Mechanical Engineering – Scientific Journal, Vol. **43,** No. 2, pp. 75–82 (2025)
Number of article 695
In print: ISSN 1857–5293
Received: October 15. 2025
On line: ISSN 1857–9191
Accepted: December 10. 2025
UDC: [681.5:338.45]:004-043.72
https://doi.org/10.55302/MESJ2543275as

Original scientific paper

INTEGRATION OF LEAN PRINCIPLES AND AUTOMATION FOR DIGITAL TRANSFORMATION IN MANUFACTURING

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A b s t r a c t: Introducing automation in manufacturing can lead to increasing efficiency in the assembly process, reducing Lean production waste, and enhancing operator ergonomics. The purpose of combining automation and Lean is to bridge the gap between digital transformation and human-centric automation, ensuring technological evolution together with the operator's well-being while driving industrial optimization, innovation, and efficiency. According to the review, synergy is required; however, challenges remain in effectively aligning automation with Lean principles. This paper aims to analyze the possibilities for integrating automation and Lean management according to literature, exploring similarities and the implementation practices to achieve sustainable and competitive manufacturing.

Key words: Lean; automation; manufacturing; Industry 5.0

ИНТЕГРАЦИЈА НА LEAN-ПРИНЦИПИТЕ И АВТОМАТИЗАЦИЈАТА ЗА ДИГИТАЛНА ТРАНСФОРМАЦИЈА ВО ПРОИЗВОДСТВОТО

А п с т р а к т: Воведувањето автоматизација во производството може да доведе до зголемување на ефикасноста во процесот на склопување, намалување на Lean-загубите и подобрување на ергономијата на операторот. Целта на комбинирањето на автоматизацијата и Lean е да се премости јазот помеѓу дигиталната трансформација и автоматизацијата ориентирана кон човекот, обезбедувајќи еволуција на производниот систем заедно со благосостојбата на операторот, а наедно поттикнувајќи оптимизација, иновации и ефикасност. Според прегледот, потребна е синергија; сепак, остануваат предизвици во ефикасното усогласување на автоматизацијата со принципите на Lean. Овој труд има за цел да ги анализира можностите за интегрирање на автоматизацијата и Lean според литературата, истражувајќи ги сличностите и практиките за имплементација за да се постигне одржливо и конкурентно производство.

Клучни зборови: Lean; автоматизација; производство; Индустрија 5.0

1. INTRODUCTION

Lean manufacturing (LM) and automation represent two complementary yet sometimes conflicting approaches to improving production efficiency. LM aims to eliminate waste, enhance flexibility, and empower workers by focusing on continuous improvement and value-driven processes [1]. On the other hand, automation integrates technology to streamline operations, reduce human error, and improve overall performance. While lean automation offers significant advantages – such as minimizing process inefficiencies and optimizing workflow – it also presents challenges, including high implementation costs, reduced process flexibility, and increased reliance on technology over human expertise [2]. A balanced approach to digital technologies and ultimately automation is essential to keep it simple, cost-effective, and aligned with lean principles. Too much automation can make systems overly complex, reduce operator engagement, and limit flexibility in production. To ensure efficiency without compromising lean benefits, automation should be strategically planned.

The motivation for this paper comes from the need to implement digital technologies for processing automation, efficiency improvement, and enhanced ergonomics within the Smart Learning Factory – Skopje. These needs were identified during the initiation of the TEAM 5.0 scientific research project, led by the Faculty of Mechanical Engineering – Skopje, and supported by Ss. Cyril and Methodius University in Skopje and the Smart Learning Factory – Skopje. This paper builds on these efforts by exploring the relationship between Lean principles and automation to optimize manufacturing processes. The introduction should briefly place the study in a broad context and define the purpose of the work and its significance. In the first part of the paper, Lean Automation concept will be reviewed through several relevant papers. In the second part, Automation in manufacturing as a subject will be covered to establish a connection with the mentioned project where an improvement is needed in the assembly process, preferably done with a Pick-by-Light (PbL) system on the existing manual workstation. The third part includes discussion on the relationship between Lean and Automation providing synergy between the familiar Lean principles and main automation & control benefits.

