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Empowering Field Operators in Manufacturing: a Prospective Towards Industry 5.0

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Abstract

In manufacturing systems, field operators represent a key bottleneck for operational efficiency to secure production systems' productivity, quality, and resilience. Through their direct engagement with production resources, they obtain a genuine understanding of the course operations on the manufacturing floor. The effective leverage of this knowledge within a digital framework that embraces human intelligence is a crucial value for the emerging Industry 5.0.
In this article, we envision the integration of intelligent Decision Support Systems (DSS) for empowering Blue-collar workers in production facilities. The paper makes a theoretical discussion about the role of digitalization in improving field operators' awareness of Production Planning and Maintenance. Moreover, we propose a software architecture for a DSS-enabled digital twin for empowering field operators in production decisions.

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Keywords: Digital Twin, AI, Industry 5.0, Situational Awareness, Production Planning, Maintenance, Field Workers, Operator 4.0

1. Introduction

Industry 5.0 (I5.0) is the human-centric industrial evolution from the fourth industrial revolution (I4.0). Whilst the key priority of I4.0 is process automation through the integration of digital technologies (e.g., Artificial Intelligence (AI), Internet of Things (IoT), and Cypher Physical production systems (CPPS)).

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The objective of I5.0 is conceptualized around leveraging the unique creativity of human experts to create smart, sustainable, and value-driven production systems [1].

The concept of I5.0 is still in its infant stage. Nevertheless, various adjacent definitions have been adopted to describe this evolving concept. According to Rada [2], I5.0 is the first industrial revolution led by human creativity that holds high regard for living standards and environmental conditions. The European Economic and Social Committee recognizes I5.0 as the new industrial wave based on Synergetic factories that integrate CPPS and human intelligence to address I4.0s' workforce weakening [3]; such perspective looks at I5.0 as an enhanced version of I4.0.

Maddikunta et al. [4] identified the I5.0's key added features (i.e., Smart additive manufacturing, Predictive Maintenance, Hyper customization, and Cyber-physical Cognitive Systems). To this end, I5.0 is envisioned to substantially impact fields like healthcare, cloud manufacturing, supply chain, and manufacturing systems. Various key enabling technologies contributes to the creation of the next industrial revolution (e.g., Edge Computing (EC), Digital Twins (DTs), Internet of Everything (IoE), Blockchain, and Collaborative Robots (Cobots). These digital technologies, alongside others, may allow manufacturers to fulfill the ultimate I5.0 goal of mass customization by effectively integrating humans' cognitive abilities [4].

Production planning entails extensive decision-making by subject matter experts (i.e., production planners) to ensure the resilience of operational and strategic production plans. The automation of Production Planning & Control (PPC) (i.e., Smart PPC) has been extensively realized within the context of I4.0 by using AI and Machine Learning (ML) techniques [5,6]. However, smart PPC represents an essential pillar of I5.0. as such, incorporating the human component as a central player in the PPC processes makes it a hot prospect for value-driven and human centrism in future factories. This paper embraces human centricity in PPC, so we propose a framework architecture based on key I5.0 enabling technologies to build intelligent decision support systems (DSS) that will allow humans' active engagement in managing the manufacturing floor.

The paper is organized as follows; the second section displays a brief literature review and discusses the contribution of this paper. Section 3 discusses the paradigm shift of I5.0 from the field workers' perspective. Section 4 depicts a DSS architecture proposal in the era of I5.0 for an integrated PPC and maintenance application. Finally, the conclusion discusses the managerial implications, limitations, and future directions for this work.

2. Literature Review

I5.0 aims to increase the connectivity and intelligence of smart factories by synergizing human intelligence with machine computing capabilities enabled by AI to achieve a fundamental paradigm shift in manufacturing systems' automation. This novel shift in the production paradigm leads to improved productivity, higher overall quality, and energy efficiency [4]. The scientific community has a divided belief between the I4.0 and I5.0 campaigns. However, various studies started elaborating on the concept of I5.0 and its applications. For instance, Nahavandi et al. [1] provided practical insights about the economic and productivity impacts of I5.0; this study also concludes that I5.0 will be able to create jobs in the field of human-machine interaction. Similarly, Maddikunta et al. [4] investigate the definitions of I5.0, its potential use cases, and enabling technologies. Through their state-of-the-art analysis, Maddikunta et al. [4] expect that the humanization of the working space in I5.0 will considerably increase manufacturing productivity and customer satisfaction.

The application research of I5.0 in the manufacturing domain is prematurely emerging. Nevertheless, various studies build their application ground around the concept of I5.0. Thus, Javaid and Haleem [7] identified critical indicators for applying I5.0 in manufacturing. Cary Sherburne [8] suggested the utilization of I5.0 in the textile industry. In a similar context, Fatima et al. [9] investigated the role of IoT on production plant and workhouse automation within I5.0. The foundational ground of workforce empowerment using digital technology is well-tackled in the literature body of Operator 4.0 [10,11]. This well-tracked record for designing human assistive technologies in manufacturing systems is essential for developing value-driven applications in I5.0. In this study, we address the case of empowering the front-line workforce (i.e., operators in the field) to perpetually improve their ability to make sound and prompt decisions using I5.0 technologies.

