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Corresponding author:
Karolin Kelpman
karolin.kelpman@taltech.ee

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An overview of smart workplace solutions and potential improvement areas

Karolin Kelpman, Kristo Karjust and Jüri Majak

Department of Mechanical and Industrial Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia

ABSTRACT

The development of Industry 5.0 aligns with the aims of the European Commission's 2024–2029 priorities and contributes to three of the six key goals. Therefore, enhancing manufacturing practices remains a growing priority. However, flexible manufacturing systems (FMSs) and smart workplace solutions are still not widely used, especially in small and medium-sized enterprises (SMEs). A possible reason for this is that the process of adjusting and reconfiguring assembly lines is time-consuming, labour-intensive, requires higher investment and specialized expertise. However, an up-to-date review and analysis of the field is needed to start finding advanced solutions. This research identifies potential improvement areas for smart workplace solutions.

The current study provides an overview of the technologies of existing flexible manufacturing systems, pinpoints current limitations and research gaps, analyzes which areas could be improved by implementing AI methods and tools. The drawbacks of current solutions and existing AI capabilities are analyzed. Current solutions and AI-enhanced approaches are summarized and possible benefits of AI integration are highlighted. As a result, optimization strategies and procedures tailored to particular production processes will be developed in a future study.

1. Introduction

The advancement of Industry 5.0 is an important topic for research efforts because it aligns with the three key goals of the European Commission's priorities: the European Green Deal, due to the focus on sustainability; A Europe Fit for the Digital Age, due to the implementation of smart technologies; and An Economy That Works for People, due to its human-centric approach [1]. Flexible manufacturing systems (FMSs) are an integral part of modernizing and optimizing production processes due to the ability to adapt to customer demands and process smaller batches. However, the concept used in Industry 4.0 requires an update to align with the new goals [2].

Industry 5.0 is defined as a humanized technological advancement in industry, which focuses on workers, societal impacts and sustainability. A human-centric approach requires better smart workplace solutions that would place humans at the centre of technological advancements to ensure a more sustainable, resilient and equitable industrial future by addressing both societal and environmental challenges. The focus is primarily on the human worker and on the factory-side operator. [3]

The concepts of Industry 5.0 or even 4.0 are often not feasible for small and medium-sized enterprises (SMEs), which play a substantial role in manufacturing. The implementation of smart solutions in SMEs remains limited due to high cost, complexity and the need for skilled workers. [4]

The current study concentrates on existing smart workplaces and the technologies of (FMSs), as well as on possible improvements through the implementation of human-centric AI solutions, especially in SMEs. The research for this article was conducted using a systematic literature review approach, focusing on articles, conference papers, book chapters and surveys published in English between 2015 and 2024 in the ScienceDirect database. A summary of the results is presented and references are used accordingly – a selection of the most relevant articles has been chosen to provide a concise overview.

2. Current solutions, their drawbacks and research gaps

Current solutions used in FMS focus on automation, modularity and the possibility of reconfiguring production lines to adapt to variable demands. These systems use advanced robotics, collaborative robots, and IoT-enabled tools allowing for custom and small-batch production. [2,4]

Smart workplaces utilize digital twins (DTs), augmented reality (AR), Internet of Things (IoT), and AI-driven workflows to increase productivity and enable real-time decision-making (Fig. 1), allowing enhancing operator assistance, productivity, real-time analytics, and system agility [5,6]. These technologies contribute to human-centric design by addressing the ergonomic and psychological needs of workers [ibid.]. AR applications provide guidance to operators to reduce errors and improve efficiency [ibid.]. IoT sensors and analytics platforms enable faster issue resolution by monitoring production processes [2]. Intelligent workplaces prioritize collaboration between humans and AI-enabled systems aiming to optimize workflow and enhance operator well-being [7].

However, the potential of FMS and smart workplaces remains largely unrealized, especially in SMEs, due to the following drawbacks of existing solutions:

- **High cost:** the investment required for system installation, maintenance, upgrades and reconfiguration of the lines all contribute to the cost, making these technologies unattainable for SMEs. [8]
- **Complex programming:** current solutions often require complicated programming to accommodate reconfiguration and production line adjustments, limiting system adaptability. [8]
- **Lack of expertise:** many companies, especially SMEs, lack skilled personnel to manage, operate and troubleshoot FMS. For companies in remote locations, it is often impossible to find such people locally. This expertise gap slows the implementation of advanced manufacturing technologies in SMEs. [4,8]
- **Limited use of human-centric design:** human-centric solutions, which consider the physical, cognitive and psychological needs of workers, are insufficiently implemented in current FMS setups. This results in sub-optimal operator well-being and productivity. [6,9]
- **Insufficient focus on ergonomics and operator safety:** existing FMS and smart workplace solutions often lack a focus on ergonomic and safety measures, exposing workers to risks and contributing to workplace injuries and fatigue. Enhanced safety measures, such as AI-assisted risk assessments and human-centric design, remain underutilized. [6,10]
- **Challenges in AI implementation:** significant challenges hinder the implementation of AI, such as data silos, integration difficulties, and high initial costs. [9]
- **Lack of real-time analytics integration:** many current systems rely on reactive approaches, which means a lack of real-time data use, causing delays in identifying and resolving production inefficiencies. For example, maintenance solutions are often reactive, causing unplanned downtime. [11]
- **Lack of integration between AR and AI:** the full potential of AR in manufacturing is unrealized due to insufficient integration with AI. AI-enhanced AR systems could adapt instructions in real-time based on contextual factors, further improving operator efficiency and reducing cognitive load. [5]
- **Scalability for SMEs**: many solutions are tailored to large enterprises and lack affordability or adaptability for smaller setups [8]. Cloud-based AI platforms could help SMEs to adopt and scale technologies dynamically [2]. A systematic approach would allow SMEs to identify automation opportunities by evaluating their existing workflows, resource allocation, and bottlenecks, which would ensure that automation investments are targeted and cost-effective. [12]
- **AI-driven predictive maintenance:** the integration of AI-driven predictive maintenance is limited, despite its ability to reduce downtime and improve system reliability. Instead, reactive maintenance strategies dominate current practices. [6]
- **Operator training and upskilling:** there is insufficient focus on reskilling and upskilling workers to interact effectively with AI-enhanced systems. Training programs tailored to foster AI-skilled workforces remain underdeveloped. [7]
- **Data silos and integration challenges:** lacking data integration across systems hinders the benefits of AI. Research is needed to develop open, interoperable systems to improve real-time analytics and decision-making. [11]
- **Sustainability and energy efficiency: the** sustainability aspect of automated systems is often overlooked. Advanced AI systems could monitor efficiency, optimize energy usage and reduce waste, contributing to greener manufacturing environments. [3]
- **Trust and transparency in AI systems:** AI systems often remain difficult to understand to the average person, which hinders trust among operators and managers. Research into explainable AI (XAI) could address this issue, fostering greater acceptance. Building trust is crucial, as the resistance to change often stems from limited knowledge of the long-term benefits of new technologies. [7,8]

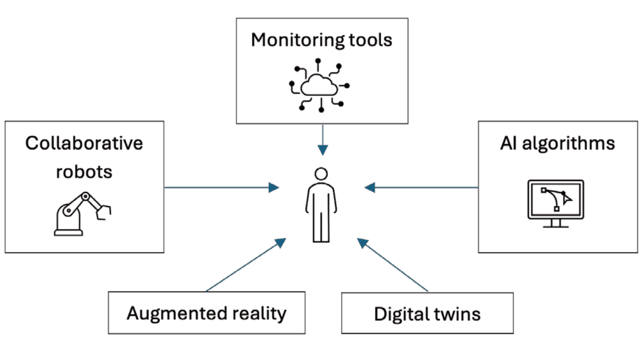

Fig. 1. Human-centric intelligent workplace technologies.

The challenges and research gaps outlined above emphasize the need for transition towards Industry 5.0 that

Table 1. Summary of current solutions and AI-enhanced approaches

Topic	Current solutions	AI-enhanced approaches	Benefits of AI integration
Safety measures	Lacking	AI-assisted risk assessment	Enhanced safety
Ergonomics	Basic	Human-centric AI	Improved operator well-being
Human collaboration	Limited	Enhanced human-AI collaboration	Safer and more productive work
Maintenance	Reactive	Predictive	Reduced downtime
Production optimization	Reactive adjustments	AI-driven analytics	Reduced bottlenecks and waste
Decision-making	Manual	Real-time AI	Increased efficiency
Cost	High	Modular and scalable	Increased accessibility for SMEs
Scalability	Static	Cloud-based, dynamic scaling	Better resource utilization
Workers' skill level	General	AI-competent workforce	Reduced need for specialists
Sustainability	Lacking	AI metrics	Monitored environmental impacts

utilizes AI-driven, human-centric, and sustainable manufacturing practices. SMEs are a critical sector of the economy and the barriers to adopting advanced technologies must be addressed.

3. Possibilities of implementing AI

AI-driven technologies have the potential to transform FMS, smart workplaces, and SMEs, aligning them with Industry 5.0. The following AI applications in manufacturing have been identified:

