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Global Value Chains and Industry 4.0 in the Context of Lean Workplaces for Enhancing Company Performance and Its Comprehension via the Digital Readiness and Expertise of Workforce in the V4 Nations

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Abstract: Industry 4.0 affects nearly every aspect of life by making it more technologically advanced, creative, environmentally friendly and ultimately, more interconnected. It also represents the beginning of the interconnectedness and metaverse associated with Industry 5.0. This issue is becoming decisive for advancement in all areas of life, including science. The primary goal of this study is to concisely explain how current Industry 4.0 trends might interact with existing work systems in global value chains to accelerate their operational activity in the context of firms from the Visegrad Four (V4) nations. Through an examination of the digital abilities in these nations, the purpose of the study is also to demonstrate how well citizens, employees, and end users are able to comprehend the problem at hand. The most recent resources for the topics are covered in the first section of the work. The next one uses graphic analysis and mutual comparison methods, generally comparing existing data over time; it is secondary research, and through these methods the Industry 4.0 applications can significantly speed up the work process itself when compared to the traditional lean process, primarily because of its digital structure. It is difficult to predict which of the V4 will be digitally prepared, as the precedent shifts are based on distinct indicators; therefore, it is crucial that all V4 nations expand their digital adaptability dramatically each year, primarily as a result of spending on scientific research, and education that is organised appropriately. The extra value of this effort may be attributed to how lean processes are intertwined with the Industry 4.0 trend's digital experience, which already includes the Industry 5.0 trend's artificial intelligence and metaverse, which represent the potential for further research in the future.

Keywords: Industry 4.0; lean manufacturing systems; digital economy; Internet of Things; global value chains

MSC: 91-11

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1. Introduction

Digitalization has become a deciding factor in the growth of national economies as a result of all previous development processes, including the deepening of internationalization and integration, the expansion of interdependence and transnationality, as well as international specialization and cooperation. Recent developments in science and technology have accelerated this tendency to the point that a new economic structure is necessary to fully use them. Concerns about globalization are connected to a variety of issues. Because they allow for greater integration of developing countries, the eradication of poverty, and the introduction of new possibilities for manufacturing, innovation, employment, large-scale industry, and value chains are essential to global commerce [1]. The overall impacts of globalization are favourable for ecological collaboration, improved working conditions, and long-term economic development. However, because of its very complicated structure, lack of transparency, and weakened promises, there may be a rise in violence, risk of political breaches, criminal activity related to the law and the environment, and tax fraud [2]. Humanity has entered a new era marked by rapid advancements in robots and autonomous vehicles, and massive digitalization of manufacturing and logistical systems. New technologies are being created and incorporated into daily life at a rate that has never been higher, which naturally begs the fundamental question of where man will fit into such a society [3]. Will man still work in future production systems, or will he be replaced by a mechanically superior device that, when production data is analysed, can fix problems more quickly, more economically, and more effectively? Industry 4.0′s role in the widespread lean manufacturing style is discussed by most automakers [4–6]. These methods are based on the Kaizen principle, which strives to enhance plant employees' abilities and then promote their proposals for improvement to achieve continuous improvement of production processes [5]. The human being is at the heart of a lean manufacturing system. Therefore, it would seem at first that the ideas promoted by the Industry 4.0 movement and the ones derived from lean manufacturing techniques are at conflict. The ability of the populace, both inhabitants and end customers, whom this business may benefit greatly, must also not be overlooked. However, it is crucial that the general public comprehend and be ready for such a transformation [6]. Particularly because of the effects of globalization, significant and vital driving forces for the dynamic growth of international trade have emerged, including extensive technical-technological innovations and the application of scientific-technical knowledge in all spheres of business activity [7]. Due to the quick increase in the proportion of commodities and services with a high degree of added value (high-tech) in global commerce, both huge transnational companies and entire nations are experiencing fast change in their operations [8]. These concurrent processes—improvement in already-existing technologies, introduction of radical innovations that qualitatively alter the mode of production, the beginning of big data-based discoveries, and realization of scientific and technical knowledge—attest to the complexity of scientific and technological knowledge development [9]. Industry 4.0 technologies are now more widely available, which lowers entry barriers, virtualizes the global value chain, and increases the potential of lean processes [10]. A growing number of high-end service providers can now enter the market as a result of this growth in innovation.

To improve sustainable business performance in the unique circumstances of the V4 countries across every industry in these economies, this paper's main aim is to analyse the development of production systems based on Industry 4.0, the current trend in digitization and associated production automation [11]. This analysis will be carried out in terms of computer vision algorithms, remote-sensing data fusion techniques, and mapping and navigation tools [12]. In this study, wherein a temporal analysis was employed predominantly, the available data were analysed to determine how particular variables changed over time. The V4 nations considerably contribute to the overall economic performance of the European Union (EU), making the study's conclusions important at both sectoral and national levels. The examination of these populations' digital preparedness is the study's principal contribution, along with information on how Industry 4.0 will affect the structure of international commerce and changes in global value chains [13]. The analysis demonstrates the importance of leveraging visual perception and remote-sensing technologies, route detection and object localization algorithms, real-time connected navigation data, big geospatial data analysis, and trajectory planning and mobility simulation tools across the automotive industry and network transport systems [14].

This paper is organised as follows: the literature review situates our study within a body of knowledge that is primarily committed to Industry 4.0, as well as to global value chains and manufacturing methods. The paper analyses the data on these concerns in the Methods section before performing a graphic and visual analysis of them. Before establishing a discussion of the numerous implications of Industry 4.0 in regard to raising value added in the V4 nations, the next section analyses the findings. The study's outcomes indicate that deep learning-based computer vision algorithms, cognitive data fusion methods, and data visualization tools are crucial components of cyber-physical manufacturing systems based on digital twins in practically all V4 industrial sectors. Through the use of virtual modelling and simulation tools, digital twin modelling, and neural network algorithm systems in these economies, future visions of how cloud computing and remote-sensing technologies, immersive visualization tools, and cyber-physical production systems can operate in virtual enterprises and immersive 3D environments are proposed.

