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Editors/Uredniki

Polona Šprajc
Damjan Maletič
Nataša Petrović
Iztok Podbregar
Andrej Škraba
Daniel Tomić
Anja Žnidaršič

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Implementation of Industry 4.0: Examples from the Serbian Manufacturing Industry

TEODORA RAJKOVIĆ, ISIDORA NIKOLIĆ,
NIKOLA JANKOVIĆ, DANICA LEČIĆ-CVETKOVIĆ
University of Belgrade, Faculty of Organizational Sciences, Belgrade, Serbia
teodora.rajkovic@fon.bg.ac.rs, isidoraa.nikolic@gmail.com,
jankovicnikola999@gmail.com, danica.lecic-cvetkovic@fon.bg.ac.rs

Industry 4.0 presents a revolution in the manufacturing sector by integrating advanced technologies such as the Internet of Things, artificial intelligence, augmented reality and others. This integration sets the foundation for autonomous, effective and highly efficient manufacturing processes, increasing the levels of digitization and automation. The purpose of this paper is to present examples of the implementation of Industry 4.0 in manufacturing companies. The aim of this paper is to analyze the key aspects of digital transformation through Industry 4.0 and present concrete examples of its implementation in manufacturing companies in the Republic of Serbia. The intention of this paper is to indicate the importance of the implementation of Industry 4.0, identify key challenges in the development of Industry 4.0 and define recommendations for improving production management in manufacturing companies, based on examples of Industry 4.0 application from the practice. Industry 4.0 creates an intelligent production environment with greater efficiency, effectiveness and adaptability.

Keywords:
industry 4.0,
digitalization,
technology,
manufacturing,
Republic of
Serbia

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1 Introduction

Industry 4.0, known as the digital revolution, presents a new industrial stage. It introduces a new paradigm in approaching technological innovations. Industry 4.0 aims to enable the digital transformation of all processes in the industry, whether it is manufacturing, transportation, logistics and others. It is achieved through the use of modern technologies such as Cloud Computing (CC), the Internet of Things (IoT), Data Analytics (DA), Artificial Intelligence (AI), automation, robotics and others (Frank et al., 2019). This concept is based on "smart" manufacturing as a central element but also relies on the application of digital technologies, used to collect data in real-time for analysis and provide useful information to the production system (Lee et al., 2015). Industry 4.0 was initiated in 2011 by the German federal government together with universities and companies, as "a strategic program for the development of advanced production systems, to increase the productivity and efficiency of national industry" (Kagermann et al., 2013).

This paper presents the term Industry 4.0, some of the most commonly used Industry 4.0 technologies, as well as examples of implementation of Industry 4.0 in manufacturing companies in the Republic of Serbia. This paper consists of four chapters. The first chapter is an introduction to the paper. The second chapter presents the theoretical concepts of the most commonly applied Industry 4.0 technologies in the manufacturing sector. The third chapter presents the current level of digitalization, as well as examples of the implementation of Industry 4.0 in manufacturing companies of the Republic of Serbia. The fourth chapter presents the conclusion of the paper.

2 Technologies of Industry 4.0 in manufacturing companies

Industry 4.0 applies a large number of technologies such as (Çınar et al., 2020; Wamba et al., 2015; Zheng et al., 2020): Big Data and Analytics (to collect and analyze large amounts of data), Cloud technology (to provide online data storage services without installation for all programs and applications on a virtual server), Blockchain (a database that creates a distributed and protected digital ledger of transactions), predictive maintenance (as an advanced maintenance strategy that refers to the continuous monitoring of the performance of the equipment to predict potential failures), Simulation and Modelling (technologies that create virtual versions of the physical world, facilitating the design, as well as the operation and testing of systems). Authors Rajković, Vasiljević & Lečić-Cvetković (2023) consider that "in manufacturing, Industry 4.0 technologies are used to improve information flow and data exchange, control, business and process costs, warehouse, distribution/transport and employees". Also, in Industry 4.0, the concept of digital twins emerges as replicas of existing machines, processes or systems to achieve "smart" manufacturing. They assist in decision-making and control of processes in real-time (Shao et al., 2020).