- **Safety measures:** current manufacturing systems often lack proactive safety mechanisms. AI-assisted risk assessment enables real-time hazard detection and prevention, enhancing operator safety and reducing workplace incidents. [10]
- **Ergonomics:** traditional systems provide only basic ergonomic support, but human-centric AI systems adapt to the physical and cognitive needs of workers. This improves operator well-being by personalizing work environments through real-time feedback, workload balancing and ergonomic adjustments. [6,13]
- **Human collaboration:** unlike traditional setups that limit interaction, AI can enhance human-AI collaboration. This allows machines and workers to collaborate seamlessly, creating safer and more productive environments. Developing XAI models to build trust and improve operator adoption must be a priority. [7,13]
- **Maintenance:** AI enables the use of predictive maintenance strategies instead of traditional reactive ones, significantly reducing downtime. AI systems can predict potential equipment failures, enabling preemptive actions. [6,12]
- **Production optimization:** AI-driven analytics optimize production workflows by identifying bottlenecks and reducing waste. These improvements are particularly beneficial in dynamic production environments. [11]
- **Decision-making:** traditional systems rely on manual decision-making, which is slow and prone to errors. Real-time AI decision-making increases efficiency by providing instructions based on real-time data. [7]
- **Cost and scalability:** conventional systems are often costly and lack flexibility, which makes them difficult for SMEs to implement. AI's modular and cloud-based solutions provide dynamic scaling, enable better resource utilization and cost reductions. [2]
- **Workers' skill level:** AI-driven tools reduce dependence on highly specialized personnel, as the systems are designed to assist and upskill general workers, fostering an AI-competent workforce. A structured training framework for SMEs to enhance operator competencies in AI-driven systems would be beneficial. This can include leveraging AR, virtual reality (VR), and interactive training modules to familiarize operators with new technologies. [6,12]
- **Sustainability:** sustainability metrics embedded into AI algorithms help to monitor the environmental impacts of manufacturing processes and align them with Industry 5.0's focus on environmental responsibility. [13]

Based on the above listed drawbacks of existing solutions and AI capabilities, current solutions and possible AI-enhanced approaches are summarized in Table 1.

As shown in Table 1, several parameters can be improved with AI implementation in smart workplace solutions. It can improve safety, efficiency, cost-effectiveness, human-centrism, and the resilience of manufacturing systems, in line with Industry 5.0 initiatives [3]. By leveraging AI, manufacturers can address evolving operational challenges and unlock new opportunities for growth and innovation.

Some of the mentioned AI solutions have been implemented in industry, but not on a large scale, and usually not in SMEs due to lack of tailored solutions, uncertainty about return on investment, and resistance to change [8]. The working group has long-term experience in applying AI methods and tools, with recent research covering safety/risk analysis [14–16], product/process optimization [17,18], etc.

Finding the best solutions requires collaboration between SMEs, academic institutions and technology providers to fill the knowledge gaps. A phased, data-driven approach is needed for SMEs to reap the benefits of human-centric automation. This includes using diagnostic tools to identify inefficiencies, piloting small-scale AI solutions, and scaling up based on the measurable outcomes. An iterative approach allows SMEs to start with low-cost automation solutions and gradually integrate AI-driven tools. [12]

4. Conclusion

This study provides an overview of current FMS and smart workplace technologies, highlighting their limitations and identifying areas where AI integration can make improvements. The outlined AI solutions contribute to human-centric design, predictive maintenance, and scalability. Proper implementation of AI can solve issues that hinder SMEs from enhancing their manufacturing practices through the adoption of advanced technologies. The study summarizes current solutions and possible AI-enhanced approaches, highlighting possible benefits of AI integration.

The current study may have missed some relevant publications due to the specific search strings and keywords used for reference selection. Publications not available on ScienceDirect were not reviewed. Case studies are needed for further research on this topic. Information from real workplaces needs to be collected and evaluated to ensure that practical solutions are developed.

Future research will focus on defining and conducting case studies, as well as developing AI algorithms that analyze data from production lines and provide relevant information and instructions to the operator. Further investigation into AI communication design will also be conducted to enhance understandability and trust, thereby enabling wider applications.

Data availability statement

All research data are contained within the article and can be shared upon request from the authors.

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Ülevaade targa töökoha lahendustest ja võimalikest parendusvaldkondadest AI-algoritmide rakendamiseks

Karolin Kelpman, Kristo Karjust ja Jüri Majak

Tööstuse 5.0 arendus on kooskõlas Euroopa Komisjoni 2024.–2029. aasta prioriteetidega ja panustab kolme peamise eesmärgi saavutamisse kuuest. Seetõttu on tootmistavade täiustamine jätkuv prioriteet. Siiski ei ole paindlikud tootmissüsteemid (FMSs) ja nutikad töökohalahendused veel laialdaselt kasutusel, eriti väikestes ja keskmise suurusega ettevõtetes. Võimalikuks põhjuseks on asjaolu, et koosteliinide reguleerimine ja ümberseadistamine on aeganõudev ja töömahukas ning nõuab eriteadmisi. Kaasaegsete lahenduste leidmiseks on vajalik valdkonna ajakohane ülevaade ja analüüs. Uurimistöö käigus määratletakse võimalikud parendusvaldkonnad AI-algoritmide juurutamiseks FMS-i ja targa töökoha lahendustesse.

Uuringus antakse ülevaade olemasolevatest paindlikest tootmistehnoloogiatest, tuuakse välja praegused piirangud ja uurimislüngad ning analüüsitakse, milliseid valdkondi saaks täiustada tehisintellekti meetodite ja tööriistade rakendamisega.