3. Industry 5.0: a shift in the Working paradigm

3.1 Empowerment of field workforce in operational decisions

Many challenges are related to deploying the concept of I5.0 on industrial floors. Alongside the preexistent technological constraints associated with the disposition of data-driven and interconnected CPPS, the human-centricity of I5.0 represents an additional contest for designing standardized and ethical systems that embrace human creativity and contemplate legal policies and environmental considerations [12]. Since the I5.0 wave is primarily associated with the human component, it is expected to cause a paradigm shift in the nature of human work within the industrial systems toward increased operators' autonomy and overall production flexibility.

Field operators represent the front liners in every manufacturing system. This role naturally makes them a bottleneck for operational effectiveness regarding quality, safety, and productivity. A skilled workforce is expected to swiftly make hard operational decisions to continuously alter the course of production in the short and middle term. However, in many cases, those decisions are hindered through prolonged bureaucratic communication that increases the reaction time and reduces the overall efficiency of production significantly. The pursuit of I5.0 is based on actively engaging humans in the industrial processes using their adequate interaction with digital technologies and leveraging data-driven applications to improve their situational understanding, allowing them to prompt decisions accurately.

3.2 AI-based Decision support systems for Operators

Decision Support systems (DSS) represent a significant legacy of the I4.0. Many systems utilize industrial information leveraging simulation, ML, and industrial analytics, in the form of AI applications and digital twins to infer handy insights for decision-makers in the strategic and tactical levels of manufacturing management. The quality of the produced insights naturally depends on the utilized models, approaches, and the raw data collected from the production floor. However, as described in fig 1, most DSS applications in the I4.0 framework focus on the strategic and tactical levels of the organizational hierarchy. Therefore, DSS in I4.0 are more tailored to white-collar workers. In I5.0, digitalization helps to tackle the necessity to engage managers, planners, and font liners (i.e., blue-collar workers) in manufacturing decisions.

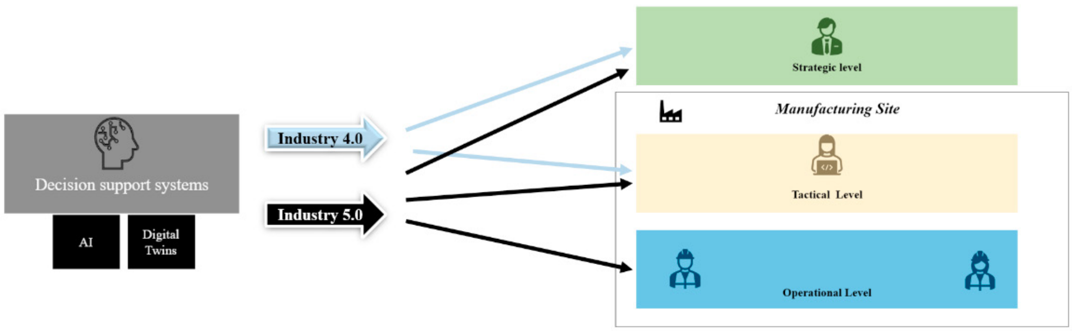

Fig 1. Prospective focus of DSS in Industry 5.0

4. Operational DSS in PPC and Maintenance

Operators that work near industrial machinery need to continuously monitor their operational status in terms of health and productivity. Usually, planners are responsible for providing continuous plans for the operational activities; nevertheless, operators on the field need to have a crystal-clear understanding of the various operational considerations (I.e., Remaining Useful Life (RUL), Production Sequence, and dispatching rules).

A typical problem of the PPC faced by production planners is finding an optimum tradeoff between scheduling maintenance activities and maximization of productivity. This issue can be primarily addressed using digitalization strategies, adopting a DSS of interconnected manufacturing systems that empower planners with the optimum solution for their production dilemmas.

As described in fig 1, DT-enabled AI DSS in I5.0 may improve decisions throughout the entire chain of command on the manufacturing floor. At the operational level, blue-collar workers represent an essential stakeholder of the DT-enabled AI systems. From one side, meaningful inference about the systems' status can be transmitted by the DSS; on the other side, field operators provide feedback to the system allowing input updating of the system.

4.1 Software architecture of DSS

The framework described in fig 2 depicts the software architecture and the principal inputs and outputs of a DSS that improves field operators' awareness about production and maintenance plans in a disruptive and uncertain industrial process.

The Industrial Internet of things (IIoT) is an essential component of the system's design. Industrial information flows through the IIoT infrastructure (i.e., IoT edge devices and cloud) to allow the industrial data to flow continuously from the industrial system to feed DSS.

A simulation-based DT represents the basic construct of the DSS. The DT is achieved by integrating ML and simulation models using cloud infrastructure. This integrated AI-based simulation fashion aims to produce three core components that comprise the DSS for situational awareness in integrated PPC and Maintenance (i.e., Simulation-based DT, Adaptive production planning, and Smart maintenance modules).