2. Literature Review

The concept of the global value chain (GVC) was first put out by Gereffi [15], who integrated business difficulties and competitiveness by utilizing the specific example of the garment industry. The value of the GVC's products and services is the result of several social actions [16,17]. According to Mugge [18], the economies that provide the additional value through participation may be fully evaluated. As a result of the forces of globalization, there has been a substantial advance in the elimination of periodic barriers in international commerce. According to Ye et al. [19], the goal and conclusion of global value chains is an optimal input–output ratio. The emergence of various elements, which are typically referred to as megatrends in terms of their weight and impact on large-scale commerce, has had a huge impact. The most important catalyst for the explosive growth of international trade is scientific progress [20]. The value chain is being virtualized, integrating machine and deep learning technologies, digital twin algorithms, and spatial data visualization tools in the V4 industries because of the growth of artificial intelligence-based decision-making algorithms, the Internet of Things sensing networks, and cyber-physical production systems, which lower entry barriers for an increasing number of marginal service providers through outsourcing or offshore sourcing [21]. Digitization is strongly related to Industry 4.0, a term introduced by Klingenberg et al. [22] to define horizontally connected operations within the value stream. Digitization acts as a link between Industry 4.0 and the Internet of Things throughout the manufacturing and consumption stages. According to Rogers and Zvarikova [23], Industry 4.0 integration would increase global trade productivity by 6% to 8% yearly. The rising necessity to implement data-driven technology networking and achieve complete connection is highlighted by Ruttimann and Stockli [24]. In the majority of instances, a full link has not yet been established, and it is only feasible to talk of a partial one. However, the data and the concept of this connection are still continuously expanding. Dalenogare et al. [25] mention developments in the social sectors of society in addition to advancements in the economy. Digitalization will have an impact on the connected supply chain, as it will reduce costs and enhance end-to-end process management using industrial artificial intelligence [26]. When approaching Industry 4.0, one should consider the potential value of data and the purpose of each technical development, as well as its originality and value [27]. Industry 4.0 technology and real-time big data analytics, as key factors in this change, clearly interconnect. The growth of employees' roles during automated production processes is the subject of research by Svabova et al. [28], which outlines the cutting-edge products made possible by utilizing intelligent manufacturing. Digitization and robotic wireless sensor networks will significantly enhance the value chain by increasing productivity, reducing costs, and fostering increased creativity and cooperation through real-time big data analytics [29]. Said et al. [30] use four fundamental characteristics to define and explain Industry 4.0-based manufacturing systems: vertical connectivity of intelligent production systems, Internet of Things-based real-time production logistics, digitalized mass production, and interconnected virtual services in cyber-physical system-based smart factories [31]. The horizontal integration of international networks in the industries of the V4 nations will subsequently be used to configure customer and business partner networking. According to Lawrence and Durana [32], the foundation of Industry 4.0 is the direct connection and cooperation of individuals, devices, machinery, equipment, logistics systems, and products. By optimizing company processes, Zavadska and Zavadsky [33] stress the importance of digital data and the swiftness with which management operations develop corporate strategy. Real-time sensor networks cannot capture the dynamic transformation configured by production systems based on Industry 4.0 [34]. Globalization may spur national economies to make ground-breaking discoveries, significantly increasing a country's level of creativity [35].

The Internet of Things, smart sensors, and cyber-physical production networks, according to Lăzăroiu and Harrison [36], are essential parts of Industry 4.0 manufacturing systems in that they combine cognitive decision-making algorithms, sustainable organizational performance, and networks of physical and digital production [37]. Zhong et al. [38] offer a variety of alternatives for real-time data processing using mathematical optimization models based on multi-correlation dependencies. The COVID-19 problem presents challenges that must be solved in order to hasten the adoption of digital technology, according to Belhadi et al. [39]. By utilizing product decision-making information systems, organizations may increase their profits while optimizing their efficiency and competitiveness. Digitization therefore calls for enough investment in measures to adapt to digital transformation [40]. Consumer satisfaction will rise as more and better services become accessible. To advance innovation, technology, ecological policy, and education, Industry 4.0 is now underway [41]. This is due to the internet's rapid growth, and associated technological advancements. The core components of Industry 4.0 are as follows [42]: (i) technology application (throughout the entire product life-cycle); (ii) horizontal integration (networking clients and business partners, advanced business models, and large-scale production networks); (iii) vertical connection (integrating cutting-edge manufacturing systems, logistics, production, and marketing); and (iv) technology application (throughout the entire product life cycle). The market's adoption of exponential technologies is accelerated by the decline in their operational costs. Among the areas in which Industry 4.0 may be explored in the Slovak automobile industry are digital twin-based product development, autonomous production systems, virtual reality modelling tools, and spatial data visualization techniques [43]. Industry 4.0 technologies may be divided into two groups, depending on their main goal. The basis of the framework will be the front-end technologies of Industry 4.0, which take into consideration how manufacturing operations are changing in response to new technologies (smart manufacturing) and how goods are being sold (smart products) [44]. The method of distribution (smart supply chain) and processing (smart working) are also incorporated [45] (Figure 1).

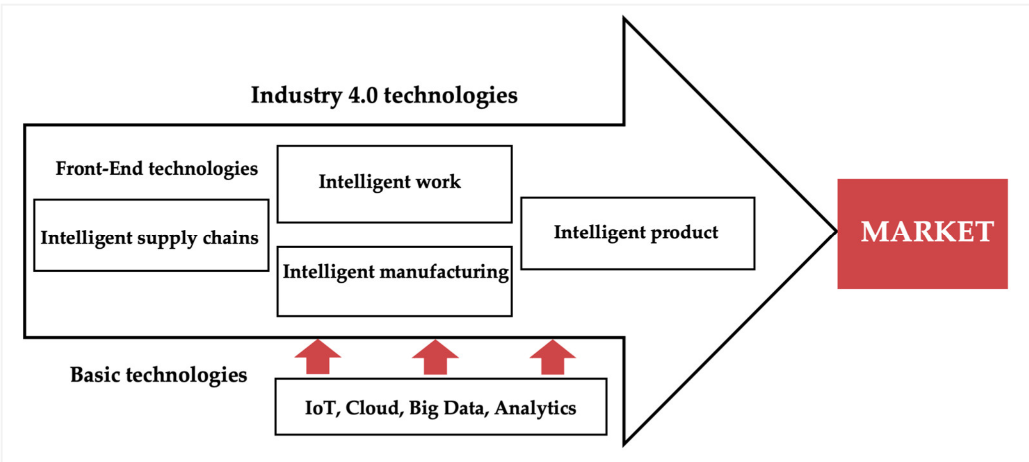


Figure 1. Schema for technologies in Industry 4.0. Source: Authors' compilation.

One of the challenges in implementing Industry 4.0 is standardization. In this sense, it almost seems mandatory to align all standards—internal and external—with the requirements and international standards developed in partnership with key global actors across international platforms [46]. Above all, it is critical to assess if adopting Industry 4.0 would provide the EU with a competitive edge in global markets or, alternatively, whether doing so will support it in maintaining its existing position by embracing sustainable production systems and the Internet of Manufacturing Things. It is also important to assess whether, in the worst-case scenario, the spread of technology through multinational firms would cause quickly expanding economies such as China to ultimately overtake developed nations as the dominant industrial power [47].

Under the guidance of the manager of the Toyota company, Taichi Ohna, a new management system for production enterprises was created in the 1950s [48], synchronically using a variety of approaches and concepts to achieve just-in-time production without losses [49]. The system was created soon after World War II, in a difficult environment with few resources, and in circumstances unfavourable for industrial growth. Despite the detrimental situation, the company was able to develop its own manufacturing technique, which is now known as the Toyota production system (TPS) [50]. Taylorism, a system that was prominent at the beginning of the 20th century in the USA and attempted to build a universal complex production theory based on scientific research, contrasted with the TPS, which is based on meticulous monitoring of one's own production processes with subsequent assessment of the situation [51]. When the largest US automakers were going through a crisis and many of them were searching for ways to close their plants, cut capacity, and shift manufacturing abroad, the TPS showed its efficacy at the beginning of the 21st century [52]. At the same time, Toyota was expanding its market, setting up new factories in the USA and increasing its yearly earnings. Both success for the Japanese firm and awareness of the TPS among the general public grew. In 1990, Womack et al. published the first article outlining the TPS's processes in the USA [53]. They utilized the word "lean," which has gained popularity. Subsequent scholars have provided a quite comprehensive philosophy of lean management for manufacturing and non-manufacturing businesses. Liker [54] lists 14 lean company management concepts. Shah and Ward [55] examined the factors impacting the implementation of lean production and provided a full explanation of the methods of mapping production processes. Several Western automakers embraced lean manufacturing concepts and based their own production systems on the TPS and lean manufacturing principles. Production systems associated with Audi, Scania, and Volvo are predominant in the car industry. After that, relevant suppliers, such as Bosch and Gestamp, joined them. Currently, there are over 100 production systems in use across the world that are based on TPS concepts and have several things in common [56]. Some firms have updated their unique production system with modern TPS principles [57]. The formation and growth of GVCs have been influenced by the growing division of labour. The industrial activities occurring all over the world are widely distributed and spread throughout multiple countries. Each economy focuses on the various stages of the industrial process wherein it is significantly operational and has a competitive advantage. The nations that participate in service or R&D-related activities are typically where added value is highest [58]. Although GVCs may seem predominant, certain production processes are regionally concentrated. In general, jobs requiring more sophisticated technology are carried out in more developed countries, whereas intermediate consumption and finalization (assembly) are carried out in less developed countries [59]. Industry 4.0 integrates cloud computing technologies, deep learning-based computer vision algorithms, and digital twin-based cyber-physical production systems [60]. This is a result of the internet's explosive expansion and big data-driven technologies. Based on the literature review, two research questions have arisen:

(1) Do all business sectors benefit from the deployment of Industry 4.0 components?
(2) What is the level of the digital preparedness of European economies, particularly the V4 nations?

3. Materials and Methods

This article approaches two fundamental study topics. The first focuses on the deployment of Industry 4.0 components that can benefit all business sectors. The investigation utilised diagrams of Toyota's lean production method and mutual comparison. The second topic covers the digital preparedness of V4 nations. The methodology is primarily based on a graphical analysis of indicators of the digital skills of the inhabitants of these countries (DESI), related to the adoption of digital technologies over a number of years (2015–2022). In cases where updates are not yet public, the data for the most recent year available (2021) were used.

The first step in the systematic approach of secondary analysis is the formulation of research questions, followed by the identification of the dataset and a comprehensive evaluation of it. This study's principal objective is to illustrate succinctly how current Industry 4.0 trends may interact with ground-breaking operational systems in GVCs to accelerate their activity in the context of enterprises from the V4 countries. Several secondary data analysis sources, including academic papers, books and book chapters, conference proceedings, government records, and annual reports of businesses, were evaluated in order to meet the study's primary objective.

In addition to European Commission, OECD, and Statista data, screening and quality evaluation methods were applied for the study (e.g., AMSTAR, Dedoose, Distiller SR, MMAT, and SRDR). Together with studies on the added value of non-financial industries, these assessments focused on covered subjects. In conjunction with secondary data analysis from the SME Alliance, a specific study was conducted. The secondary data were processed using the following scientific methods (Figure 2): (i) *the method of analysis*—which investigates a complicated research subject by decomposing it into sub-problems; (ii) *the method of synthesis*—which is used in processing and synthesising the acquired knowledge; (iii) *the method of comparison*—the result of which is the discovery of a mutual relationship between the researched knowledge, phenomena, or objects, making it possible to gain new knowledge about the researched topic; (iv) *the method of exploration*—used to interpret the results of the performed analyses; (v) *the method of explanation*—which aims to derive theoretical conclusions from the examined knowledge and is then organised into logical contexts and causal dependencies, serving as the basis for the development of theoretical conclusions about the research problem [60].

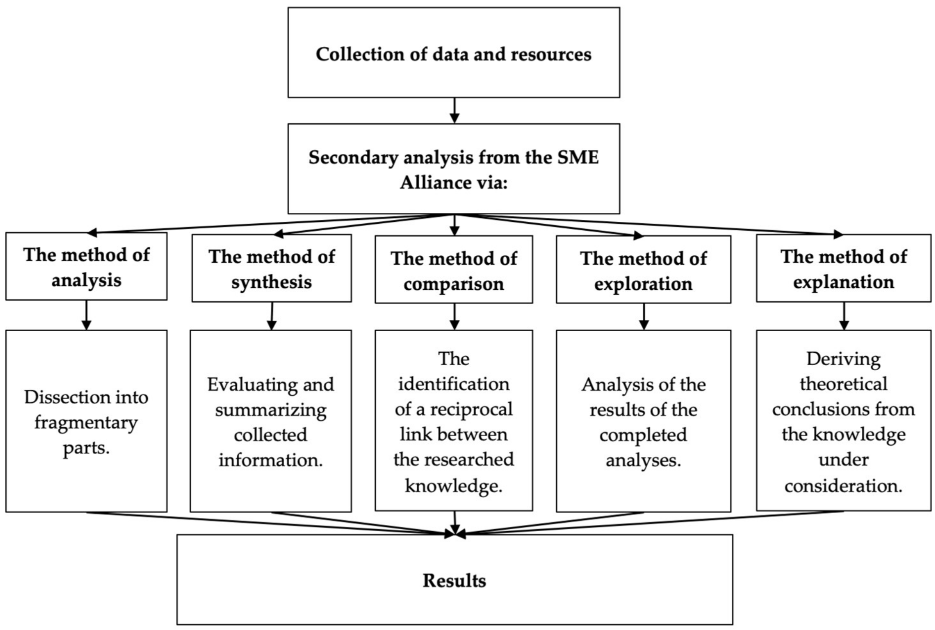


Figure 2. Diagram depicting the methodology employed in this investigation. Source: Authors' compilation, according to [60].

Womack and Jones [53] claimed that automated systems can integrate lean production through the following techniques: beginning with the customer, establishing corporate excellence, determining what is important to the customer, determining how value flows, and ensuring that the process is operational. Then, Liker [54] expanded on this idea by supporting a way of thinking that aims to ensure the continuous flow of the product through the process of introducing a culture wherein everyone aspires to development, and the balancing of the customer's demand against the movement of the product throughout the entire manufacturing process is such that what is taken away by the subsequent activity is replenished at irregular intervals. Liker [54] summarised the ideas of lean manufacturing using a two-pillar paradigm, as shown in Figure 3. Because a production system is only as strong as its weakest link, as the model rightly emphasises, breaking any one of the principles instantly jeopardises the stability of the entire production system [61]. The dynamic character of the manufacturing process is not considered in the design, and the relationships between the different principles are not immediately clear. These are both significant weaknesses [62].

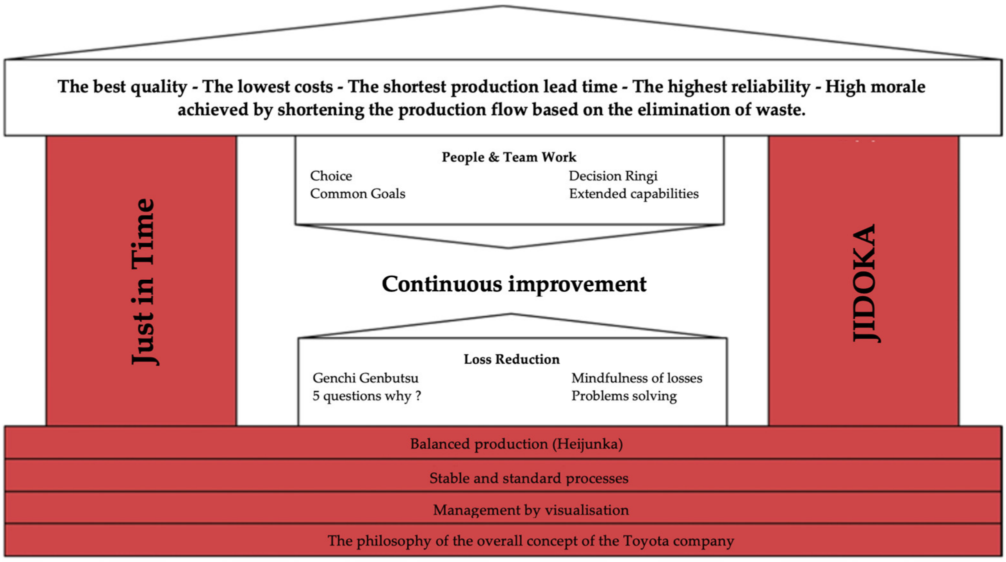


Figure 3. Two-pillar scheme of the Toyota Corporation's production system. Source: Authors' compilation according to [24].

