace.

The testing of the solution in real shopfloor conditions whilst in production, yielded interesting insights beyond the increased productivity and reduction of errors. These insights can be distilled into the following key outcomes:

- The premise behind the KIT-AR solution is to augment the worker, meaning that the worker is highly skilled and knowledgeable, requiring assistance in doing a better job. This is an important distinction that has major impact on the successful adoption of new technology on the shopfloor with human-in-the-loop.
- Although across all the use cases, the least experienced workers benefitted the most from the timely delivery of the information, as the complexity of the product with rich configuration options increased, so did the more experienced workers benefit from the instruction sets.
- The overall quality of an assembly process was improved by delivering a standard set of instructions, with noticeable impact on instilling conformance across all workers and eliminating deviations of good work practice in-between shifts.
- The monitoring and capturing of assembly data improved the dialogue between shopfloor workers and the engineering department for continuous process improvement.
- There was the added benefit of not dealing with slow propagation of knowledge on the shopfloor

as the most recent process information was instantaneously delivered to any worker

- Across the three use cases, which were carried out in Spain and Italy, one of the greatest risks towards adoption was the resistance from social actors. An important mitigation strategy is to involve them as a relevant stakeholder in the early stages regarding discussions regarding the uptake of new technology, in particular one so targeted to the worker.
- Although the hardware platform to support augmented reality has permitted to move from the laboratory to real industrial environments, there is still improvements to be made for greater adoption, from the ergonomics of device usage over long periods of time to the battery poor design.

Future research should focus on extrapolating the results of such studies on various production environments characterized by different processes and tasks.

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