EXPLORING TECHNOLOGY ADOPTION TRENDS: EMPIRICAL INSIGHTS FROM A EUROPEAN MANUFACTURING SURVEY

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Abstract: *This article investigates the adoption trends and implications of advanced manufacturing technologies in Serbian manufacturing companies. The objective is to analyze the evolving manufacturing landscape and provide insights into technology adoption patterns. The study utilizes the European Manufacturing Survey (EMS)—Serbian data set, which includes responses from 280, 240, and 147 manufacturing companies in the years 2015, 2018, and 2022, respectively. Through data analysis, changes in the adoption of advanced manufacturing technologies over time are aimed to be identified. Additionally, the study seeks to determine whether there is a growing trend in technology adoption. The research contributes to a deeper understanding of the dynamics surrounding technology adoption within the context of Serbian manufacturing, offering potential implications for companies' future strategies and development in a rapidly changing manufacturing landscape.*

Key words: Smart Manufacturing, Technology Adoption, European Manufacturing Survey (EMS)

1. INTRODUCTION

The traditional manufacturing industry has recently been confronted with a significant global threat, attributed to the rapid expansion and advancements in digital technologies that enable the seamless integration of interconnected intelligent components within the shop floor (Bianco et al., 2023; Ciric et al., 2021; Todorovic et al., 2022). This integration, forming the foundation of the Industry 4.0 concept, has been made feasible by the increasing adoption of information and communication technology by manufacturing organisations (Negri et al., 2017; Rakic et al., 2021).

Furthermore, over the past few years, a gradual rise in complexity and demands has been witnessed in the manufacturing sector (Hofmann & Rüsch, 2017a). These changes can be ascribed to various factors, including heightened market volatility, intensified global competition, and a growing demand for highly customized products, leading to shortened product life cycles (Prester et al., 2018; Todorovic et al., 2020). As a result, significant challenges are faced by companies in meeting these demands, particularly concerning cost-effectiveness, flexibility, adaptability, stability, and sustainability (Fatorachian & Kazemi, 2018; Ford & Despeisse, 2016). Traditional methods of value generation appear insufficient in addressing these growing difficulties (Ćirić & Lalić, 2016; Hofmann & Rüsch, 2017b; Nagy et al., 2019).

Additionally, rapid technological breakthroughs have revolutionized the manufacturing industry, creating new business opportunities and challenges (Ciric et al., 2020; Stefanovic et al., 2020; Todorovic et al., 2020). Trends such as digitalization, the internet of things, the internet of services, and cyber-physical systems (CPS) have gained considerable relevance in this context (Kusiak, 2018).

Throughout its evolution, Industry 4.0 has been shaped by the challenges and impacts brought about by the COVID-19 pandemic (Siriwardhana et al., 2020). The manufacturing industry, which is crucial to economies worldwide, has been significantly impacted by the COVID-19 pandemic (Bianco et al., 2023). Resilient and sustainable manufacturing practices are deemed essential to mitigate the pandemic's negative impacts and enable a smooth recovery (Hussain et al., 2021). The adoption of advanced technologies can play a critical role in enhancing risk preparedness and ensuring operational continuity, supporting economies and livelihoods amidst these unprecedented challenges (Dakovic et al., 2020; Hussain et al., 2021; Sofic et al., 2022).

In light of the available data from 2015, 2018, and 2022, the investigation of technology adoption patterns in Serbian manufacturing companies over the years (source: European Manufacturing Survey) and the identification of any differences or trends that may have emerged is the aim of this article. Specifically, the focus is on the adoption of various technologies within the context of Smart Manufacturing.

The following research question is proposed:

- *How has the evolution of technology adoption in Serbian manufacturing companies been from 2015 to 2022?*

Through the analysis of data from different years, a comprehensive understanding of the technology adoption landscape in Serbian manufacturing companies is aimed to be gained, and insights into the dynamics and trends associated with the adoption of Smart Manufacturing technologies over time are provided.