The main advantage of this method is how well the authors were able to capture the fluidity of production processes and the interconnectedness of lean techniques. This method more properly represents how a lean manufacturing system is created: through coherent, iterative actions that lead to minor improvements. The Toyota company spent decades gradually creating a distinctive and unrivalled manufacturing concept [63]. It consists of many steps connected to a one-piece flow that enable the flawless mass production of a range of manufactured items without any loss of quality.

Ruttimann and Stockli [24] developed a more appropriate scheme, which is depicted in Figure 4.

In order to accomplish this, it was first necessary to create a reliable one-piece flow, which can only be maintained if a number of requirements are met [64]. All work processes need to be standardised and improved, and the production line can be clocked by knowing the rate of output at each location through using standard work, which allows for the following state to be reached:

$$CT_L = CT_1 \approx CT_2 \approx \ldots \approx CT_n \quad (1)$$

where:

CT_L—operation of the production line

CT_{1-n}—operation of individual workplaces of the production line.

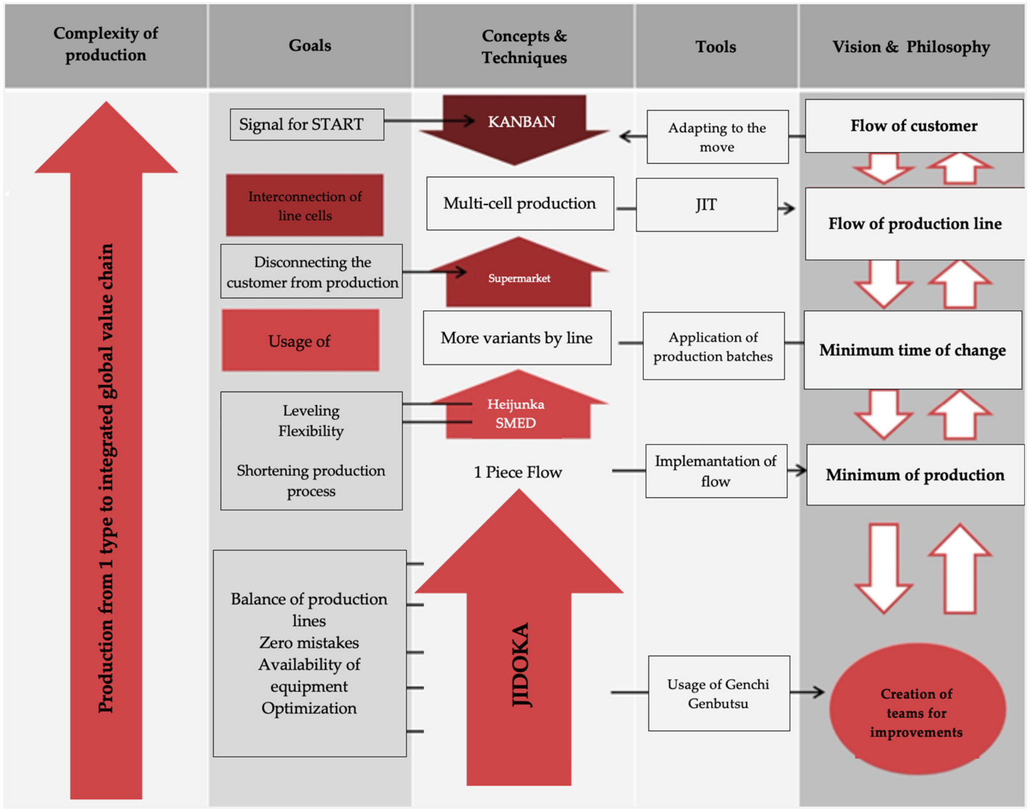
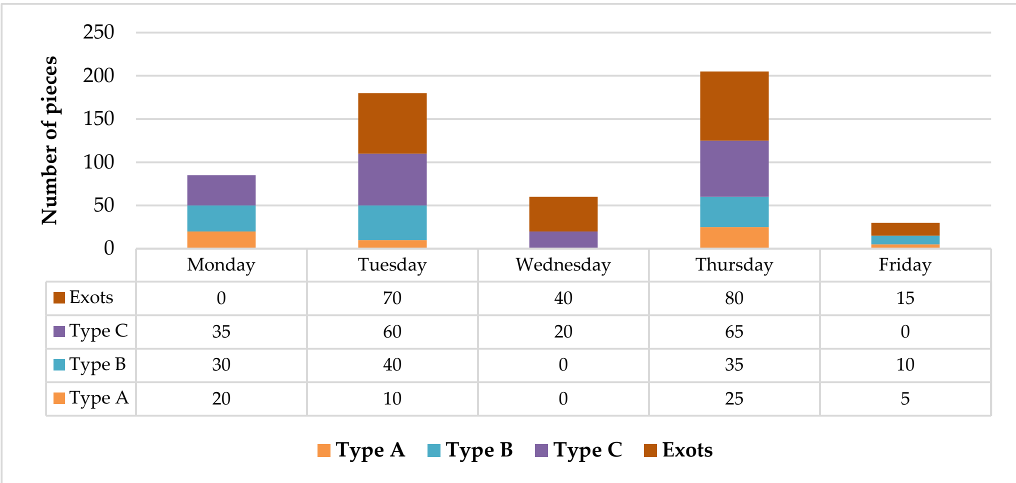


Figure 4. The Toyota production system's one-pillar diagram (modified). Source: Authors' compilation according to [24].

