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Original scientific paper

ENHANCING MANUFACTURING EFFICIENCY: A LEAN INDUSTRY 4.0 APPROACH TO RETROFITTING

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A b s t r a c t: Industry 4.0 technologies are already affecting global supply chains by revolutionizing how companies manufacture and distribute their products and services. Many companies are affected by this transformation, especially small and medium-sized enterprises (SMEs) that are keen to enhance their market competitiveness as quickly and easily as possible. The transformation from traditional approaches to Industry 4.0 can bring many benefits, however, this transition involves adopting technologically advanced machinery with a high level of digitalization and communication. The cost and time to replace old machines could be unsustainable for many SMEs and that is why these enterprises seek alternative solutions for the digitalization of their legacy machines, such as retrofitting. This paper conducts a review of both retrofitting and Lean Industry 4.0 (Lean 4.0) to identify the challenges and benefits of both concepts and explore how they can interact and merge with each other to help SMEs to increase their market competitiveness.

Key words: Lean industry; Industry 4.0; retrofit; manufacturing; digitalization

ПОДОБРУВАЊЕ НА ПРОИЗВОДСТВЕНАТА ЕФИКАСНОСТ: ПРИСТАП НА ПОСНАТА ИНДУСТРИЈА 4.0 КОН РЕФОРМИРАЊЕТО

А п с т р а к т: Технологиите на Индустријата 4.0 веќе влијаат на глобалните синџири на снабдување, посебно во начинот на кој компаниите ги произведуваат и дистрибуираат своите производи и услуги. Многу компании се погодени од оваа трансформација, особено малите и средни претпријатија (МСП), кои сакаат што побрзо и за што пократко време да ја подобрат својата конкурентност на пазарот. Трансформацијата од традиционалните пристапи кон Индустрија 4.0 може да донесе многу придобивки, но оваа транзиција вклучува усвојување технолошки напредни концепти со високо ниво на дигитализација. Трошоците и времето за замена на старите машини може да не бидат одржливи или достижни за многу МСП, и затоа овие претпријатија бараат алтернативни решенија за дигитализација на нивните постоечки машини. Овој труд спроведува преглед на концептот на реформирање преку призмата на Посната и Индустријата 4.0, за да ги идентификува предизвиците и придобивките од двата концепта и да истражи како тие можат да им помогнат на МСП да ја зголемат својата конкурентност на пазарот.

Клучни зборови: Посна индустрија; Индустрија 4.0; реформирање; производство; дигитализација

1. INTRODUCTION

Industry 4.0 (I4.0) offers many modern technologies that companies could utilize to enhance their manufacturing processes, such as smart sensors, the Internet of Things (IoT), cloud computing, artificial intelligence (AI), robotics, simulations, and 3D printing. These technologies enhance efficiency, cut costs, boost production speed, and improve product quality. They enable real-time data collection and analysis, empowering informed decision-making and operational optimization. However, to prepare the organization for I4.0, it is not necessary to incorporate all the available features and technologies that I4.0 offers. Also, many companies, especially small and medium enterprises (SMEs), are not financially capable of implementing these technologies and/or buying entirely new machines that employ these technologies [9]. Considering this challenge, an alternative to taking off to I4.0 with low cost and agility is known as retrofitting, which is the reuse of old equipment and its integration with new I4.0 technologies [15]. By prioritizing the implementation of I4.0 technologies that align with important company objectives, such as process optimization, continuous improvement, and lean manufacturing, organizations can achieve significant improvements while minimizing costs and realizing a quick return on investment.

If we investigate the reports about the digitalization of enterprises (mainly SMEs), it is easy to observe that many of them struggle to digitally transform, mainly due to the high cost of digitalization [4, 21, 23]. Although many of these SMEs have digital transformation strategies in place, less than half can implement these strategies successfully due to the shift in investment priorities during the pandemic [21]. Whilst the economic uncertainties in recent times have also added unique challenges – the high implementation cost, cash flow challenges, the workforce digital upskilling gap, and low awareness of government initiatives are some common drawbacks faced by SMEs along their digital transformation journey [14].