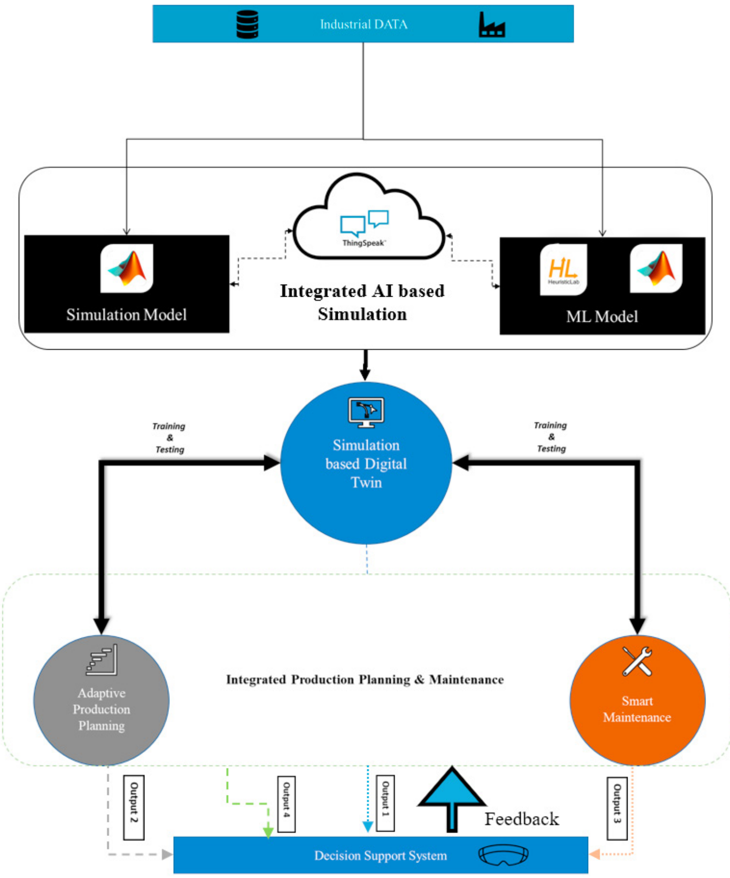

Fig 2. Architectural framework for empowering field operators in integrated PPC and Maintenance in I5.0

4.1 Simulation-based DT module

The goal of this module is to mirror and simulate the production facility. The module is primarily based on a simulation model built to provide near-real-time analytics about the production's Key Performance Indicators (KPIs) and its potential bottlenecks (i.e., Output 1). As described in fig 2, the simulation model obtains input data about productivity, waste, and machine failures from the manufacturing floor's sensors (i.e., sensors in machines, workers, and their environment). The choice of the simulation environment is application-dependent to a great extent. However, for this specific use case, we utilize MATLAB SimEvents [13] to replicate the manufacturing facility and obtain fruitful connectivity with IIoT devices using ThingSpeak [14] through Cloud.

4.2 Adaptive production planning module

This module aims to leverage ML models and Heuristics to dynamically find optimum production schedules and resource allocations (i.e., Output 2). The module is linked with the simulation-based DT to test the developed solutions, hence having and continuous learning & testing process of the ML model. We suggest using the HeuristicLab software [15] for the ML and optimization problems at this stage. Output 2 assists field operators in understanding the upcoming production activities and may facilitate their cooperation with other human and robotic resources (i.e., Cobots).

4.3 Smart maintenance module

This module applies ML algorithms in machine data to conduct predictive and prescriptive maintenance [16]. The output of this module (Output 3) displays the RUL of machines to the operators in the field to have a clear idea about machine handling. Moreover, through prescriptive maintenance, the DSS can suggest to the workers the best intervention strategy that can prolong the machine's life span, decrease waste, and optimize productivity. Like in the case of the production planning module, this utilizes the simulation model as a test bed for improving the inference quality of the DSS.

4.4 Integrated Production planning & maintenance

The output of this module (i.e., Output 4) aims to find an optimum tradeoff between the production and maintenance schedules. The decision at this level helps the entire organizational structure, including blue-collar workers, to dynamically have clear visibility of the production plan. Moreover, field operators can continuously engage with the DSS by providing swift feedback about the production status and machines' health.

5. Conclusion & Future remarks

This paper paves the way for a novel application ground in the field of integrated PPC and maintenance. The contribution embraces the human centricity of the emerging I5.0 framework by proposing a software architecture for a DSS-enabled DT that improves the workforce's situational awareness about PPC and maintenance decisions. The contribution of this paper is twofold; first, we make a theoretical discussion about the potential of the DSS in production planning within the I5.0. Secondly, we propose a conceptual design for the DSS software component and key outputs.

In future research activities, we plan to elaborate upon the utility of the proposed theoretical contribution by putting the proposed architecture into implementation in an industrial use case. Additionally, future activities incorporate the deployment of ML and heuristics using near-real time data integration , and the user experience (UX) investigation to understand the proposed approach's effectiveness in workforce employment.

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