If this assumption is wrong, the flow of materials is disrupted, as material starts to pile up in front of the workspace wherein it is most required. Machines must be always available because unforeseen organisational, technical, quality, or performance issues in machines can cause a build-up of pieces in front of shut-down equipment, and hinder the material's smooth flow throughout the production line [65]. To do this, lean manufacturing systems introduce total productive maintenance. The highest possible quality of the products travelling down the assembly line must be ensured (Jidoka). Lean manufacturing lines typically use "poka-yoke" components to cut down on human error-related mishaps. A few examples include the use of threads with various pitches to prevent incorrect assembly, the use of grooves in a variety of shapes to guide the operator of the assembly station in the proper assembly of the product, and the creation of provisions to prevent incorrect insertion of the semi-finished product into the machine tool [66]. Another element used is the Andon system, which notifies employees of quality issues in the production line that are produced for any reason. In accordance with the Genchi Genbutsu concept, the whole authorised team of employees gathers at the location of the quality failure when the Andon signal is activated, and collaborates to find the root cause. The designated line's production is not restarted until the underlying reason has been found. However, in the current market, a one-piece flow does not currently offer just-in-time production. The one-piece flow itself may operate in mass production of a single type of product without the need for additional superstructure, i.e., in a market setting where the provider determines which product the client will purchase. After all, Toyota did not invent the concept of one-piece flow, which was instead heavily incorporated into the manufacturing of Ford automobiles during the heyday of Taylorism. On the other hand, lean manufacturing systems must be able to produce a range of commodities depending on the particular requirements of their customers. Lean manufacturing facilities use flexible assembly lines and machine tools as a result, making it possible to launch a new type of product very quickly. The necessity of a quick change of production type is taken into account, while focusing on form typification and technological simplicity throughout the product design process [67]. By standardising and subsequently optimising work activities during the rebuilding of the line, it is feasible to entirely eradicate all losses caused by frequent changes of the manufacturing type, provided that the production lines and the products themselves are suitable to quick changes of type. The lines are then ready to produce a constant volume of commodities with a constant kind of mix after this adjustment [68]. However, levelling is necessary to sustain output, since consumer demand is frequently irregular; this results in production balance, levelling, and smoothness without removing the production line's relationship to customer demand. Heijunka, or the planning board, is used to determine a type of mix that must be made in each time period in order to satisfy all of the customer's long-term requests without using overtime (often one production day) [69]. Heijunka is stocked using a long-term demand prediction that is modified by the forecast stability coefficient and spreads the production of different types across the entire scheduled period of time. Each manufacturing day consists of a number of shorter time periods that are used to produce a specific kind of product. Renners, or the products that satisfy 80% of demand, are frequently produced over a certain time period. Exotics, or the products that make up the other 20% of demand, are operationally scheduled as well as planned for a certain time slot throughout the manufacturing day. The effect of levelling production is seen in Figure 5. The graphic illustrates how levelled production encourages effective use of manufacturing lines and the creation of planning standards in addition to stabilising output [70].



	Monday	Tuesday	Wednesday	Thursday	Friday
Exots	0	70	40	80	15
Type C	35	60	20	65	0
Type B	30	40	0	35	10
Type A	20	10	0	25	5

Figure 5. The stability of the manufacturing process is impacted by levelled production. Source: Authors' compilation according to [70].

Analysis of the added value per employee and the digital readiness of the people in the V4 nations using the DESI index is the supplementary aim of the study (Digital Economy and Society Index). The index's goal is to evaluate how EU nations are faring in terms of the digital economy and society. It gathers a collection of pertinent metrics broken down into five categories: connection, human capital, internet use, integration of digital technology, and digital public services [71]. The amount of corporate innovation potential, educational attainment, and worker skill levels all have an impact on technical and dynamic growth. For further analysis, it is crucial to specify that the research was conducted in EU nations and that its purpose was to assess the digital preparedness of these nations for a shift in industry and everyday life. The subjects of this study are predominantly EU citizens and SMEs. Other sections of the paper present this issue and provide potential solutions. Additionally included in the investigation were screening and quality evaluation methods, as well as data from the European Commission, OECD, and Statista. Data from the DESI index and the WEF were used in the study to gain a deeper knowledge of the population's digital aptitudes. According to Zabojnik [72], connected car technologies, intelligent transportation planning, and cognitive wireless sensor networks will put more strain on the workforce in terms of automation and robotization, perhaps reducing employment by up to 30%. Given the growing need for industrial systems built on smart manufacturing, creativity will become an essential ability. A person's ingenuity and ability to cope with a wide range of unanticipated situations will be required by artificial intelligence and information technology, which include a far wider range of technologies and commodities [73]. Figure 6 depicts EU countries equipped at various levels for the transition to the digital revolution and industry.

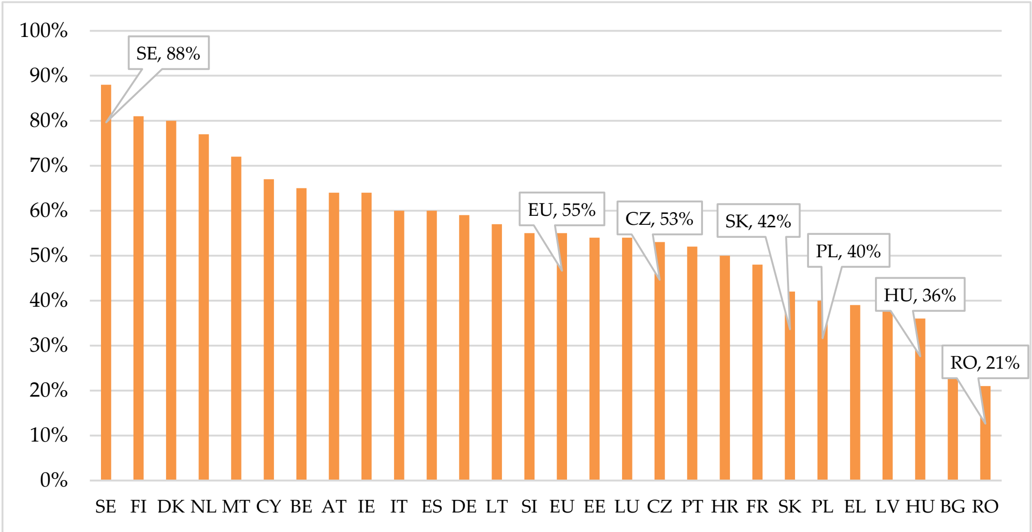


Figure 6. SMEs with at least a basic level of digital intensity (2021). Source: Authors' compilation according to [71] and cumulative data.

To conduct a more thorough analysis of the digital maturity and of the added value across the V4 economies, a number of techniques built on actual data that are readily available were used. The paper's main body is made up of statistical and graphical analyses [74,75]. Additionally, the work uses extensive analysis, and a synthesis of the results comes after. The findings of this case study can essentially be applied to all V4 countries.

4. Results and Discussion

To maintain the flow of material while generating a wide range of types, the production sections that are directly connected to the final assembly must be able to deliver an acceptable quantity of components. If not, the assembly would not continue and the customer would not receive the required components. Since assembly lines frequently have longer production cycles, it is not practical to directly connect machining processes to them. A solution to this issue is offered by controlled stocks with a predetermined maximum and minimum created between production regions with a visibly varying production rate or a different shift model. By connecting workplaces with roughly the same rate directly (FIFO track—first in, first out) and situating controlled stocks between works whose pace is significantly different, a smooth flow of material from the source to the end consumer is ensured in manufacturing.

By combining all the aforementioned techniques, it is possible to create a continuous flow of goods from the supplier to the final customer, as well as a flow of information in the opposite direction. "The necessary products are transported to the necessary location at the necessary time without sacrificing the necessary quality and quantity" [66,76]; thus, the goal of lean manufacturing techniques is accomplished. The value stream is shown in Figure 7, both before and after the application of lean manufacturing techniques.

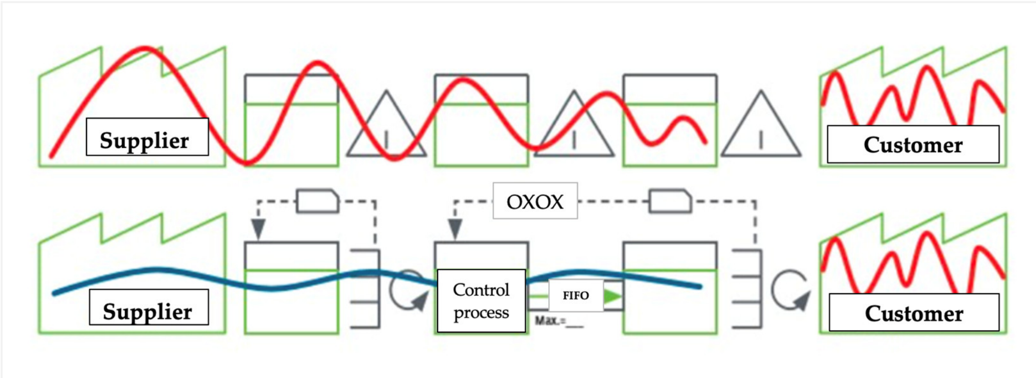


Figure 7. Value stream before and after implementation of lean manufacturing tools. Source: Authors' compilation.