Authors Frank et al. (2019) consider that Industry 4.0 technologies can be divided into two layers according to their main objectives, as shown in Figure 1. The central "Front-end" technologies of Industry 4.0 have the purpose of end use for the value chain of companies and they transform production processes through new technologies, optimizing access to production and delivery of raw materials and products ("Smart" Supply Chain, "Smart" Manufacturing and "Smart" Products). These technologies also help employees perform activities through the use of new technology tools ("Smart" Working). The "Front-end" layer relies on the "Base technologies" layer, enabling connectivity into a complete integrated production system (Frank et al., 2019). Technologies that are within the "Base technologies" layer, as well as other key technologies of Industry 4.0, are presented in the following.

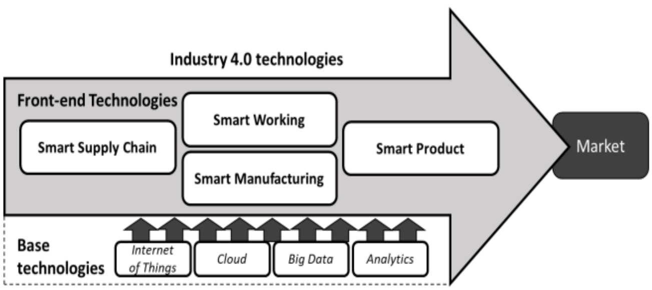

Figure 1: The conceptual basis of Industry 4.0 technologies
Source: Frank et al., 2019

2.1 Internet of Things (IoT)

The Internet of Things (IoT) presents a system that connects different technologies, computers, objects, digital and mechanical machines, or individuals. The IoT applies "smart" devices, i.e. devices such as communication hardware, sensors and processors, connected to the Internet, that collect large amounts of data, that are further processed and used to track employees' performance, operations, production and others (Gaber et al., 2018). The advantages of the implementation of IoT in manufacturing are improved process efficiency, resource optimization and better control, while the main disadvantages are issues with data privacy and management of large amounts of data. The application of IoT in manufacturing allows devices to communicate with each other and perform tasks without direct human intervention but also provides the ability for people to communicate with devices and access data. IoT has great potential to transform the manufacturing sector for high contribution to improved integration of resources used in different stages of production.

2.2 Artificial Intelligence (AI)

Artificial Intelligence (AI) is defined as "the discipline of computer science that deals with the development of data processing systems and functions related to human intelligence, thereby redefining production processes and business models in the industry" (Peres et al., 2020). The increasing use of AI in industry highlights its importance for supporting manufacturers in solving challenges. It enables companies to make decisions through predictive analytics based on data, especially useful in complex and nonlinear environments. This technology is used within machine learning and robotics to solve problems within companies, emphasizing the importance of data infrastructure, algorithms, decision making and achieving concrete goals (Peres et al., 2020). AI enables the prediction of machine failures, changes on the market, reduces production stoppages through improved production quality, leading to faster decisions, improved services and reduced costs in production (Yao et al., 2017).

2.3 Digital Twins (DT)

A Digital Twin (DT) is "a digital replica of an existing product, machine, process or system that enables companies to better understand, analyze and optimize their processes in real-time" (Rai et al., 2021). The "twin" in this context presents the digital information connected with a physical system, available throughout its entire life cycle. Implementation of DT in manufacturing improves process analysis and control, while a lack of resources and standardization makes their effective implementation more difficult (Shao et al., 2020). Within the DT, manufacturing is supported by advanced technologies such as robots, Virtual Reality (VR) and additive (3D) manufacturing, while cloud technology, as a key driver of the DT, uses Internet connections for storage, access and data processing. A DT in manufacturing can be used for equipment monitoring (to minimize the impact of production stoppages and optimize production planning), supply chain optimization, virtual simulation and continuous performance monitoring to optimize processes and reduce production costs. This technology is also used to analyze the production process to identify potential improvements, as well as to simulate different scenarios to make optimal decisions to improve efficiency and productivity (Shao et al., 2020).