The rest of the article is structured as follows. Firstly, the introduction outlines the purpose of the article and introduces the research questions. The second section briefly provides an overview of the research flow and delves into the theoretical foundations of Smart Manufacturing. The third section explains how data was collected and analyzed for the research. In section four, the results and discussion are presented. The conclusion summarizes the findings and provides directions for future research.

2. THEORETICAL BACKGROUND

To establish the theoretical foundation, the authors of this article aim to address the research question posed in the introduction. We selected and extracted the most influential papers encompassing literature on Smart Manufacturing from the Elsevier Scopus database, which stands as one of the world's largest scientometric databases.

Table 1 shows the research flow; the concept of smart manufacturing was researched within the article title, abstract and keywords to establish their connection. The research string used for the search can be seen in the table, including limitations in the document type, language and year of publication, and the final number of observed papers. Among all the research papers available, only the most highly cited ones were selected as the most relevant sources, based on the Scopus indexing database. The inclusion of previous articles covering the European Manufacturing Survey was regarded as essential by the authors. Consequently, we incorporated a second research strand that encompasses a significantly smaller body of literature but serves as the foundation for drawing conclusions and making parallels with previous studies.

Table 1: Literature review research flow

Research String	Limitations	Time span	Number of publications
"Smart Manufacturing"	Document type: Journal articles, Conference Papers Language: English	2015-2023	3,964
"European Manufacturing Survey"	Document type: Journal articles, Conference Papers Language: English	2015-2023	48

Industry 4.0 is primarily driven by four key factors: Internet of Things (IoT), Industrial Internet of Things (IIoT), Cloud-based manufacturing, and Smart Manufacturing. These drivers play a vital role in transforming the manufacturing process into a fully digitized and intelligent one (Vaidya et al., 2018).

The key idea of Industry 4.0 is rooted in advanced manufacturing, with Smart Manufacturing being employed (Frank et al., 2019). Tao et al (2019) defines Smart Manufacturing as a common strategic priority among major manufacturing initiatives, including Industry 4.0 and the Industrial Internet (Tao et al., 2019). A flexible production system is used, where procedures are automatically adjusted for different products and varying environmental conditions (Kamble et al., 2018). The possibility of large-scale production of customized items with sustainable resource use is made possible by the improved quality, productivity, and adaptability offered by Smart Manufacturing (Kang et al., 2016a).

The main support structure for internal operational operations within the Industry 4.0 framework is provided by technologies for Smart Manufacturing (Ciric et al., 2020; Kang et al., 2016b; Miloradov et al., 2022). The use of multiple technologies, including sensors, computing platforms, communication technology, data-intensive modeling, control, simulation, and predictive engineering, in conjunction with existing and future industrial assets is known as Smart Manufacturing (Kusiak, 2018). Smart Manufacturing makes use of the ideas of Cyber-physical systems, the Internet of Things (and everything), Cloud computing, Service-oriented computing, Artificial intelligence, and Data science (Jankovic-Zugic et al., 2023; Sofic et al., 2022).

Significant roles in promoting Smart Manufacturing are played by both digital twin and big data. The possibility of cyber-physical integration is enabled by manufacturers' ability to control real-time, two-way mappings between physical items and their digital representations (Qi & Tao, 2018).

The fifth industrial revolution will be initiated upon the full integration and harmonious coexistence of its three key elements: intelligent devices, intelligent systems, and intelligent automation with human intellect and the physical world (Nahavandi, 2019; Raut et al., 2018). These elements represent the fundamental components that will enable the realization of the fifth industrial revolution, where intelligent devices, systems, and automation collaborate seamlessly with human intelligence and the physical environment, driving significant advancements in manufacturing and technological progress (Hussain et al., 2021; Nahavandi, 2019; Siriwardhana et al., 2020).