2. LEAN AUTOMATION

In [3] authors discuss the synergy between LM and automation, emphasizing that Lean principles are a prerequisite for successful automation. The study highlights that while automation alone increases productivity from 27% to 61%, incorporating Lean tools such as inline quality control (IQC) before automation raises productivity further to 74%. This indicates that optimizing processes with Lean principles before automation maximizes efficiency, making automation more effective. The findings reinforce that digitalization and Industry 4.0 require Lean foundations to ensure smart, flexible, and responsive manufacturing. This is also discussed in [4], where the author highlights the positive correlation between I4.0 and Lean while noting the challenge of digital waste, urging its integration into value stream mapping. Limited to Swedish SMEs and select Lean practices, the study calls for further research on digital waste in areas like supplier development, employee digital engagement, and smart maintenance beyond Sweden. In [5] the authors explore the relationship between LM and Automation, focusing on the importance of finding the right balance between them to enhance manufacturing competitiveness. As industries face rising labor costs and a competitive market, automation is increasingly adopted to improve efficiency. However, without careful integration, automation may not align with Lean principles, leading to inefficiencies. The study highlights key factors for successful Lean automation, including a holistic approach, strategic planning, flexible solutions, ergonomics, waste reduction, and process simplification. It concludes that fully automated systems are not always necessary or feasible; instead, Lean tools can guide manufacturers toward simpler, cost-effective automation options. Sources [6] and [7] consistently show that combining Lean practices with Industry 4.0 technologies results in higher operational performance than applying either approach alone. Lean supports companies in adopting digital tools more effectively, while I4.0 technologies (such as IoT, AI, and cyber-physical systems) help address challenges like product customization and process complexity. Papers [8] and [9] acknowledge the fact that Industry 4.0 offers many new opportunities for automation of the traditional manufacturing processes and offers Lean-related solutions including technologies such as Automatically Guided Vehicles (AGVs), IoT, 5G and CPS.

A very important point is made in [10], where the authors explore the application of Lean Management principles beyond manufacturing, particularly in the banking and financial services sector, where automation and digitalization dominate. While this is not a priority for this paper, an interesting conclusion emerges – "Lean first, then Automate".

Finally, an integration of Lean Automation (LA), Lean Production (LP) and Industry 4.0 technologies is presented in [11]. Authors empirically test the link between LA and operational performance using data from over 200 firms. The findings reveal two key LA components: one focused on operational stability and supplier efficiency, and another on streamlining processes for improved delivery. The study confirms a positive correlation between LA and performance improvements, emphasizing the need for structured integration strategies.

Table 1

Overview of the literature review on Lean automation

Ref.	Main points
[3]	Lean as a prerequisite for automation, showing that IQC boosts productivity from 27% to 74%. Industry 4.0 relies on Lean to ensure smart, flexible manufacturing.
[4]	Industry 4.0's impact on Lean automation is examined, emphasizing digital tech adoption in SMEs, digital waste issues, and the need for further research on automation strategies.
[5]	The balance between Lean and automation for competitiveness is explored, highlighting strategic planning, waste reduction, and Kaizen for cost-effective and efficient automation.
[6]	Lean & Industry 4.0 integration, showing a strong correlation. Combining both boosts performance beyond individual effects, making Lean key to digital transformation.
[7]	Lean and Industry 4.0 enhance flexibility and efficiency in modern manufacturing. A structured model is suggested to align Lean with digital transformation.
[8]	An action plan for integrating Industry 4.0 in Lean is presented via design, integration, and continuous improvement. AI, AGVs, and 5G help minimize waste and boost efficiency.
[9]	Lean-Industry 4.0 synergy is discussed, using CPS and digital tools for automation. However, gaps exist in frameworks for flexible, automated workstations in Lean environments.
[10]	Lean is applied to banking, introducing 'Lean first, then Automate,' ensuring process optimization before digitization. The model solves sequencing issues in automation adoption.
[11]	Lean Automation (LA) as the integration of Lean Production (LP) and Industry 4.0 (I4.0) technologies, showing a positive impact on operational performance. It highlights the need for a structured approach to integrating these paradigms.

The papers summarized in Table 1 consistently highlight that Lean principles serve as a foundation for successful automation and digital transformation in manufacturing. While automation and Industry 4.0 technologies enhance productivity and flexibility, their effectiveness is maximized when preceded by Lean practices such as waste reduction, process simplification, and quality control.

