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# Using simulation to orchestrate the upskilling and well-being of operators: an application to circular manufacturing systems

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## 1 Introduction

Today's environmental issues are prompting some manufacturers to rethink their production techniques and turn to the circular economy (CE). To make this shift from linearity to circularity, new production systems need to emerge. The term Circular Manufacturing System (CMS) is employed to describe industrial production systems that seek to maintain or reinstate the value of a previously used product by engaging in practices such as reuse, repair, refurbishment, reconditioning, remanufacturing, or repurposing (Denu et al., 2023). Research on circularity is currently growing rapidly, but is characterized in particular by its lack of empirical evidence and genuine contributions to research, to the point of being described as "scholarly bullshit" by Kirchherr (2023). In addition to this observation, there is no shortage of barriers inherent in these systems, and there is a strong need to provide empirical evidence on concrete issues encountered in these systems, that incorporate a multidisciplinary and sustainable approach (Denu et al., 2023).

Among the various barriers of circular systems, operators training and competences management seems particularly significant. Indeed, the extensive variability of considered products implies that customized process flows are required for each product (Klein et al., 2021). Thus, the intricacy involved in reprocessing products within a CMS demands highly skilled operators and a spectrum of specific expertise that may require an extended period of training. At the same time, industrial observations underline that the tasks required can be physically difficult and involve ergonomic risks (carrying loads, awkward posture, etc.). Moreover, the tasks could be perceived as downgrading, as they could involve cleaning used products that could be dirty. Some tasks could even involve dangerous products that need to be handled with care.

Moreover, the relationship between skills and health is intricately connected. Acquiring skills not only ensures the health and safety of employees but also contributes to the effectiveness of the systems

in which they operate. Simultaneously, the enhancement of operators' skills is tied to their well-being and impacts their responses in unpredictable work scenarios (Rabardel et al., 1998). Consequently, it becomes imperative to develop tailored training programs for operators to facilitate the mastery of essential skills for circular processes (Arredondo-Soto et al., 2016), that will both impact operator health and industrial system performance.

Simultaneously, various researchers speculate that emerging Digital Technologies (DTs) hold promise as valuable resources for CE (Bressanelli et al., 2018; Chauhan et al., 2022; Jabbour et al., 2022). These prospects are also in line with the principle of Industry 5.0, which aims to “places the well-being of the worker at the centre of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet” (European Commission, 2022). However, empirical evidence supporting this notion is scarce, and multiple barriers hinder the implementation of DTs, including high costs and technical challenges, as (Birkel and Muller, 2021; Denu et al., 2023; Raj et al., 2020). These obstacles dissuade companies from experimenting with DTs to enhance their processes.

## **2 Using Discrete Event Simulation to manage operators' skills in CMS.**

The aim of this communication is to present one of the possible applications of Discrete Event Simulation (DES) in a CMS in a perspective of Industry 5.0. Starting from an industrial problematic concerning the difficulty and time required to train operators in this type of industrial environment, a DES has been built to model the acquisition of skills in this type of system, as well as the preservation of their health.

### **2.1 Objectives**

A major challenge lies in the training of operators in CMS. Faced with these difficulties, hypotheses have been put forward concerning the organisation of work (such as job rotation for example (Battini et al., 2022; Bocewicz et al., 2023)) or the use of DTs to improve working conditions and learning, but their impact has not yet been fully demonstrated. The aim of this presentation is therefore to present a methodology for developing a DES that can simulate complex production systems and integrate the health and learning of operators. This type of simulation could for example be used to test work organisation scenarios that maximise the learning of the workforce while reducing the impact on health. However, there are a number of technical and scientific difficulties in simulating operator learning and health using DES. DES that takes human behaviour into account have already been used on the basis of existing mathematical models, but these are controversial and cannot faithfully reproduce operators in a system [12]. There is therefore a challenge in integrating social aspects (in particular the acquisition of skills, health, fatigue, etc.) and modelling these impacts on workshop performance in a DES.

### **2.2 Approach**

This presentation develops the methodology used to model the operator's learning and health in a CMS, as well as the choices made to create a DES. A multidisciplinary research teams combining engineering and human and social sciences (H&SS) has been put in place to integrate the complexity of human behaviour in DES. The first step was to create a physical simulation of one of S.MART Grenoble Alps technology platforms to study some of the processes involved in CMS. Real experiments were carried out with students on the case study of a tidal-turbine disassembly. The second step was to model

the data collected using Simio simulation software, and then to verify their relevance using simulations on the technology platform. Particular attention was paid to human modelling, with the help of an ergonomics and occupational psychology researcher involved in this research project, demonstrating the importance of multidisciplinary in this type of work.

### 3 Conclusions et perspectives

The implementation of CMS brings many complexities, and little empirical evidence with a systemic and multidisciplinary vision exists to support this transition to circularity in industry. Operators are particularly affected by the task's complexities, thus the need to monitor their health and skills

Succeeding in modelling operators in detail by including the latest knowledge in H&SS would make it possible to take better account of the human aspect in simulations, and thus to test scenarios that take account of the health and development of the operator in the workplace. As DES are mainly used in decision-making and industrial system design, the social stakes are high. However, a number of limitations need to be overcome. The complexity of modelling should not be underestimated, and current research has not been able to represent humans faithfully. In the search for a model based on real system data, it is important to list the variables needed to simulate the human in a way that is relevant and personalised to the simulation. The next step is thus to validate this methodology in a real industrial case. Further development would also integrate environmental aspects, to take account of the three pillars of sustainability.

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