2.4 Robots

Robots have a wide range of applications in the manufacturing sector, such as picking and placing, sorting, assembling, storing and retrieving materials, parts and tools, as well as maintaining and monitoring machines. They are programmed to navigate a sequence of points in either two-dimensional (2D) or three-dimensional (3D) space, executing specific tasks. Modern methodologies, like collaborative robots ("Co-robots"), streamline programming by enabling the recording of these points through physical robot positioning. Combining AI with cameras empowers robots to steer clear of potential disruptions caused by humans or other robots, as well as to adjust to misplaced objects without the intervention of the operator (Bécue et al., 2021). Robots in manufacturing can be used to support employees in performing tasks where high physical effort is required, in tasks that are repetitive or are tasks of high risk, such as the manipulation of hazardous chemicals and materials. In addition, robots in "smart" factories can autonomously handle materials, where they can perform product measurement and quality control tasks. Robots such as AGVs (Automated Guided Vehicles) can efficiently transport finished products or materials within the factory, thereby reducing transportation time (Grau et al., 2020).

2.5 Software in Industry 4.0

The software presents digital assistance for the execution of Industry 4.0, offering support in its implementation and has a key role in modern business. It enables efficient management and decision-making in complex systems. Among the many solutions, ERP (Enterprise Resource Planning), MES (Manufacturing Execution System) and SolidWork software are presented in the following as the most applied software in manufacturing companies.

ERP is a modular software that integrates multiple processes within a company. This software can be used to track movements of inventory, raw materials and finished products, for production planning, manage orders, track costs, optimize resource use and others. By monitoring these activities, the efficiency of the production process improves and production costs are reduced. MES is a system that provides information to optimize manufacturing activities from order to delivery of finished products, using accurate and current data. In addition, the application of MES software enables monitoring, initiating, reacting and reporting of production activities in real-time. This helps in continuous improvement of production through the monitoring of machines, employees and equipment. MES software is used to monitor the quality of the production process, allocate resources and generate reports by integrating all information following the set standards, but it also allows the adjustment of plans and reactions to changes in the production process (Mantravadi & Møller, 2019). SolidWorks software is a CAD (Computer-Aided Design) software used in manufacturing companies as a product design tool. It allows the creation of product models through the generation of technical drawings, that facilitate the design, development and manufacturing processes of components and assemblies. In addition, it is used for the detailed modelling of products, the creation of 2D drawings, simulation of mechanical characteristics of products, contributing to the improvement of the efficiency and quality of the manufacturing process (Planchard, 2019).

3 Examples of implementation of Industry 4.0 in the Republic of Serbia

In recent years, the level of digitalization in the Republic of Serbia has shown notable progress. However, numerous challenges remain to be overcome. The Government of the Republic of Serbia has recognized the significance of digitalization and adopted the Digital Agenda to improve the digital economy. This initiative outlines strategic priorities in electronic communications, e-health, e-commerce, e-justice, e-government, information and communication technologies (ICT) in education, science, culture and information security (Veselinović & Stanišić, 2021). ICT and Internet enable business transactions to become simpler, faster and more cost-effective (Rađenović et al., 2023). Examples of the implementation of modern technologies and Industry 4.0 in manufacturing companies of the Republic of Serbia are presented in the following.