Another concept that is widely known in literature is the Automation pyramid which represents the hierarchical structure of industrial automation systems [12]. The control level (PLCs, DCS) automates processes, while the supervisory level (SCADA) enables monitoring. The MES level optimizes production, bridging automation with business operations, and the enterprise level (ERP) handles planning and resource management. With Industry 4.0, this rigid hierarchy is evolving into a more interconnected, data-driven system. Considering the evidence from Table 1, authors suggest modification of this pyramid (Figure 1) by adding a base that is related to the Lean practices that are essential for smoother implementation of the following layers. Continuous improvement along the pyramid layers is also present to sustain the Lean aspects during the work.

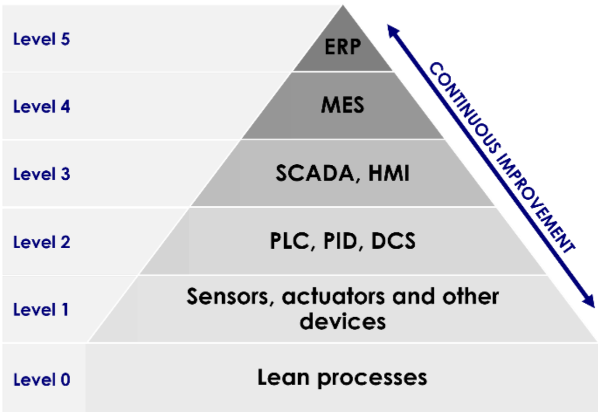

Fig. 1. Modified automation pyramid

3. AUTOMATION IN MANUFACTURING

This part of the paper focuses on reviewing scientific papers in the field of automation in manufacturing, especially in the assembly process. Nowadays, some product assembly processes still include manual activities that contribute to the Lean waste such as waiting, motion, over-processing, defects, inventory, unused talent, and more [13]. Implementing automation should replace the manual assembly process. As required in Industry 5.0, human satisfaction and well-being must be in collaboration with smart technologies and digital transformation for maintaining a suitable working environment. Including automation in the digitalization of some manual processes can raise the operator's productivity and self-esteem. Sometimes operators find process automatization stressful due to losing their job position or working with machines, following sequences, but it can help them increase their productivity or possibilities of doing more intelligent jobs.

In manufacturing, especially in Poka-Yoke-related solutions, the assembly process is led with the pick-by-light (PbL) method to prevent the process from making unexpected mistakes. It is considered an effective method to ensure detection and prevention while assembling. So, according to [14], 31 participants have been involved in assembly material order picking using both pick-by-paper (PbP) and PbL methods. In this paper operator's situation awareness (SA) has been measured through the Situation Awareness Global Assessment Technique (SAGAT) methodology. According to the results presented, no significant differences in SA levels between the two methods have been noticed. This finding suggests that PbL systems do not enhance or reduce a worker's ability to understand and respond to their surroundings during order picking. Evaluating the operator's physical stress while performing tasks, the heart rate has been monitored. The results represented that PbL led to increased physiological strain, but reduced subjective workload compared to PbP methods. Providing a smart manufacturing environment, in [15] is represented Poka-Yoke principles with PbL providing higher operational efficiency with error minimization. This paper presents an improved PbL configuration, combining hardware and software to guide operators with visual cues, boosting productivity, quality, and flexibility. The system includes a control unit, visual indicators (LEDs or displays), input devices (barcode readers, optical sensors), and communication interfaces. Sensors detect operator presence and item selection, while barcode readers track inventory movement. A central processing unit (CPU) processes signals, manages PbL operations, and ensures seamless communication with MES or ERP systems via wired or wireless networks for real-time updates. To enhancing product assembly assistance and avoid errors during it, the authors in [16] developed a PbL system based on computer vision technology. The product was developed using an ESP-32 microcontroller, a USB camera with a computer vision algorithm, LED indicators, TCP/IP communication protocol, and a router for data transfer. The camera is used for object detection based on a machine learning (ML) or deep learning (DL) approach. A few studies [7–21] reveal that PbL is a much more effective approach for efficient product assembly than alternatives such as augmented reality (AR).

In [22], the authors proposed the system that dynamically adjusts its automation level in response to varying production demands and conditions, providing flexibility and efficiency in manufacturing processes. According to adaptive automation, there is represented integration of cyber-physical systems (CPS) and the Internet of Things (IoT) to enable real-time monitoring and control of the picking sequences. This paper focuses more on the software part, including advanced human-machine interfaces (HMIs) to enable smooth operator interaction and system adaptability. Also, the embedded large network of CPS enables real-time data exchange between physical components and digital control systems, while the IoT devices collect and transmit the data from the actions in the picking station. The author's approach is more inclined to Industry 4.0 by promoting interoperability, information transparency, and decentralization of decision-making in assembly systems.