Retrofitting, which involves modifying existing machinery, is not new and predates Industry 4.0. However, its practical implementation has gained popularity for its cost-effectiveness. In digital transformation (DT), retrofitting is crucial for integrating legacy machinery into a networked production environment. While retrofit projects aren't always low-cost, a strategic approach can help identify and address inefficiencies, bottlenecks, and waste in processes and equipment. This concept also addresses the Sustainability Development Goals (SDG) set by the United Nations as a common objectives for "peace and prosperity for people and the planet, now and into the future" [42]. Considering retrofit's nature of enabling easier digitalization and avoiding replacement of legacy machinery, it can be associated with the following SDG:

– SDG8 Decent work and economic growth,

– SDG9 Industry, innovation, and infrastructure,

– SDG12 Responsible consumption and production.

The following chapter of this paper focuses on the methodology that was utilized to perform this research. In the third chapter, literature review on retrofit in manufacturing is shown. The fourth chapter introduces Lean 4.0 including a brief introduction to both Lean manufacturing, Industry 4.0, and the relationship between them. The fifth chapter focuses on the joint benefits of Lean manufacturing and retrofit towards faster, easier, and low-cost digital transformation of the companies.

2. METHODOLOGY

The research methodology used for this paper is shown in Figure 1. The paper is intended as a preliminary investigation of the topic of retrofitting and its relation to Lean manufacturing and Industry 4.0. The first three steps include more general literature review regarding the main topics: retrofit (in manufacturing), Lean and Industry 4.0 (Lean 4.0), followed by a discussion regarding the mutual impact of Lean 4.0 and retrofit.

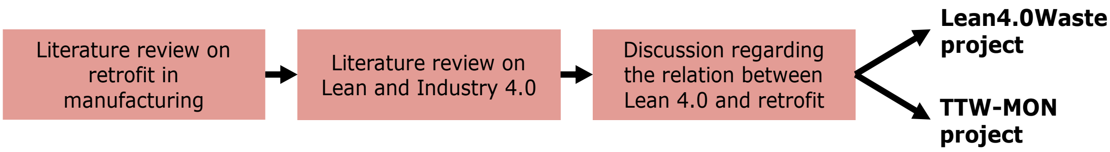

Fig. 1. Research methodology

This paper is also an initial input to two scientific projects that are currently on-going at the Faculty of Mechanical Engineering in Skopje: Lean 4.0 Waste and TTW-MON. This research helped the project teams to establish general understanding of retrofit, Lean 4.0 and their joint benefits towards the digital transformation. The Lean 4.0 Waste project aims to eliminate Lean wastes using digital technologies like sensors and augmented reality. The experiments will take place at the Smart Learning Factory – Skopje (SLFS). TTW-MON, focuses on retrofitting a legacy turning machine with a monitoring system. This system enables predictive maintenance by tracking tool wear during processing. Monitoring cutting forces and vibrations, advanced signal processing, and machine learning algorithms will model tool wear in real-time. The experiments within this project will take place at the laboratory for production engineering and FabLab Skopje.

Findings from Lean4SMEs project [34] as well as DigiTS-ME project [35] will also be incorporated within the paper.

3. RETROFITTING IN MANUFACTURING

Retrofitting can be defined as the process of extending a system, *e.g.*, an industrial production line, with an additional functionality that was not available when it was originally designed and built [11]. Another definition of retrofitting states that it is a process of replacing obsolete operating systems and machine components to extend their working lives. It benefits the organizations as retrofitting incurs lower costs as compared to purchasing the new machine, enhances the precision of the machine and delivers higher quality output [26].

When it comes to manufacturing, considering the new digitalization trends, the need for retrofitting legacy equipment instead of completely new machinery is a preferred option [52], especially for SMEs in less developed countries that have limited resources to invest in bigger digitalization projects. However, although retrofitting seems like a simple solution, there are many factors that could make manufacturers' minds up on whether to retrofit or not [9, 11], including:

– current process readiness/leanness – leaner processes tend to be more flexible and ready for changes,

– cost and duration of the retrofit projects, considering that retrofit projects size can vary therefore the cost and the duration of such projects are not always certain,

– upskilling/reskilling of the personnel – due to the change investment in additional training for the operators is needed.

According to the literature, retrofitting provides many benefits for the manufacturing industry, including extending the lifecycle of legacy machines and enabling the implementation of cost-effective, easily deployable solutions. These retrofits facilitate the integration of modern Industry 4.0 technologies, improving connectivity in existing equipment. Furthermore, retrofitting enhances machine monitoring for predictive maintenance, preventing maintenance-related issues and downtime. A detailed analysis by [11] categorizes the benefits of retrofitting into sustainability, viability, compatibility, and functionality. Even though the benefits of retrofitting in manufacturing are notable, during the literature review, it was observed that there has been a lack of practical examples of retrofitting in manufacturing in recent years. Retrofit concepts are much more present in the research areas such as energy efficiency [6], building efficiency [22], CO_2 capture [19], and sustainability in general [7].