3. RESEARCH METHODOLOGY

For the purpose of this article, basic statistical methods were employed, specifically relying on descriptive statistics, to examine the adoption of Smart Manufacturing technologies within manufacturing companies in Serbia. The data used for this analysis was obtained through a survey conducted under the international project European Manufacturing Survey (EMS), which is coordinated by the Fraunhofer ISI Institute in Germany. The primary focus of EMS is on technological and organisational innovation in manufacturing companies, encompassing various aspects of manufacturing processes (Ćirić et al., 2016; Marjanovic et al., 2019). The survey is conducted every three years and targets manufacturing companies under NACE Rev 2 codes from 10 to 33, with more than 20 employees.

The dataset used in this article consists of responses from Serbian manufacturing companies. It includes 285 responses from the year 2015, 240 responses from 2018, and 147 responses from the 2022 round of the survey. Due to the COVID-19 pandemic, the latest survey was postponed by one year and conducted in 2022, officially concluding at the beginning of 2023.

Within the questionnaire, companies were asked about the technologies they currently employ in their production processes. Our analysis identified technologies falling within the domain of Smart Manufacturing. We used this information to compare the use of Smart Manufacturing technologies in 2015, 2018, and 2022. In this manner, we aimed to discern trends in the adoption of these technologies over time.

4. RESULTS AND DISCUSSION

This section presents the research results on the adoption of 12 different Smart Manufacturing technologies, as shown in **Figure 1**, illustrating the adoption trends in Serbian companies and comparing the data from 2015, 2018, and 2022.

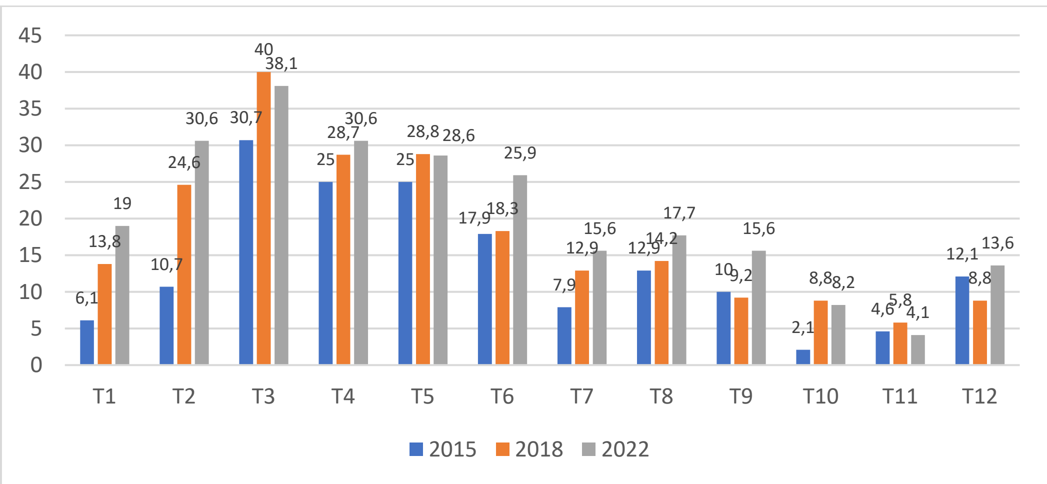

Figure 1: Adoption of Smart Manufacturing Technologies in Serbian Companies: A Comparative Study of 2015, 2018, and 2022

Based on the analysis of the adoption trends of various Smart Manufacturing technologies in Serbian manufacturing companies, several key findings can be observed:

- *Mobile/wireless devices for programming and controlling machinery and/or facilities* (T1) saw a remarkable increase in adoption, with its usage rising from **6.1%** in **2015** to **19%** in **2022**. This significant growth indicates that Serbian companies are increasingly recognizing the benefits of mobile-based solutions in enhancing machinery control and production processes.
- *Digital solutions to provide drawings, work schedules, or work instructions* directly on the shop floor (T2) exhibited substantial growth, with adoption rates climbing from **10.7%** in **2015** to **30.6%** in **2022**. This trend suggests that Serbian manufacturing companies acknowledge the value of incorporating digital tools in their daily operations to improve productivity and decision-making.
- *Software for production planning and scheduling* (T3) maintained its significance and demonstrated steady growth over the examined period. Although there was a slight decline in its adoption rate between 2018 and 2022, it remains considerably high overall at **38.1%**. This indicates that scheduling technology plays a crucial role in streamlining production operations and optimizing efficiency.
- *Digital Exchange of product/process data with suppliers/customers* (Electronic Data Interchange EDI) (T4) and *Near real-time production control system* (T5) both experienced moderate growth, with adoption rates increasing from **25%** to **30.6%** and **28.8%** respectively from **2015** to **2022**. These technologies play essential roles in facilitating seamless communication and real-time data monitoring in manufacturing processes.
- *Techniques for automation and management of internal logistics* (T6) showed noticeable growth, with adoption rates rising from **17.9%** in **2015** to **25.9%** in **2022**. The increasing interest in automation solutions, such as Warehouse Management Systems and RFID, indicates a growing recognition of their potential to optimize logistics operations.
- *Product-Lifecycle-Management-Systems* (PLM) or *Product/Process Data Management* (T7) saw gradual growth in adoption, with usage increasing from **7.9%** in **2015** to **15.6%** in **2022**. PLM systems are becoming more valued by Serbian manufacturers for efficiently managing product and process data throughout the lifecycle.
- *Industrial robots for manufacturing processes* (T8) and *industrial robots for handling processes* (T9) exhibited sustained growth, with adoption rates climbing from **12.9%** and **10%** respectively in **2015** to **17.7%** and **15.6%** in **2022**. The continuous interest in robotics indicates their increasing importance in enhancing precision, efficiency, and safety in production processes.
- *3D printing technologies for prototyping* (T10) experienced significant growth, with its adoption rate rising from **2.1%** in **2015** to **8.2%** in **2022**.
- *3D printing for manufacturing of products, components and forms, tools* (T11) showed a slower growth rate in 2022 (4.1%) compared to 2018 (5.8%) and 2015 (4.6%), possibly due to maturing technology and companies becoming more selective in its application.
- *Technologies to recuperate kinetic and process energy* (T12) demonstrated fluctuating adoption rates, with usage declining from **12.1%** in **2015** to **8.8%** in **2018** before rebounding to **13.6%** in **2022**. The varying adoption rates may reflect the ongoing efforts of Serbian companies to explore sustainable practices and energy-efficient solutions.

5. CONCLUSION

The adoption of advanced technologies can be more challenging for emerging countries (e.g. Serbia), as their economies have historically been centered around the extraction and commercialization of commodities (Dalenogare et al., 2018). However, the findings from the comparative study conducted in this article show the opposite - a positive trajectory of Smart Manufacturing technology adoption in Serbian companies is reflected. A growing interest in implementing smart technologies is highlighted by the observed trends. Technologies T1, T2, and T3 stand out with the highest adoption growth rate in 2022, while only one technology, T11, experienced a decline.

Manufacturers are now able to better, more rapidly, and more economically meet customer expectations thanks to developments in information technology. Manufacturers are increasingly using data to support a range of cutting-edge production models, such as mass customisation, sustainable manufacturing, flexible manufacturing, intelligent manufacturing, and cloud manufacturing (Dakic et al., 2019; Tao et al., 2018). But it has proven difficult to fully utilize data, particularly for small and medium-sized manufacturing enterprises (Tao et al., 2018; Tao & Zhang, 2017). In order to better understand how technology adoption differs depending on the size of the company and the industry it serves (which is also covered by the European Manufacturing Survey), the authors plan to investigate this topic in future research.

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