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Lean 4.0: typology of scenarios and case studies to characterize Industry 4.0 autonomy model

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***Abstract**: Industry 4.0 is leading to rethink how operational decisions are made within companies. In particular, it raises the question of the evolution of employee involvement and autonomy in operational decision-making in a Lean 4.0 context. Dealing with such issues within companies presents high stakes but also involves many risks and difficulties. Therefore, it is necessary to test these new Industry 4.0 autonomy models within our Evolutive Learning Factories by developing a suitable experimental protocol. This article proposes a typology of scenarios and case studies that will serve as a basis for future experiments to study these issues in a standardized work context. This first study framework confirmed that the decisions induced by all the problems and opportunities encountered at the operational level are numerous and varied. This research work is a first step and opens up much broader research perspectives on the contribution of Industry 4.0 technologies in implementing new models of autonomy at work.*

Keywords: Industry 4.0, Lean, Decision-making process, Experimentation, Use case, Typology of cyber-autonomy

1. INTRODUCTION

The evolutions inherent to implementing Industry 4.0 (I4.0) technologies naturally impact companies' performance even if these are difficult to dissociate from the human aspects associated with work (Eslami *et al.,* 2021). Companies have focused on implementing these new technologies to increase their productivity while oftentimes neglecting the human dimension during the implementation. If technology implementation impacts this human dimension, it turns out that the latter also acts on these approaches in return. This feedback, carried out in a virtuous manner, can lead to an optimized execution of operations while providing appropriate support to employees in carrying out the activities they are responsible for. However, appropriation of these new technologies or the modifications of the organizational mechanisms are rarely studied.

In particular, the question arises whether these technologies, at the interface between humans and industrial systems, participate in the empowerment (the ability to become autonomous in one's work) of employees and/or facilitate interactions between collaborators in decision-making. These considerations are becoming more and more important since I4.0 would already give way to Industry 5.0 (Maddikunta *et al.*, 2021) focused on human-centered and resource-efficient manufacturing. Many studies highlighting social benefits investigate the connections between I4.0, Lean, continuous improvement, and social systems (Arredondo-Méndez *et al.*, 2021). In this context, the employees' autonomy remains crucial but, to date, under-explored. Current work undertaken within our Evolutives Learning Factories (https://tv.arts-et-metiers.fr/levolutive-learning-factory-bordelais-explique/) aims to provide a structuring framework to measure the impact of developments related to the deployment of new technologies by combining two types of analysis: performance analysis and human behavior analysis. In particular, the following question arises: what are the effects of the implementation of 4.0 technologies on the involvement and autonomy of employees in operational decision-making?

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Therefore, this article proposes a typology of scenarios and case studies that aims to support the realization of experiments addressing this research question. Section 2 presents a review of the literature on Lean 4.0 and the impact of I4.0 on work autonomy in a standardized work context. We demonstrate the need to develop new experimental frameworks to explore these topics. In section 3, we propose a typology of scenarios and case studies for which an experimentation methodology will be developed and tested within our Evolutive Learning Factories. We will conclude with a presentation of the perspectives offered by these developments.

2. LITERATURE REVIEW

2.1 Lean 4.0

I4.0 is defined as a collective term that brings together technologies and organizational concepts in the value chain. I4.0 aims to make factories and agents smarter, more flexible, and more dynamic by equipping production processes with sensors, actuators, and autonomous systems relying on data acquisition, analysis and communication (Roblek *et al.*, 2016). This smart industry then raises key questions, particularly on the reorganization of work in the physical space induced by the coupling with the cyberspace. While there is no single definition of the I4.0 concept, improving operational activities and the decision-making process appears to be a recurring focus and a primary objective in implementing I4.0.

The current literature also presents several comparisons between I4.0 and the Lean approach. The most commonly adopted vision positions Lean as a necessary basis for Industry 4.0 (Buer *et al.,* 2018). Liao *et al.* (2017) specify that I4.0 acts primarily on the organization and design of work. Based on a socio-technical approach, Lean is positively associated with I4.0 technologies and their simultaneous implementations lead to greater performance improvements (Rosin *et al.,* 2022). Many studies on the relationship between I4.0 and Lean propose a conceptual approach, revealing the need to develop experimental areas to test, through practice, the operational benefits induced by the deployment of I4.0 technologies as part of a Lean 4.0 approach.