Despite PbL, PbP, pick-by-display (PbD), pick-by-projection (PbD) [23] is a method that introduces innovative prototype assistance designed to enable the manual order-picking process by projecting visual cues directly onto storage locations, guiding operators in real time. This approach utilizes projection technology by displaying picking information directly onto storage racks/shelves. The setup involves projectors mounted in the picking area to ensure clear and accurate visual guidance. Further improvement of the system is implementing sensors for the operator's action detection and correct item selection confirmation. PbP according to the authors, could be found as a promising tool that provides efficiency and accuracy while picking sequences and could be a very inclusive method by incorporating those with cognitive impairments. Most of the papers focus on software development instead of hardware improvement of the manufacturing system. In [24] is represented integration of Advanced planning and scheduling (APS) software in the traditional zero-defect manufacturing (ZDM) architecture where the main point is to enhance production efficiency and sustainability by reducing costs, energy consumption, and material waste, improving lead times and production planning. According to [25] is presented standard, semi-automated PbL Poka-Yoke working station where the operator picks the item according to the light and then activates the button to confirm that the item is picked from the container. A display visualizes the remaining number of parts in the container. According to the Lean principles, the assembly time for one item is 15 minutes. Improving the PbL system with additional hardware (sensors and other devices) and software, implementing CPS or IoT, there is a possibility that assembly time could drop below 15 minutes in the meantime rising the operator's satisfaction at the workplace. Digitization and interconnection of industrial processes through technologies like IoT, CPS, and big data analytics are a baseline of Industry 4.0 principles. It serves as the foundation for developing more sophisticated automation solutions in production and warehousing. Nowadays, one of the important factors is not only having the smartest manufacturing or assembly process but the evolution towards human-centric collaboration is the key factor leading to a smart, efficient, and successful environment [26].

PLCs, as one of the crucial devices in the control systems, continue to play an important role in industrial automation, but their functionalities are evolving to meet new requirements such as making the software more user-friendly and adaptable to changing manufacturing needs. Such improvements align with the human-centric focus of Industry 5.0 [27]. Table 2 summarizes these insights.

T a b l e 2

Overview of the literature review on automation in manufacturing

Ref.	Main points
[14]	Comparison of PbL and PbP methods in assembly order picking. 31 participants were tested using SAGAT methodology. No significant differences in SA were found. PbL increased physiological strain but reduced subjective workload.
[15]	PbL enhances operational efficiency and error minimization in Poka-Yoke systems. New PbL architecture integrates hardware (sensors, controllers, barcode readers) and software for guiding operators via visual cues. Data is transferred via MES/ERP for real-time updates.
[16]	Development of a PbL system using computer vision with ESP-32 microcontroller, USB camera, machine learning (ML)/deep learning (DL) for object detection, LED indicators, and TCP/IP communication. More effective than AR-based solutions.
[17], [18], [19], [20], [21]	Studies highlight that PbL is more efficient than AR for product assembly assistance, reducing cognitive load and improving accuracy.
[22] [18]	Adaptive automation in PbL integrates Cyber-Physical Systems (CPS) and IoT for real-time monitoring and flexible automation. Advanced Human-Machine Interfaces (HMI) improve user experience and system adaptability.
[23]	Pick-by-Projection (PbD) introduces a method where projectors display picking instructions on storage locations, enhancing accuracy and accessibility. Future improvements include sensors for detecting operator actions.
[24]	Integration of Advanced Planning and Scheduling (APS) software into Zero-Defect Manufacturing (ZDM). Focus on software improvements, reducing costs, energy consumption etc. Industrial Internet of Things (IIoT) is used for data transfer.
[25]	PbL Poka-Yoke workstation requires manual confirmation by pressing a button. Upgrading with additional sensors and CPS/IoT could reduce assembly time while improving operator satisfaction. Lean principles suggest reducing assembly time by 15 minutes.
[26]	Industry 4.0 focuses on digitization, IoT, CPS, and big data analytics for smart manufacturing and automation. However, Industry 5.0 shifts towards human-centric collaboration and sustainability.
[27]	Programmable Logic Controllers (PLCs) remain crucial in automation but are evolving to be more user-friendly and adaptable. This aligns with Industry 5.0 principles of human-centric design.