No matter the research field, many authors addressed the need for structured approach to retrofitting. Such is [36], who designed detailed methodology for retrofitting of production systems focusing on low-cost and user-friendly approach to retrofitting in SMEs. There are also many companies that work in the field of digitalization such as FESTO [17] and Siemens [24] who developed their own methodological approaches to retrofitting. Most of these methodologies consist of four general phases as shown in Figure 2.

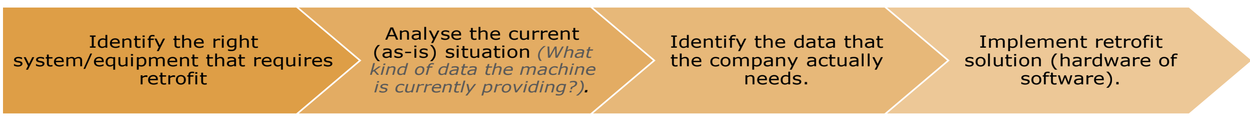

Fig. 2. General retrofit implementation methodology

4. LEAN 4.0

The term "Industry 4.0" originated in 2011 [43]. In the following year, a working group on Industry 4.0 presented implementation recommendations to the German Federal Government where manufacturing and logistics systems, embodied as Cyber Physical Production Systems (CPPS), extensively leverage the globally accessible information and communications network for highly automated information exchange [44, 45]. This system aligns production and business processes seamlessly [37]. On the other hand, Lean Manufacturing is a systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product or service at the pull of the customer in pursuit of perfection [38].

The relationship between Lean and Industry 4.0 is often discussed in the scientific community, and in the previous research of the authors of this article [5]. In a comprehensive elaboration regarding the relationship between Lean and Industry 4.0, [46] states that there are several possible scenarios of this relationship:

– Lean and Industry 4.0 have nothing in common,
– Lena is the foundation for implantation of Industry 4.0,
– Industry 4.0 is the foundation for implementation of Lean,
– Lean and Industry 4.0 overlap and create new concept – Lean 4.0,
– Lean and Industry 4.0 oppose each other,
– Lean and Industry 4.0 are the same thing.

According to this, the development of the relationship between Lean and Industry 4 can be described in three phases: ignoring, opposing, and finally – getting together.

T a b l e 1

Development phases of the relationship between Lean and Industry 4.0

Phase	Discussion
Ignoring	This potentially comes from the fact that the definitions regarding Lean and Industry 4.0 are usually different. Lean is a manufacturing philosophy that focuses on waste elimination through following the principles of Lean, while Industry 4.0 focuses on technologies that are not necessarily related to each other. In the other hand, many times, Industry 4.0 is defined as simple as a period of time just like the past three revolutions, while Lean is more related to the organizational culture that have been around no matter what type of technology is used in the manufacturing processes.
Opposing	Some authors do indicate that they oppose each other [47, 48], and this is due to the fact that Lean focuses heavily on the people, while one of the biggest risks when relying on technology is reduction of the teams. Additionally, Lean is considered as an "on-budget" initiative, as opposed to the Industry 4.0 technologies which are a costly investment in the most cases.
Getting together	Lean being the foundation for the implementation of Industry 4.0 technologies is quite an expected perspective considering the complexity of the digital technologies. It is very important that whenever manufacturers upgrade their existing processes with some of the digital technologies, these processes should be previously optimized (waste to be eliminated), so that they could adopt the digitalization easier and faster [49]. According to previous literature review on this topic [5, 50], most of the authors indicate that Lean is the needed foundation that the organization needs to implement before implementing the technologies of Industry 4.0. This provides a perspective of strong synergy between the two terms.