At the operational level, these links between I4.0 and Lean promote flexibility and temporality in decision-making by increasing responsiveness and users' autonomy (Ghobakhloo and Fathi, 2019). I4.0 brings out reactions and decision-making in real-time, decentralized, but coordinated at the scale of the global system while collaborating humans and machines (Bousdekis *et al.,* 2019). Technological enhancement leads to an evolution of the assumption of responsibility in activities and operational decision-making. Nevertheless, few articles deal with the core of Lean, namely the involvement of employees in continuous improvement initiatives, grounded in standardized work.

2.2 Standardized work and Industry 4.0 autonomy model.

Contrary to popular belief, the researchers argue that digitization of systems will not decrease human-machine interaction or the emergence of production facilities without employees, but rather to a shift in employee skill requirements and specializations (Weyer *et al.,* 2015). Further studies should be conducted on the human impacts of I4.0 to confirm these developments. The arrival of I4.0 would change how work is performed by freeing up more time to participate in improvement initiatives and complex problem solving activities (Kaasinen *et al.,* 2020). These complementary activities to the execution of operations aim to increase the employees' autonomy. This increase could, in some cases, be perceived as contradictory to the Lean principle of standardization and process stabilization.

In today's Lean organizations, standardized work makes it possible to consolidate production processes in a consistent, precise, and repeatable way to reduce their variability while simultaneously improving their performance (Monden, 2011). The three characteristics of standardized work are: (1) individual responsibility, (2) experiential learning, and (3) discipline in execution (Berger, 1997). Standardized work appears not only as a method of documentation, but it also allows everyone to analyze work situations and serves as a reference point for future improvements (Marksberry et al., 2011). These elements highlight the strong relationships between this standardized work and decision-making guided by problem-solving (back to standard) and/or promoting incremental improvements (Jituri et al., 2021). These improvements seems only possible through human intervention, in his working environment, with or without I4.0 technologies. These technologies profoundly change the relationship between standardized operations, decision-making processes, and continuous improvement. However, the analysis of the effects of I4.0 technologies on the execution of work and the decision-making process seems to be little explored to date.

Some work based on the concept of Human-Cyber-Physical Systems (H-CPS) attempts to identify work systems that allow human-automation symbiosis. Romero *et al.* (2020) propose an operator 4.0 typology around the enhancement of these physical, sensorial, and cognitive capabilities by technologies of I4.0. However, this work does not specify how building these capacities changes autonomy at work and improves decision-making in an operational context. However, the few studies on autonomy illustrate the importance of autonomy in the introduction technologies of I4.0 (Kaasinen et al., 2020).

In conclusion, the literature studying the relationship between I4.0 and Lean today highlights the challenge of employee involvement, but few articles explored the evolution of autonomy models induced by the duplication of technologies of I4.0. This is particularly true for standardized work which is nevertheless systematic in "lean companies". This confirms the need to develop new experimental frameworks to test different degrees of autonomy induced by the introduction of technologies of I4.0 in the context of standardized work. In order to fill this gap, this article proposes a typology of scenarios and case studies that will serve as a basis for the development of experimentations. These will soon be tested within our Evolutive Learning Factories.

3. TYPOLOGY OF EXPERIMENTATION SCENARIO OF INDUSTRY 4.0 AUTONOMY MODEL

Trends in using experimental medium ("in the laboratory") closer to the industrial environment will guide our research methodology by projecting a series of experiments to be conducted in our observation platforms (learning factory), thus making it possible to collect qualitative, quantitative, and relatively close data to those from an industrial environment.

3.1 Conceptual framework

New models of autonomy have been structured around the decision-making process by Industry 4.0 technologies (Rosin et al., 2021). Following the model of Mintzberg *et al.* (1976), this process consists of three phases: (1) Validation of the problem or opportunity, (2) Validation of the solution, and (3) Validation of the implementation (see Appendix A).

The problem or opportunity validation phase includes the *Capture-Measure* and *Gap Recognition* steps. The *Capture-Measure* step consists of collecting real-time information in the production system. The second step, *Gap Recognition*, is to recognize an abnormal situation that requires a response. The validation phase of the solution mobilizes the *Diagnostic, Search, Design, and Selection* steps. The *Diagnosis* step represents the understanding of cause-and-effect relationships in the situation studied. Subsequently, a choice will be made between the *Search* or the *Design* steps. If solutions are known, the *Search* step is used to obtain the solution that offers an adequate answer to the problem. If no solution is known, the *Design* step is preferred to design a new solution. Subsequently, if the *Selection* step allows it, it leads to eliminating inappropriate solutions. Then, the *Evaluation* step makes it possible to compare the solutions and ensure that the chosen solution will solve the situation. Finally, the third phase consists of a single step: *Authorize*. Here, an authorization is issued either by the production center itself (the operator or machine) or by a hierarchically superior entity (a superior or an information system).