The company "Toyo Tires", a Japanese manufacturer of tires for a wide range of vehicles worldwide, has implemented the principles of a "smart" factory in factory in the Republic of Serbia by integrating digital innovations into production lines. The rise of the "smart" factory as a manufacturing model, driven by digital innovations such as the IoT, AI and automation, has transformed production processes, enhancing efficiency and enabling real-time data-driven decision-making (Shi et al., 2020). This factory implemented software for optimizing production processes, such as ERP and MES, a solar energy system (contributing to the reduction of CO_2 emissions) and lines for testing of tires (ToyoTires, 2022). In addition to the physical facility, there is a virtual environment called the "T-mode" that applies computer simulation and AI for virtual testing of tires on vehicles under various conditions, analyzing factors such as driving noise, uneven tread wear and others, to optimize tire design and improve performance. Figure 2 shows a simulation of tire behaviour in snowy conditions (figure left) and aerodynamic resistance (figure right). With effective aerodynamics, tires can contribute to the reduction of fuel consumption.

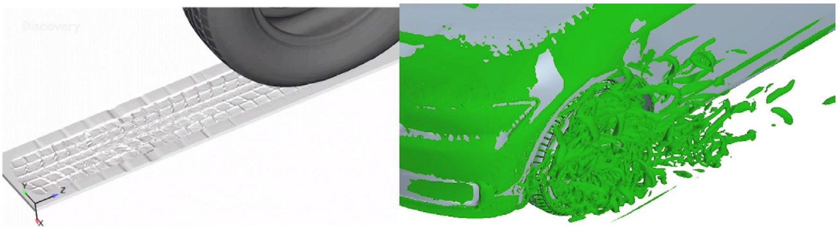

Figure 2: The T-Mode, a virtual testing environment for tires at "Toyo Tires" company
Source: Izrez zaslona (Discovery)

“Naftna Industrija Srbije” (NIS) presents the leading energy company in the Republic of Serbia, with a key role in the national petroleum industry sector (Lukić, 2018), that implements predictive maintenance. While “smart” factories enable real-time monitoring and control of the production system and processes, the implementation of predictive maintenance presents a crucial upgrade that enhances the reliability and durability of industrial systems. Predictive maintenance helps in reducing maintenance costs, extending the life of spare parts and reducing inventory, but also increasing the production volume (Çınar et al., 2020). The adoption of predictive maintenance has significantly improved the level of safety in operational processes within the refinery and simultaneously reduced operational costs, improving business efficiency and the company's competitive advantage (NIS, 2023). Figure 3 shows the outcomes of continuous monitoring of the condition of one of the centrifugal pumps used in the factory. Before the implementation of technologies for monitoring the machine condition, installation of sensors, as well as the application of predictive maintenance, the percentage of stoppages in NIS caused by faulty bearings was 34 [%], but after that implementation, the percentage decreased to 15 [%] (NIS, 2023). Furthermore, there has been a reduction in overall stoppage, while equipment availability has increased by 0,6 [%] (NIS, 2023). This system is crucial for the evolution of maintenance in refinery facilities, from a reactive to a proactive approach. Through continuous monitoring of operations, computers analyze past data about the equipment and provide predictions of potential failures, applying the latest machine learning techniques.

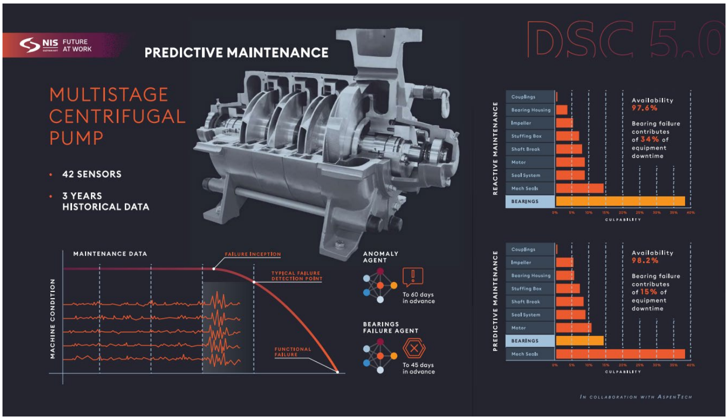

Figure 3: Predictive maintenance at NIS factory

Source: https://www.nis.rs/blog/nove-tehnologije-u-rafineriji-nafte-pancevo-prepoznaju-kvar-i-pre-nego-sto-se-dogodi