Every business must adhere to the following key strategic elements in its culture and production, while avoiding blunders. The pull principle—under which specialists simply manufacture and supply what the customer demands; process orientation—with which creators value the evolution and improvement of processes; flexibility—with which consultants can easily adjust products and services to suit evolving market conditions; standardization—wherein researchers standardise procedures and utilise industry-leading technologies; transparency—with which business processes and the course of production are clear at first glance, and deviations from the defined state are immediately visible; avoiding mistakes—meaning preventive measures should be deployed; continuous improvement—which encompasses incessant and purposeful development; personal responsibility—with which roles and competences are integrated. To achieve the quickest production time with the fewest losses and a guarantee of excellent quality, these fundamental ideas and techniques, which are utilised at the same time in the administration of lean manufacturing facilities, were discussed in the previous chapter. The application of these principles increases mass production's flexibility, transparency, and degree of uniformity, and opens the prospect of lowering the batch size. This enables the production of a larger number of types of manufactured items and quick responses to market demands.

Kolberg et al. [4] assert that lean production has reached its limit. Strong variations in client demand are not be able to be offset by levelling in the market any more in the future. This levelling itself runs counter to the widespread practice of directly linking production to market demands. Although the use of lean manufacturing principles enables the creation of a broader variety of kinds and increases product diversity, it is hard to fulfil unique, one-off orders due to the predetermined order of manufactured types and a defined production rate. Cycles in customer demand serve as the foundation for lean production systems. Production must be regular, with no notable fluctuations, in order for the number of Kanban cards, the dimensions of production batches, and the quantity of interoperational stocks to be properly set up. However, the shortness of product life cycles and their individualization make it difficult to debug manufacturing in the same manner as lean production. These justifications serve as the foundation for assertions that Industry 4.0 technologies will displace lean production concepts, and that autonomous cyber-physical systems will take over the administration of the whole production, including its planning. As a result, highly adaptable manufacturing lines will be able to process customised goods at a lower cost than mass production. However, the concepts outlined in lean production systems must be respected in order to put Industry 4.0 ideas into practice. If these rules are broken, the level of workplace visualization may reduce, transparency may be limited, Gemba access may be suppressed, effective optimization of processes may become impossible due to low awareness of the physical links between individual operations, and suppression of continuous improvement may happen [77].

Thus, Industry 4.0 is a crucial component of lean production systems, with lean automation managing production. This idea first appeared in the 1990s, when computerised production was at its height in popularity. Many experts back then thought that computers would eventually take over the whole industrial process. This was mostly caused by an absence of reason for such a solution, rather than the excessively high implementation costs or the great complexity of the solution. Lean production and Industry 4.0 development may coexist as long as the latter is utilised to supplement rather than to substitute human labour activities.

The primary areas for automation may be identified from the perspective of how Industry 4.0 will affect the circumstances of any industry in the V4 nations. The major focus of automation is on the foundational tasks performed by assembly lines inside businesses, including the production of autos. With the launch of the new generation of electric vehicles, several automakers were able to put into practise ground-breaking technologies that have increased the effectiveness of their business operations (e.g., full kitting, laser geometry control, robotic arms, and edge supplying). These automation components, which make use of industrial big data, deep learning-assisted smart process planning, and real-time advanced analytics, are the major focus areas for such businesses [78,79].

It is crucial to prepare corporations and people and provide them with digital skills in order to handle such a powerful wave of automation. As a result, displaying the level of digital proficiency in the V4 nations via components of Industry 4.0 is relevant (Figure 8).

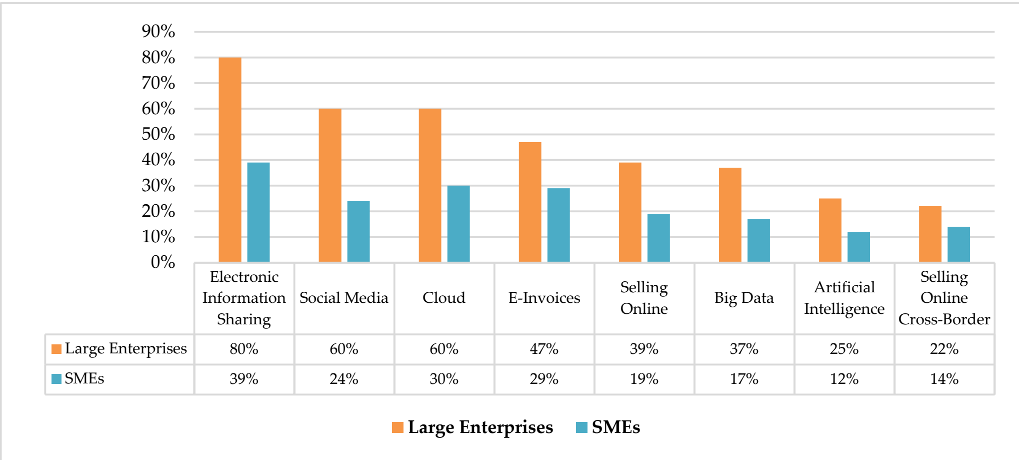


Figure 8. Adoption of digital technologies (% of enterprises—2020, 2021). Source: Authors' compilation, according to [71] and cumulative data.

According to Figure 8, social media (60%) and electronic information sharing (80%) have the highest digital adaptability of the V4 countries for large companies (over 250 employees), being at a level of about 40% for SMEs.

From the intersection of all the Industry 4.0 components (Figure 9) for the V4 countries, Slovakia and the Czech Republic account for the largest share of readiness (about 5%) (Figure 10).

Based on Figure 10, most nations have a satisfactory degree of preparedness throughout public services for the digital revolution. The Czech Republic is the best positioned of the V4 nations, scoring close to 70%. A retraining process should be implemented to enable older citizens of certain nations be up-to-date technologically, and the primary focus should be on educational procedures.

For a more accurate depiction of the acquisition of digital experience and abilities, it is necessary to measure adaptability over an extended period, and track its evolution throughout time (Figure 11).