In order to clarify the relationship between these two concepts, a new concept is arising in the literature, known as Lean 4.0 – a concept that unites both Industry 4.0 and Lean [5, 39, 40, 41]. Lean 4.0, also known as Digital Lean or Lean Industry 4.0, is a concept that describes the enhancement of the traditional Lean methods with I4.0 capabilities. While the question whether Lean and Industry 4.0 are compatible concepts still remains attractive to the scientific community [50], many authors have already published successful examples of traditional Lean tools that have been digitalized such as Digital Kanban [12], CPS oriented smart Jidoka systems [12, 15, 17], IoT supported JIT production systems [51], and Lean Six Sigma 4.0 [3].

5. RETROFIT WITH LEAN 4.0 PERSPECTIVE

Lean is constantly evolving, especially in the ever-changing context of I4.0 [9]. However, the transition from traditional production systems and Industry 3.0, especially for SMEs in North Macedonia has been, and still is, very poor. This can be clearly seen during the research project DigiTS-ME, where the digital maturity of the Macedonian SMEs is investigated [35]. Companies are lacking both Lean and digital solutions. Lean is an approach that needs time to be implemented, and the same goes for digital transformation. However, smaller steps should be undertaken as soon as possible if the companies want to stay competitive on the global market. This is where retrofit solutions should play their role, especially in fast, targeted to specific areas or indicators, and cost-friendly delivery of results towards leaner and more digitalized production process [1, 10]. Figure 3 shows the benefits of merging retrofit and lean practices [25, 29, 30, 31, 32].

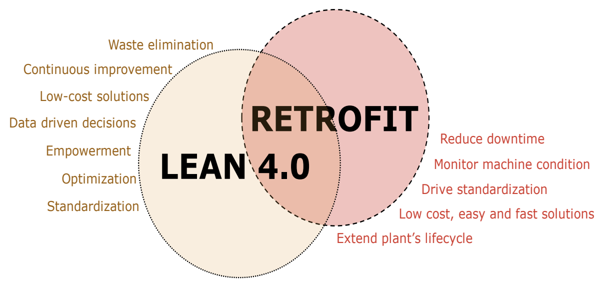

Fig. 3. Joint benefits of retrofit in manufacturing and Lean 4.0

The two main concepts of Lean, continuous improvement, and waste elimination can be clearly addressed by retrofit. It is important to note that the applicative examples of employing retrofitting to foster continuous improvement and waste elimination are very rare, however from a more philosophical aspect this relation is evident.

Continuous Improvement (CI), a concept that revolves around Kaizen which is an activity that continuously improves all functions and involves the entire organization. Kaizen relies heavily on data, and retrofitting can play a vital role in supporting this process by digitalizing machines and processes to provide data to the Kaizen teams, therefore supporting the entire process of CI. It is also important to mention that some retrofit projects can easily be classified as Kaizens since Kaizens are considered as improvements that involve minimal or no financial investments. The same goes for problem-solving methodologies such as Six Sigma which is based on shopfloor data, especially in the Measure and Analyze phases of the DMAIC framework [13]. This methodology, which is strongly connected to the Lean philosophy, would be carried out more efficiently and effectively with more reliable and up-to-date data.

Eliminating waste, as another perspective where retrofitted systems help Lean 4.0 production systems. Traditional Lean philosophy defines seven (or eight, depending on literature source) different wastes. Waste in Lean Manufacturing is defined as activities that do not add any value for the customer. They can come in the form of time, material, and labor. The seven wastes according to Toyota Production Systems include: transport, inventory, motion, waiting, overproduction, over-processing, and defects. In literature, usually one more waste is included in this list which is the non-utilized talent [12]. The relation of this aspect with the retrofit concept will be explained through the example of employing sensors on legacy equipment.

Legacy equipment lacks sensors to indicate their operating status, making sensors one of the most common retrofitting solutions when it comes to enhancing manufacturing efficiency through digital means. Led by this, both aforementioned projects Lean4.0Waste and TTW-MON that are currently running at the Faculty of Mechanical Engineering – Skopje, the possibilities of sensors in an attempt to step into the digitalization era without replacing the legacy equipment are exploring.

As it is planned within both aforementioned projects, Lean4.0Waste and TTW-MON, by employing sensors within selected areas of the manufacturing, we can foster continuous improvement and low-cost digitalization (retrofitting). Some of the examples found in literature for this type of improvements include employment of temperature sensors for avoiding downtime due to machine overheat [20], or accelerometers for detecting abnormal vibrations. Many quality aspects of the products and the processes can be addressed through low-cost digitalization such as detection of the right position of the products during the process, avoiding additional operator motion [27, 2], detecting unwanted parts in the products and therefore avoiding rework and defects [8]. Force sensors can help avoid product variations (therefore avoid defects or reworks) by measuring the weight of the raw material, parts, or assemblies [28].