4. RELATION OF LEAN AND AUTOMATION

As a starting point for any Lean discussion are always the Lean principles as set by Womack [1]. Table 3 summarizes the Lean principles and the Automation & Control aspects that commonly C these principles.

If we review the Toyota House of Lean, also known as the House of Toyota Production System (TPS) [28], it does not explicitly include automation as one of its core pillars. However, automation is indirectly incorporated through the concept of Jidoka and continuous improvement.

One of the main pillars of the House of Lean is Jidoka, which refers to "automation with a human touch." It means that machines and processes are designed to detect abnormalities and stop automatically when a problem occurs. This concept is a form of smart automation that ensures quality at the source while allowing human intervention when needed. In modern applications, Jidoka has evolved to include IoT, AI-driven quality control, and predictive maintenance, making automation a key enabler of Lean principles [29].

The House of Lean emphasizes Kaizen, or continuous improvement. While traditional Kaizen focuses on incremental changes through human-driven problem-solving, modern Lean systems integrate automation to enhance efficiency and accuracy. Digital tools, real-time data, and Industry 4.0 technologies now support Lean improvements, such as automated data collection, machine learning for process optimization, and robotic process automation for repetitive tasks [30], [31].

The Just-in-Time (JIT) pillar of the Toyota House of Lean focuses on eliminating waste by delivering exactly what is needed, when it is needed, and in the right quantity. Automation supports JIT through automated material handling (AGVs), real-time inventory tracking, and digital Kanban systems, reducing lead times and improving production flow.

T a b l e 3

Relationship between Lean principles and Automation & Control

Lean principle	**Definition**	**Relations to Automation & Control**
Define value	Focus on what customers consider valuable and eliminate anything that does not add value.	Optimization – automation and control are implemented to enhance efficiency and eliminate non-value-added processes through digital technology.
Map the value stream	Identify waste and inefficiencies in the process flow and remove bottlenecks.	Data and analytics – Automation systems collect and analyze real-time data to identify inefficiencies using technologies such as IoT, SCADA etc.
Create flow	Ensure a smooth production process with minimal delays, interruptions, or inefficiencies.	Operational stability – Automated feedback systems ensure steady operations and flow between (automated) systems.
Establish pull	Produce only what is needed, when it is needed, to reduce inventory and waste.	Adaptability - Automated scheduling, demand forecasting, and smart inventory management optimize production without overproduction or excess stock.
Seek perfection	Commit to constant optimization and refinement.	Continuous improvement – AI and machine learning continuously refine system performance, while predictive maintenance prevents downtime and inefficiencies.

5. CONCLUSIONS

Automation in manufacturing is crucial for efficiency, operator ergonomics improvement, and error reduction. However, prior process optimization and a certain level of leanness are essential for successful implementation. This paper reviewed Lean automation and manufacturing automation, exploring their synergy and mutual benefits. While automation is not a core pillar of the Toyota House of Lean, it plays a key role through Jidoka (automation with a human touch), continuous improvement (Kaizen), and Just-in-Time (JIT). Industry 4.0 technologies, such as IoT, AI-driven quality control, and predictive maintenance, enhance these Lean principles by improving responsiveness and waste reduction. However, automation must be strategically integrated to prevent inefficiencies, reinforcing the need for Lean foundations before digital transformation. Future research should focus on structured approaches to merging Lean and automation for optimized, sustainable manufacturing.

Future research in the beforementioned TEAM 5.0 project will include practical implementation of these findings and providing experimental evidence of the synergy between Lean and automation in manufacturing.

Acknowledgement: The authors would like to thank Ss. Cyril and Methodius University in Skopje, Faculty of Mechanical Engineering and Smart Learning Factory – Skopje, for the support in the scientific project "TEAM 5.0 – Towards Industry 5.0 and Automation Excellence Transforming Efficiency in Assembly Macnufacturing" and making the publication of this paper possible.

REFERENCES

[1] Womack, J. P., Jones, D. T. (1997): Lean Thinking – Banish Waste and Create Wealth in Your Corporation. *Journal of the Operational Research Society*, **48** (11), 1138 – 1148. https://doi.org/10.1038/sj.jors.2600967.

[2] Alqoud, A., Schaefer, D., Milisavljevic-Syed, J. (2022): Industry 4.0: Challenges and Opportunities of Digitalisation Manufacturing Systems. https://doi.org/10.3233/ATDE220560.