The company "Elixir Group" from the city of Šabac is a manufacturer of phosphoric acid and complex mineral fertilizers that has created a DT for one of its production lines. The most complex project involves the creation of a DT, necessitating the integration of advanced technologies to achieve precise simulation and optimization of a real system or product (Qi et al., 2019). This process includes translating a physical system into a digital format, where DT can be accessed through an Internet platform. This enables the easy defining of instructions and following the real-time status of the tasks (Solfins, 2023a).

"Delta Holding" is one of the largest companies in the Republic of Serbia, operating across various sectors such as retail, agriculture, energy, real estate, food and beverages. One of the primary investments of this conglomerate is the project titled "Digital Village". Through this project, investments are made in digital technologies to improve the infrastructure and production in rural areas, striving towards an increased digital transformation of agriculture in rural communities. The main aim of this project is to enable easier, more efficient and sustainable production in the agricultural sector, by increasing the income of agricultural workers and making rural life more attractive, especially for the young population (DeltaHolding, 2023). "Delta Holding" actively participates in this project by providing expert support and training for agricultural workers. Digital platforms, training programs and virtual cooperatives enable the modernization of production in the village of Mokrin, considered the first digital village in the Republic of Serbia.

The constant need for efficiency, precision and speed in creating new products sets challenges for engineers. In response to these challenges, the SolidWorks software emerged as a CAD 3D modelling software. This software translates digital models from STL (stereolithographic) files into physical models, enabling 3D printing of both individual components and entire assemblies (Jovanović & Jovanović, 2023). Leading manufacturing companies in the Republic of Serbia, recognized within and beyond the borders of the country, have implemented this software, as presented in the following (Solfins, 2023):

- "Metalac" (Gornji Milanovac), a manufacturer of kitchenware, has implemented this software, leading to accelerated product development. Application of this software automated the process of forming family parts and tools, resulting in increased efficiency and precision in construction;
- "Sloboda AD" (Čačak), a company known for its production and innovations in the field of the military industry, has adopted this software as a comprehensive solution in the development and construction of ammunition, machinery, equipment, tools, as well as for programming of the latest CNC machines;
- "Tigar Tires" (Pirot), a leading tire manufacturer in the Republic of Serbia, successfully applies this software for managing comprehensive documentation used in the maintenance of machinery and tools, as well as in the production process.

4 Conclusion

Implementation of Industry 4.0, globally, presents a new approach aimed at automation and digitalization of manufacturing processes. The application of technologies such as IoT, AI, DT, robotics and software, change how the activities are realised, as well as the level of human participation. Applying Industry 4.0 in the manufacturing industry significantly improves process efficiency, optimizes resources and enhances product quality by integrating technologies with physical devices. The implementation of Industry 4.0 in manufacturing companies of the Republic of Serbia is mostly done in large manufacturing companies (Marjanovic et al., 2017), increasing the efficiency of e-commerce by over 80% (Rejman Petrovic et al., 2022), enabling improved communication with customers, production per their request and development of complex products (Medić, Anišić & Tešić, 2017). It indicates the importance of implementing new technologies to enhance manufacturing processes, reduce costs and consequently achieve a competitive position in the market. Despite continuous progress in the digitalization of industry in the Republic of Serbia, challenges persist, such as inadequate company structure and slow export growth in manufacturing sectors (Ćorović, Gligorijević & Manasijević, 2019), including the need for additional training of personnel and improved infrastructure. The direction of future research of the authors of this paper is to examine the implementation of other Industry 4.0 technologies in manufacturing companies in the Republic of Serbia, to assess the effectiveness of these technologies and identify opportunities for further improvements in production processes.

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