6. CONCLUSIONS

By retrofitting the legacy equipment, many Lean 4.0 challenges can be addressed. Retrofitting can foster some of the main Lean aspects such as continuous improvement and waste elimination. This paper performed a literature review on three seemingly different concepts: Lean, I4.0, and retrofit, and focuses specifically on the relationship between Lean 4.0 and retrofit, building upon previous research that has established and defined the relationship between Lean and I4.0 [4, 5]. Although there are not many production-related retrofitting examples, there are meaningful aspects where both Lean 4.0 and retrofitting benefit from each other. Starting from the cost of implementation to the easier transition from traditional to digital Lean, retrofit projects could help the manufacturers, especially SMEs, reach their digitalization goal in an easier and faster manner while they contribute to keeping the established Lean standards and/or enhancing leanness.

Considering the lack of literature in the field of practical manufacturing applications, more such solutions should be explored and verified. This will partially be done during the aforementioned projects Lean4.0Waste and TTW-MON. Additionally, there is a lack of standardized approach/methodology to retrofit, specifically in the manufacturing sector where existing concepts such as Lean, should be considered in the base.

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REFERENCES

[1] Müller, J., Voigt, K.-I., Kiel, D. (2018): What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*. **10**(1) DOI:10.3390/su10010247

[2] Anjoran, R. (n.d.). 14 *Mistake Proofing Examples: Improve Quality at Virtualy no Cost*. Retrieved from CMC: cmc-consultants.com

[3] Antony, J., McDermott, O., Powell, D., Sony, M. (2022): The evolution and future of lean Six Sigma 4.0. *The TQM Journal*. **35**(4), DOI:10.1108/TQM-04-2022-0135

[4] Argilovski, A., Jovanoski, B., Minovski, R., Kochov, A. (2022): Industry 4.0 for more competitive SMEs – Review of existing Industry 4.0 maturity models. *15th EPIEM Conference* 2022, (pp. 41–47). Graz. DOI:10.3217/978-3-85125-889-9

[5] Argilovski, A., Jovanoski, B., Minovski, R., Musliji, A. (2022): Mapping the current research on the different viewpoints regarding relationship between Lean and Industry 4.0. *8th International Conference on Industrial Engineering*. Belgrade.

[6] Boldyryev, S., Gil, T., Ilchenko, M. (2022): Environmental and economic assessment of the efficiency of heat exchanger network retrofit options based on the experience of society and energy price records. *Energy*, Volume **260**, 125–155. https://doi.org/10.1016/j.energy.2022.125155

[7] Chen, G., Cheng, L., Li, F. (2022): Integrating Sustainability and Users' Demands in the Retrofit of a University Campus in China. *Sustainability*. Volume. **14**, Issue 16, DOI: 10.3390/su141610414

[8] Elmedint. (n.d.). A guide to metal detection in the food manufacturing industry. Retrieved from: www.elmedint.com: https://www.elmedint.com/uploads/editor/Guide_to_Metal_Detection.pdf

[9] Etzab, D., Brantnera, H., Kastnera, W. (2020): Retrofitting-based Development of Brownfield Industry 4.0 and Industry 5.0 Solutions. *Procedia Manufacturing*, 327–332. https://doi.org/10.1016/j.promfg.2020.02.085

[10] Ingaldi, M., Ulewicz, R. (2019): Problems with the implementation of Industry 4.0 in enterprises from the SME sector. *Sustainability*. **12**(1) https://doi.org/10.3390/su12010217

[11] Jaspert, D., Ebel, M., Eckhardt, A., Poeppelbuss, J. (2021): Smart retrofitting in manufacturing: A systematic review. *Journal of Cleaner Production*. Vol. **312**,127555, https://doi.org/10.1016/j.jclepro.2021.127555

[12] Kirchbach, K., Koskela, L., Gehbauer, F. (2014): Digital Kanban for earthwork site management. *Proceedings IGLC-22*, pp. 663–673, Oslo.