[3] Urmee, S. A., Hossain, Md. M. (2023): Lean Manufacturing is a Prerequisite for Automation, A Quantified Study. August 8. https://doi.org/10.21203/rs.3.rs-3196059/v1.

[4] Alieva, J., Powell, D. (2021): The Automation of Lean Practices: Digitalized or Digitally Wasted? *Journal of Industrial Ecology* pp. 651–661. https://doi.org/10.1007/978-3-030-85910-7_69.

[5] Shafras Nafais (2017): *Automated Lean Manufacturing*. Thesis. DOI:10.13140/RG.2.2.15047.70561

[6] Buer, S.-V., Semini, M., Strandhagen, J. O., Sgarbossa, F. (2021): The Complementary Effect of Lean Manufacturing and Digitalisation on Operational Performance. *Int J Prod Res*, **59** (7), 1976–1992. https://doi.org/10.1080/00207543.2020.1790684

[7] Saraswat, P., Agrawal, R., Rane, S. B. (2024): Technological Integration of Lean Manufacturing with Industry 4.0 toward Lean Automation: Insights from the Systematic Review and Further Research Directions. *Benchmarking: An International Journal,* **32**(1), 1909–1941. https://doi.org/10.1108/BIJ-05-2023-0316.

[8] Vlachos, I. P., Pascazzi, R. M., Zobolas, G., Repoussis, P., Giannakis, M. (2023): Lean Manufacturing Systems in the Area of Industry 4.0: A Lean Automation Plan of AGVs/ IoT Integration. *Production Planning & Control*, **34** (4), 345–358. https://doi.org/10.1080/09537287.2021.1917720

[9] Kolberg, D., Zühlke, D. (2015): Lean Automation Enabled by Industry 4.0 Technologies. *IFAC-PapersOnLine*, **48** (3), 1870–1875. https://doi.org/10.1016/j.ifacol.2015.06.359.

[10] Bortolotti, T., Romano, P., Nicoletti, B. (2010): Lean First, Then Automate: An Integrated Model for Process Improvement in Pure Service-Providing Companies, In: Vallespir, B., Alix, T. (eds): *Advances in Production Management Systems. New Challenges, New Approaches*. APMS 2009. IFIP Advances in Information and Communication Technology, Vol. **338**, pp. 579–586, Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-16358-6_72.

[11] Rossini, M., Costa, F., Tortorella, G. L., Valvo, A., Portioli-Staudacher, A. (2022): Lean Production and Industry 4.0 integration: how Lean Automation is emerging in manufacturing industry. *Int J Prod Res*, *60* (21), 6430–6450. https://doi.org/10.1080/00207543.2021.1992031.

[12] Chhetri, S. R., Faezi, S., Rashid, N., Al Faruque, M. A. (2018): Manufacturing Supply Chain and Product Lifecycle Security in the Era of Industry 4.0. *Journal of Hardware and Systems Security*, **2** (1), 51–68. https://doi.org/10.1007/s41635-017-0031-0.

[13] ISO 22400-2:2014(en): *Automation systems and integration – Key performance indicators (KPIs) for manufacturing operations management* – Part 2*: Definitions and descriptions,* 2014.

[14] Stockinger, C., Steinebach, T., Petrat, D., Bruns, R., Zöller, I. (2020): The Effect of Pick-by-Light-Systems on Situation Awareness in Order Picking Activities. *Procedia Manuf*, 45, 96–101. https://doi.org/10.1016/j.promfg.2020.04.078.

[15] Trojanowska, J., Husár, J., Hrehova, S., Knapčíková, L. (2023): Poka Yoke in Smart Production Systems with Pick-to-Light Implementation to Increase Efficiency. *Applied Sciences*, **13** (21), 11715. https://doi.org/10.3390/app132111715.

[16] Hercog, D., Bencak, P., Vincetič, U., Lerher, T. (2022): Product Assembly Assistance System Based on Pick-To-Light and Computer Vision Technology. *Sensors*, **22** (24), 9769. https://doi.org/10.3390/s22249769.

[17] Dalle Mura, M., Dini, G. (2021): Augmented Reality in Assembly Systems: State of the Art and Future Perspectives, pp. 3–22. https://doi.org/10.1007/978-3-030-72632-4_1.