Based on this conceptual model, our study aims to link technologies of I4.0 and these steps of the decision-making process. In a standardized production context, three first types of scenarios emerge and are presented: (1) cyber monitoring, (2) cyber search, and (3) standard decision support.

3.2 Logic for structuring experimentation scenarios

Therefore, a set of case studies is being developed with our Evolutive Learning Factories as experimental ground. These use cases will make it possible to understand the success factors, good practices, and probably some limitations related to the implementation of technologies of I4.0 deployed to support work execution and decision-making. As mentioned, this will be done in the context of standardized work and in a manufacturing context. The following table presents in detailed the three types of scenarios on which our experiments will be build on. These first scenarios refer to the three first level of cyber-autonomy (cf. Rosin et al., 2021, 2022).

Table 1. Typology of scenarios in a standardized working context

Types of cyber-autonomy	Type 1 : Cyber monitoring	Type 2 : Cyber search	Type 3 : Standard decision support
Objectives specific to each type of cyber-autonomy	Enhance capture-measure / gap recognition and problem/opportunity identification	Enhance diagnosis (if necessary) Enhance the search for already known solutions	Facilitate the selection of solutions (if too many known solutions) Enhance the evaluation of selected solutions
Technologies of I4.0 considered in priority	Big Data and Analytics / Artificial Intelligence / Internet of Things (IoT) / Cloud / CPS / Autonomous robots and machines / inter-machine communication (M2M)	Big Data and Analytics / Artificial Intelligence / Cloud / Simulation / augmented reality / CPS / M2M	Big Data and Analytics / Artificial Intelligence / Cloud / Simulation / augmented reality / CPS
Enhanced employee capabilities	Sensorial capabilities Cognitive capabilities	Cognitive capabilities	Cognitive capabilities

This scenario typology is designed around the different types of cyber-autonomy determined by Rosin *et al.* (2021) by presenting the three types particularly adapted to the chosen conceptual framework. Any decision-making process starts with identifying a stimulus to action and ends with a specific commitment to action (Mintzberg et al., 1976). The stimulus to decision-making can be described as a problem defined as a gap between current and targeted situations. Two scenarios may arise: (1) the current situation shows a deterioration compared to the target situation concerned, which is characterized by the work standard; (2) the current situation is not satisfactory, and there is a desire to achieve a higher level of performance. This then implies challenging the existing standard of work.

The construction of the scenarios studied within the Evolutive learning factory will be based on the distinction between these two cases. However, the logic of structuring the scenarios presented in this article concerns only the first case. As an input assumption to the implementation of any scenario, this implies that a work standard exists and corresponds to the best practice currently known to carry out a given action (Marksberry et al., 2011; Monden, 2011). Table 1 specifies (1) the objectives associated with each type of scenario through the expected contribution of Industry 4.0 technologies to the enhancement of the decision-making process; (2) the technologies prioritized for implementation in each type of scenario. These were established on the basis of a previous study conducted on enhancing the decision-making process through technologies of I4.0 (Rosin *et al.,* 2021). Each type of scenario is specified below.

3.3 Type 1 *scenarios: Cyber-monitoring*

For this type of cyber-autonomy, the Cyber-Physical Production System (CPPS) must be able to identify a situation, a stimulus that induces analysis and decision-making. The teams then lead the end of the decision-making process in charge of managing this situation without any other support from the CPPS. *Cyber Monitoring* type of scenarios encompasses the *Capture-Measure* and *Gap Recognition* steps that generate the stimuli behind all decision-making (see Appendix A). By making it possible to capture and analyze more data in real-time in the workshop, some technologies of I4.0 make it possible to identify instantly, or in some cases predictively, performance gaps or errors and problems encountered in production. The decision-making process can then be initiated more quickly to identify the actions to be implemented and thus improve operational efficiency.

The Internet of Things, CPS, big data analysis, and artificial intelligence (AI) play a crucial role in the *Capture-Measure* stage. These technologies make it possible to retrieve data from the field without human intervention to provide the information necessary to activate the decision-making process by strengthening sensorial capacities through image, speech, text recognition algorithms or by detecting unusual situations from analyzing massive data flows.

In the case of production processes whose implementation is not mainly carried out by operators, autonomous robots/machines play a decisive role as actuators capable of capturing data and communicating with other systems, particularly through technologies such as inter-machine communication (M2M). Finally, the cloud plays a unique role for all types of scenarios by promoting the pooling and sharing of information, ubiquitous access to shared computing resources, and collaboration approaches.