[13] Kochov, A., Argilovski, A. (2021): Six sigma approach to enhance concurrency of the procurement process for raw materials. *Tehnički glasnik*, Vol. **15**, No. 4, 510–517. https://doi.org/10.31803/tg-20210304095657

[14] Lin, D.-Y., Rayavarapu, S. N., Tajeddine, K., Jeoh, R. (2022): Beyond financials: Helping small and medium-size enterprises thrive. Retrieved from: www.mckinsey.com: https://www.mckinsey.com/industries/public-and-social-sector/our-insights/beyond-financials-helping-small-and-medium-size-enterprises-thrive

[15] Lins, T., Ricardo, R., Correira, L., Silva, J. S. (2018): Industry 4.0 retrofitting. *2018 VIII Brazilian Symposium on Computing Systems Engineering (SBESC)*. DOI:10.1109/SBESC.2018.00011

[16] Ma, J., Wang, Q., Zhao, Z. (2017): SLAE–CPS: Smart Lean Automation Engine Enabled by Cyber-Physical Systems Technologies. *Sensors* **17** (7), 1500. DOI:10.3390/s17071500

[17] Middleton, P. (2017): FESTO – Industry 4.0 and the retrofit opporunity. Retrieved from: https://www.crown.co.za/latest-news/mechchem-africa-latest-news/4286-industry-4-0-and-the-retrofit-opportunity

[18] Mohamad, E., Rahman, M. S., Ito, T., Rahman, A. A. (2019): Framework of Andon Support System in Lean Cyber-Physical System Production Environment. *The Proceedings of Manufacturing Systems Division Conference*. DOI:10.1299/jsmemsd.2019.404

[19] Ordorica-Garcia, G., Wong, S., Faltinson, J., Singh, S. (2009): CO_2 capture retrofit options for a gasification-based integrated bitumen extraction and upgrading facility. *Energy Procedia*, Vol. **1**, Is. 1, 3977–3984. https://doi.org/10.1016/j.egypro.2009.02.202

[20] Paduloh, P., Muhendra, R. (2022): Overheat protection for motor crane hoist using Internet of Things. *International Journal of Computer Applications in Technology*. DOI:10.1504/IJCAT.2022.10050316

[21] PwC. (2020): Digital transformation for small and medium businesses. Retrieved from: www.pwc.com: https://www.pwc.com/sg/en/services/reimagine-digital/digital-transformation-for-small-and-medium-businesses.html

[22] Rucińska, J. (2018): Improving the energy quality and indoor environmental quality in retrofit buildings. In: *Design Solutions for nZEB Retrofit Buildings*. DOI:10.4018/978-1-5225-4105-9.ch008

[23] Sharma, S. S., Khatri, R. (2021): Introduction to Lean Waste and Lean Tools. In: *Lean Manufacturing*. DOI:10.5772/intechopen.97573

[24] Siemens. (2022): Retrofit Services: Protecting investments, safeguarding the future. Retrieved from https://www.siemens.com/global/en/products/services/digital-enterprise-services/service-programs-platforms/motion-control-services.html

[25] Smart retrofitting in manufacturing: A systematic review. (2021): *Journal of Cleaner Production*. DOI: https://doi.org/10.1016/j.jclepro.2021.127555

[26] Technosoft Engineering (2020): What is the role of retrofit engineering in product development? Retrieved from: www.technosofteng.com: https://technosofteng.com/what-is-the-role-of-retrofit-engineering-in-product-development

[27] THOMAS. (n.d.). All about position sensors. Retrieved from: https://www.thomasnet.com/articles/instruments-controls/all-about-position-sensors/

[28] LOMA systems (2020): *A Guide to Metal Detection in the Food Manufacturing Industry*. www.elmedint.com.

[29] Ingaldi, M., Ulewicz, R. (2019): Problems with the implementation of Industry 4.0 in enterprises from the SME Sector. *Sustainability*, **12** (1): 217. DOI:10.3390/su12010217

[30] Tran Tuan-anh, Ruppert Tamas, Eigner Gyorgy, Abonyi Janos (2022): Retrofitting-based development of brownfield Industry 4.0 and Industry 5.0 solutions. *IEEE Access*, Vol. **10** (IEEE), pp. 64348–64374. DOI: 10.1109/ACCESS.2022.3182491

[31] Alqoud, A., Schaefer, D., Milisavljevic-Syed, J. (2021): Industry 4.0: Retrofitting of legacy machines for smart manufacturing.