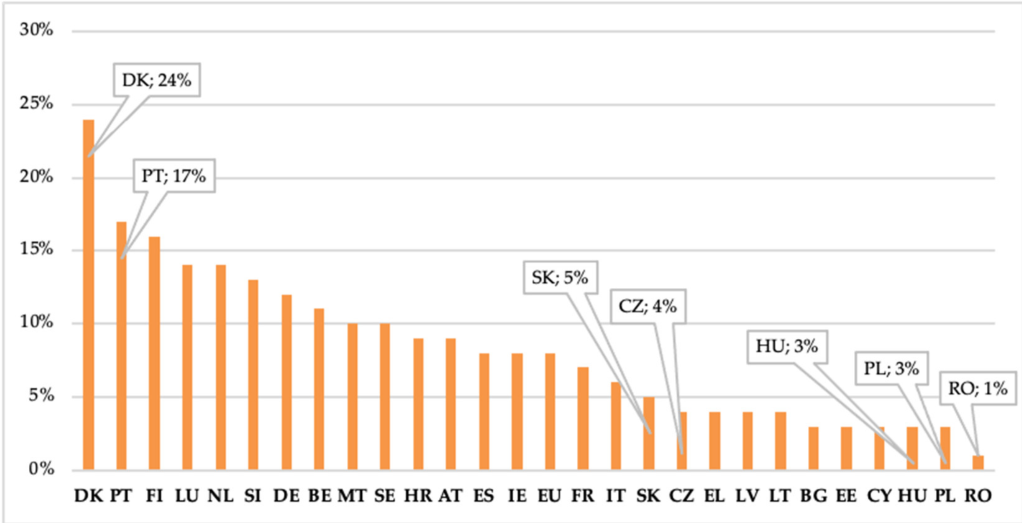


Figure 9. Companies using Industry 4.0 components (% of enterprises). Source: Authors' compilation, according to [71] and cumulative data.

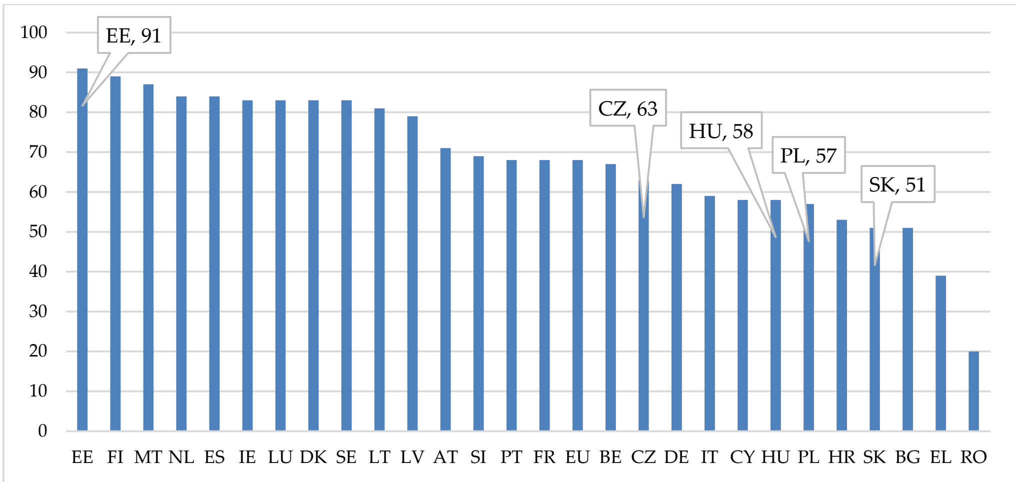


Figure 10. Digital Economy and Society Index (DESI) 2022, digital public services. Source: Authors' compilation, according to [71] and cumulative data.

Based on Figure 11, which displays the DESI index over the course of eight years in EU member states, there has been a significant growth in the flexibility of digital skills, particularly in the V4 nations. Ireland has made the most development, which can be explained by the presence of numerous international corporations. The same holds true for the Netherlands. The V4 nations and their flexibility improve each year, and the COVID-19 pandemic, during which people were obliged to labour remotely and with digital devices, contributed to this development.

Moreover, the investigation identifies the industries with the largest revenues (EU Unicorns—more than one billion euros in revenue) (Figure 12), and the digital skills that are absolutely indispensable for them. These are mostly software-based businesses. This research demonstrates conclusively that digital skills are crucial for success and must thus receive great emphasis.

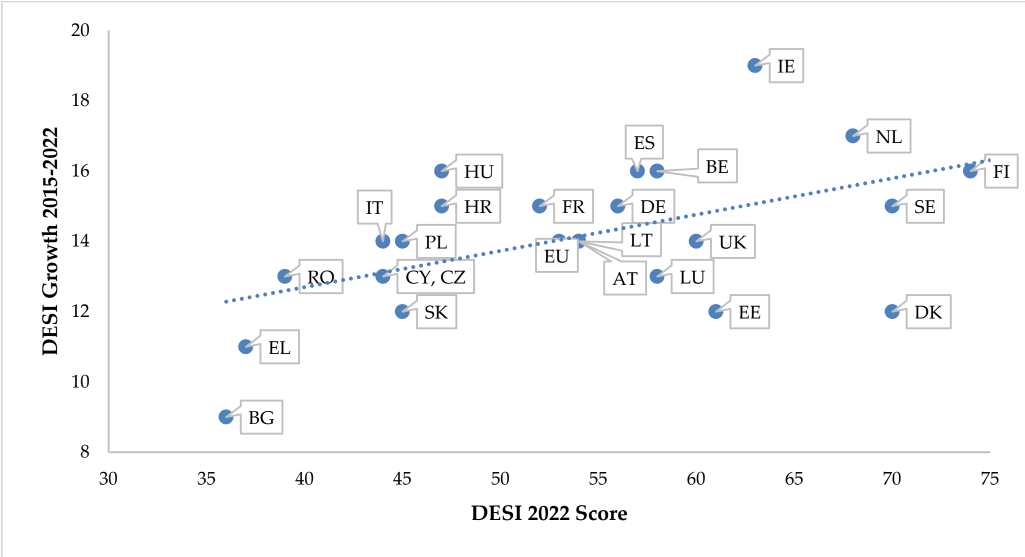


Figure 11. Digital Economy and Society Index—Progress of Member States, 2015–2022. Source: Authors' compilation, according to [71] and cumulative data.

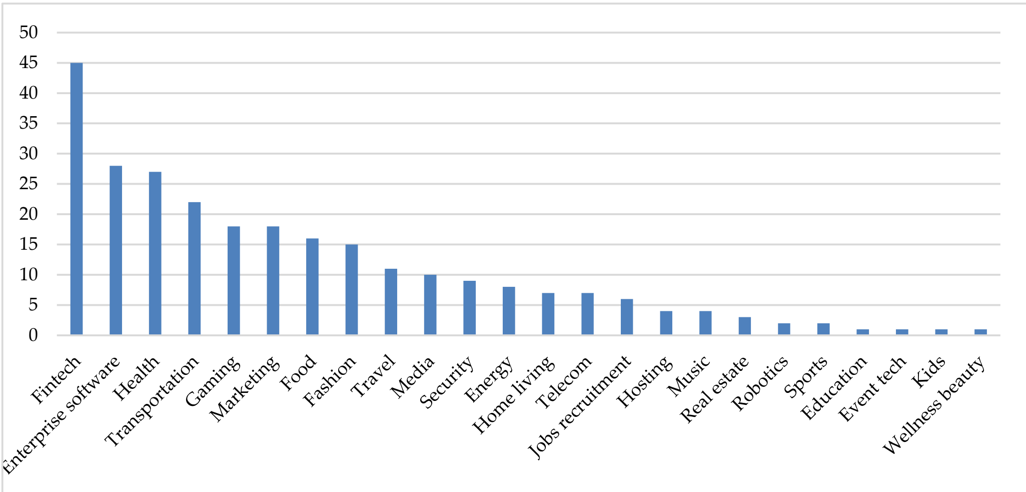


Figure 12. Industry-specific EU unicorns as of 2022. Source: Authors' compilation, according to [71] and cumulative data.