3.4 Type 2 *scenarios: Cyber search*

For this type of cyber-autonomy, the CPPS must propose one or more solutions to respond to a problem encountered by relying on a pre-established set of possible corrective actions.

Faced with an identified situation, the *Cyber Search* type of scenarios enhances the *Search* and *Diagnosis* steps to quickly analyze and target already known solutions to correct a problem or respond to an opportunity. The operator's level of attention and working memory are particularly stressed at this stage of the decision-making process and are critical factors limiting the interpretation of information from the environment. Simulation and immersion logics can also enhance the *Diagnosis* step by comparing the current situation in real time with the simulated situation on a virtual replica of the production system. Augmented Reality (AR) also helps the operator give visual access to information, allowing a better understanding of real situations and possible solutions while leaving the hands free. However, the complexity of implementing these solutions leads to favor the use of cloud-based problem-solving applications in the first phase.

The cloud's data storage and sharing capabilities make it possible to enhance the *Search* step of the decision-making process. It is then possible to build up a large knowledge base bringing together all the solutions already proven by all operational teams on several perimeters and production sites. The problem-solving methodologies deployed as part of continuous improvement processes (lean) make the search for root causes an essential and systematic step. Big data processing, advanced analysis techniques, and artificial intelligence are essential to discover hidden patterns of unknown correlations.

3.5 Type 3 *scenarios: Standard decision support*

For this type of cyber-autonomy, the CPPS must identify a problem, identify a set of possible solutions, and evaluate the most relevant(s) to propose an exploitable solution after a possible filtering of these. The specificity of this type of scenarios is based on the enhancement in the decision-making process of the *Evaluation* step preceded by the *Selection* step if one or more already known solutions have been identified.

Based on systematized data processing, the *Selection* step aims to limit the number of solutions to be processed subsequently at the level of the *Evaluation* step, which is generally more restrictive in terms of time and complexity of implementation. Filtering and questioning the relevance of solutions can be achieved by using multi-criteria decision methods coupled with IoT to compare solutions in real-time according to predefined criteria. The *Evaluation* step aims to assess whether solutions that have not been rejected at the end of the *Selection* step are likely to meet the objectives. Previous research has shown that an actor recognized for his expertise in operational decision-making situations evaluates an action plan using mental simulation to anticipate what would happen if this plan were applied in the context of the current situation. Simulation and immersion technologies play a particularly important role in supporting operational teams and reducing the cognitive load required by this step. The coupling between Artificial Intelligence (AI) and Simulation is not systematically necessary, as simulation systems can be operated without using AI. The linkage between Big Data Analysis and Simulation is also not systematically necessary, mainly because the implementation of simulation systems does not require the use of a very large amount of data. AR can complement, in some cases, simulation systems to facilitate the visualization of the consequences and outcomes of the solutions and scenarios envisaged.

4. PERSPECTIVES

Several development perspectives are possible at this stage. The first concerns the possibility of taking into account the upstream phase of training at the workstation for the mastery of (1) operational activities and (2) the steps of the decision-making process. This will include linking immersion technologies (augmented/virtual reality (AR/VR)) and learning logics (visual, auditory, or kinesthetic) to optimize the operator's function. The second perspective concerns the implementation of experiments in connection with four other types of autonomy 4.0 as identified by Rosin *et al.* (2021). This will then make it possible to have a global vision of the possibilities offered by technologies of I4.0 to strengthen the autonomy of operational teams. The third perspective will focus on conducting experiments with *opportunities* as the trigger stimulus of the decision-making process (the gap between a nominal situation and a target situation projected in the future). The objective will then be to test in another virtual environment (using digital twins, VR, or mixed reality), scenarios that cannot be considered now in the workshop or staging various strategic orientations to analyze their feasibility and impact. The last perspective will combine approaches to problems and opportunities to build a global training on Lean 4.0, allowing proposals to update Lean principles in an I4.0 context. As a continuation of the work undertaken, a new research project named GENOM for "*Généralisation d'Expérimentations Numérique, Organisationnelle, Managériales"* has been formalized and will provide an experimental platform and protocols necessary for the implementation and exploitation of the scenarios and case studies selected. On a broader level, this research project aims at defining all the I4.0 transformation plan's components with a particular focus on the human being and on integrating the technological, organizational and managerial dimensions. This will help optimizing the management role while supervising the changes related to the adoption of the innovations associated with I4.0. This project is based on a multidisciplinary approach (focused on individuals and their skills, technologies, production systems) necessary to understand these contemporary changes in a holistic way, their consequences and the role of actors in these changes.

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ANNEXE A : Proposal for decision-making processes in an operational context (Rosin et al., 2022)