[32] Zambetti, M., Muztoba A. K., Pinto, R., Wuest T. (2020): Enabling servitization by retrofitting legacy equipment for Industry 4.0 applications: benefits and barriers for OEMs. *Procedia Manufacturing,* **48** (5), pp. 1047–1053.

[33] Rosin, F., Pascal F., Pellerin, R., Lamouri, S. (2019): Impacts of Industry 4.0 technologies on Lean principles.

[34] Lean4SMEs. (2022): *Learning Factory for Improving Digital Competitiveness of SME*s. Retrieved from https://learningfactory.mf.edu.mk/projects/#learn4smes

[35] DigiTS-ME. (2022–2023): *Lean Industry 4.0 for more competitive production and maintenance in the Small and Medium-Sized Enterprises*. Retrieved from https://learningfactory.mf.edu.mk/projects/#digitsme

[36] Pueo, M., Santolaria, J., Acero, R. (2019): Design methodology for production systems retrofit in SME. *International Journal of Production Research*, Vol. **58**, Iss. 14, pp. 4306–4324.

[37] Saurabh, V., Prashant, A., Santosh, B. (2018): Industry 4.0 – A Glimpse. *Procedia Manufacturing*, Vol. **20**, pp. 233–238. DOI: https://doi.org/10.1016/j.promfg.2018.02.034

[38] Womack, J. P., Jones, D. T. (2003): *Lean Thinking: Banish Waste and Create Wealth in Your Corporation,* Revised and Updated.

[39] Elafri, Nedjwa, Tappert, J., Rose B., Maleh Yassine (2022): Lean 4.0: Synergies between Lean Management tools and Industry 4.0 technologies. *IFAC-PapersOnLine* **55** (10), pp. 2060–2066.

[40] Mayr, A., et al. (2018): *Lean 4.0 – A Conceptual Junction of Lean Manufacturing and I4.0*. 2018.

[41] Javid, Mohd, Abid Haleem, Ravi Pratap Singh, Shanay Rab, Rajiv Shuman, Shahbaz Khan (2021): *Exploring relationships between Lean 4.0 and manufacturing industry*.

[42] Secher, A. Q., Collin C., Linnet, A. (2018): Construction product declarations and sustainable development goals for small and medium construction enterprises. *Procedia CIRP*, **69**, pp. 54–58, https://doi.org/10.1016/j.procir.2017.12.011

[43] Zhanybek, S., Sabit, S., Dikhanbayeva, D., Shehab, E., Turkyilmaz, A. (2022): Industry 4.0: Clustering of concepts and characteristics. *Cogent Engineering* **9** (1), https://doi.org/10.1080/23311916.2022.2034264

[44] Madsen, D. Ø. (2019): The Emergence and Rise of Industry 4.0 Viewedt Tthrough the Leans of Management Fashion Theory. *Administrative Sciences*, **9** (3) https://doi.org/10.3390/admsci9030071

[45] Szozda, N. (2017): Industry 4.0 and its impact on the functioning of supply chains. *Scientific Journal of Logistics* **13** (4), pp. 401–414, https://doi.org/10.17270/J.LOG.2017.4.2

[46] Roser, C. (2017): Lean and Industry 4.0, Wroclaw: AllA boutLean, Lean Management Conference

[47] Malavasi, M. (2017): Lean Manufacturing and Industry 4.0: an empirical analysis between Sustaining and disruptive change.

[48] Larsson, J., Wollin, J. (2020): Industry 4.0 and Lean – Possibilities, Challenges and Rise for Continuous improvement.

[49] Pereira, A. C., Dinis-Carvalho, J., Alves, A. C., Arezes, P. (2019): How Industry 4.0 can enhance Lean practices.

[50] Buer, S.-V., Strandhagen, J. O. Chan, F. T. S. (2018): The link between Industry 4.0 and Lean manufacturing: Mapping current research and establishing a research agenda. *International Journal of Production Research* **56** (8): 2924–2940.

[51] Xu, Yuchun, Mu Chen. (2016): Improving Just-in-Time Manufacturing Operations by Using Internet of Things Based Solutions. *Procedia CIRP* **56**, 326–331, 2016. https://doi.org/10.1016/j.procir.2016.10.030

[52] Pietrangeli, I., Mazzuto, G., Ciarapica, F. E., Bevilacqua, M. (2023): Smart Retrofit: An Innovative and Sustainable Solution. *Machines* **11** (5), p. 523, https://doi.org/10.3390/machines11050523