[18] Moghaddam, M., Wilson, N. C., Modestino, A. S., Jona, K., Marsella, S. C. (2021): Exploring Augmented Reality for Worker Assistance versus Training. *Advanced Engineering Informatics*, 50, 101410. https://doi.org/10.1016/j.aei.2021.101410

[19] Schuster, F., Engelmann, B., Sponholz, U., Schmitt, J. (2021): Human Acceptance Evaluation of AR-Assisted Assembly Scenarios. *J Manuf Syst*, **61**, 660–672. https://doi.org/10.1016/j.jmsy.2020.12.012

[20] Wang, Z., Bai, X., Zhang, S., Wang, Y., Han, S., Zhang, X., Yan, Y., Xiong, Z. (2021): User-Oriented AR Assembly Guideline: A New Classification Method of Assembly Instruction for User Cognition. *The International Journal of Advanced Manufacturing Technology,* **112** (1–2), 41–59. https://doi.org/10.1007/s00170-020-06291-w.

[21] Minow, A., Stüring, S., Böckelmann, I. (2020): Mental Effort and Asability of Assistance Systems in Manual Assembly – A comparison of Pick-to-Light and AR contours through VR simulation. In: Stephanidis, C., Antona, M. (eds): *HCI International 2020* – Posters. HCII 2020. *Communications in Computer and Information Science*, Vol. **1224**. Springer, Cham. https://doi.org/10.1007/978-3-030-50726-8_60

[22] Bortolini, M., Faccio, M., Galizia, F. G., Gamberi, M., Pilati, F. (2021): Adaptive Automation Assembly Systems in the Industry 4.0 Era: A Reference Framework and Full–Scale Prototype. *Applied Sciences*, **11** (3), 1256. https://doi.org/10.3390/app11031256.

[23] Baechler, A., Baechler, L., Autenrieth, S., Kurtz, P., Hoerz, T., Heidenreich, T., Kruell, G. (2016): A Comparative Study of an Assistance System for Manual Order Picking – Called Pick-by-Projection – with the Guiding Systems Pick-by-Paper, Pick-by-Light and Pick-by-Display. In: *49th Hawaii International Conference on System Sciences (HICSS)*, IEEE, 2016, pp. 523–531. https://doi.org/10.1109/HICSS.2016.72.

[24] Trebuna, P., Pekarcikova, M., Dic, M. (2022): Comparing Modern Manufacturing Tools and Their Effect on Zero-Defect Manufacturing Strategies. *Applied Sciences,* **12** (22), 11487. https://doi.org/10.3390/app122211487.

[25] Savković, M., Komatina, N., Djapan, M. (2022): *Improving the Quality of Final Product by Poka-Yoke System on Assembly Workstation: A Case Study*, Belgrade, https://www.researchgate.net/publication/366124432.

[26] Fatima, Z., Tanveer, M. H., Waseemullah, Zardari, S., Naz, L. F., Khadim, H., Ahmed, N., Tahir, M. (2022): Production Plant and Warehouse Automation with IoT and Industry 5.0. *Applied Sciences*, **12** (4), 2053. https://doi.org/10.3390/app12042053.

[27] Argilovski, A., Vasileska, E., Tuteski, O., Kusigerski, B., Jovanoski, B., Tomov, M. (2024): Bridging the Gap: Qualitative Comparative Analysis of Industry 4.0 and Industry 5.0, *Mechanical Engineering – Scientific Journal*, Vol. **42**, no. 1, pp. 61–66. DOI: 10.55302/MESJ24421061a

[28] Jeffrey K. L. (2024): *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*.

[29] Romero, D., Gaiardelli, P., Wuest, T., Powell, D., Thürer, M. (2019): *Rethinking Jidoka Systems under Automation & Learning Perspectives in the Digital Lean Manufacturing World.* https://doi.org/10.0/Linux-x86_64.

[30] Dang-Pham, D.; Hoang, A.-P.; Vo, D.-T.; Kautz, K. (2022): Digital Kaizen: An Approach to Digital Transformation. *Australasian Journal of Information Systems,* **26**. https://doi.org/10.3127/ajis.v26i0.3851.

[31] Vasileska, E., Argilovski, A., Tomov, M., and Gecevska, V. (2024): Implementation of Machine Learning for Enhancing Lean Manufacturing Practices for Metal Additive Manufacturing, *IEEE Transactions on Engineering Management*. Vol. **71**, pp. 14836–14845 DOI: 10.1109/TEM.2024.