In accordance with global trends, Figure 12 indicates that EU unicorns are most active in fintech (20.3%), enterprise software (12.6%), and health (12.6%).

Therefore, offering competitive goods from an agile and sustainable loss-free value stream is the aim of Industry 4.0. The phrase "value flow without losses" that is mentioned in the Bosch production system concept is exactly what is meant by the following statement: "through integrating people, machines, objects and systems, it is feasible to realise advances in flexibility, robustness and optimal deployment of resources [71,78]." Therefore, Industry 4.0 may be viewed as a collection of digital technologies that support concepts of lean production systems in order to achieve flexible and long-lasting loss-free value flows. For instance, inconsistent tracking of the amount of material delivered to the production line and frequent changes to the production schedule are violations of the pull principle. The Kanban system is frequently used in well-established lean manufacturing systems to maintain the right amount of material on the lines. It is based on the circulation of a predetermined number of Kanban cards during the production process. How much inventory is placed on the production line depends on how many cards are distributed. It might be challenging to determine the optimal quantity of Kanban cards and thus stocks.

While performing the calculation, it is essential to take into account factors such as refill time, consumer behaviour, batch size, value flow performance, process stability, and the accuracy of customer recall planning. Because they are difficult to estimate exactly and are often shifting, it is important to periodically recalculate and adjust the number of cards in circulation. The solution is the E-Kanban system, which uses material boxes equipped with sensors that may transmit a signal when the box is empty.

Industry 4.0 technologies are used in lean manufacturing systems to encourage production process transparency and free up production employees from monotonous activities. Transparency is a key element of lean manufacturing because it creates the conditions for continuous process improvement, an action that reduces waste. When workers are freed up from routine activities, they may focus on tasks that will improve production processes, which boosts productivity. However, for the following reasons, using Industry 4.0 technology could not necessarily lead to more openness. An average employee cannot comprehend the intricacy of Industry 4.0 tools, autonomous systems modify the production process without the worker's awareness, and employees cannot comprehend the data that are gathered and analysed. In order to embrace Industry 4.0 tools in accordance with the principles of lean production, minimise risks associated with their introduction, and maximise their contribution to the production system [80], the following rules must be followed. Only processes with a certain level of maturity can use Industry 4.0 technologies. This ensures that even without the use of IT systems, processes are understood, clear to all personnel, stable, and to some extent automated. Production department staff members who will employ Industry 4.0 tools (including production workers) must be adequately qualified to handle these tools. Above all, expertise in data analysis is necessary. The user must be given the findings of the data analysis in a format that allows him to grasp the information. Every member of the production team must be able to spot deviations from the norm right away and pinpoint their primary cause. The autonomous system cannot have complete control over the production process in order to preserve the transparency of the material flow. Each product's route through the manufacturing process must be established in order to maintain the transparency of the material flow. In the case that the code expires, the system shall not select a different path for the product without first notifying the competent person and obtaining their approval. Until the new tool is sufficiently reliable and the workers willingly prefer it to the older system, both systems must function simultaneously in the event that the Industry 4.0 tool replaces the customary approach. It is necessary to uphold the Genchi Genbutsu approach, and constant Gemba [81]. Planners and managers must continue to spend a large amount of their working hours in production, since sensors cannot record all pertinent characteristics. They must continue to base their decisions on their own opinions and talks with other members of the production team. The development of an objective viewpoint and the provision of essential and accurate information, however, will be considerably aided by Industry 4.0 technologies, and may result in better and quicker decision making.

Based on the above graphs, two research questions from the literature review section may be addressed. On the basis of a comparison between production with and without the implementation of Industry 4.0 components, it is necessary to divide the benefits of using these components. Primarily, in shortening production processes and also by increasing the quality of products, the added value increases, as does the education of people for future generations, particularly in ecological thinking. The second issue may also be addressed clearly based on the preceding graphs. To begin with, it should be underlined that all EU nations employ digital technology, although to varying degrees. Regarding the V4 nations, the order of digital primacy varies according to individual categories, so it would be incorrect to say who is first and who is last. However, it is possible to say that digitization and education are gaining ground each year, which only indicates an increasing trend in these devices. For a more in-depth examination, it is necessary to have more comprehensive data and to consider the political structures and similar factors of the nations.

To fully understand and benefit from manufacturing systems based on Industry 4.0, all sectors must embrace them widely. By utilising cognitive wireless sensor networks, interconnected vehicle technologies, environment mapping and position tracking algorithms, and mapping and navigation tools in smart urban transportation systems, the V4 nations aim to upgrade R&D with innovation. Cyber-physical production systems will raise the standard of living in these nations by enabling businesses to include cognitive automation, robotic wireless sensor networks, and predictive maintenance systems. In-depth research must be conducted, and an intelligent industry platform must be established in order to construct Industry 4.0-based production systems built upon machine and deep learning technologies, spatial simulation and motion-planning algorithms, and traffic flow prediction tools [82–87].

Data visualisation tools, knowledge acquisition-based organisational successes, cyber-physical smart manufacturing systems, and sustainable economic development are configured. In the Slovak automobile industry, Industry 4.0 wireless networks span immersive workspaces [88,89]. Tradeable digital assets, artificial intelligence-driven Internet of Things technologies, and decision modelling and intelligence articulate sustainable smart manufacturing. Cyber-physical production networks are aided by real-time big data analytics, immersive extended reality technology, and socially networked virtual services [90–95]. Deep learning-assisted smart process planning is made possible by geospatial big data management algorithms, decision intelligence and modelling, and the implementation of blockchain technology. The Internet of Manufacturing Things is furthered by robotic wireless sensor networks and sensory algorithmic devices [96–105]. Spatial analytics are advanced by immersive virtual technologies, virtual marketplace dynamics data, knowledge co-creation, and remote working tools [106–111]. Cyber-physical manufacturing and immersive visualisation systems are shaped by sensing technologies, global business performance, knowledge capitalism, and cognitive analytics management [112–120].

5. Conclusions

In this article, the authors aimed to solve two issues related to the main topic: Industry 4.0 lean production systems and the digital skills of the V4 countries can create added value by integrating Industry 4.0 technologies.

A comparison between the concept of the lean production system and the definition of Industry 4.0, as well as the activities described above, shows that lean manufacturing systems will not disappear with the advent of Industry 4.0. On the contrary, lean manufacturing principles will be more important than ever because they must be followed in order to successfully use Industry 4.0 technology. Industry 4.0 has enormous potential for the growth of truly lean production (or evolution). A lot of information about customer demand can be acquired and quickly disseminated throughout the whole value chain with the help of Industry 4.0 tools. In smart factories, which can also manufacture more swiftly and with less waste, a streamlined flow of one item is possible. The amount of inventory across the value chain may be greatly reduced with the help of real-time monitoring of the material movement. When more advanced and potent technologies such as those offered by Industry 4.0 are used, lean production will surely change. It is anticipated that physical Kanban cards, Andon "saving brakes," process monitoring boards, and other lean manufacturing system components will decline in use. However, it is crucial to note that Toyota, the business that invented the lean manufacturing technique, never claimed that the use of these material tools was the reason behind its success. The TPS's use of tools was justified at the time of its founding because it allowed their values and vision to be realised. As a consequence, if Industry 4.0 technologies are implemented in accordance with the principles of lean production and lead to the attainment of the company's goals, their adoption will be justified and will greatly improve the production system.

Regarding the V4 nations, the most added value is produced in the automobile sector, with the highest automation taking place in the manufacturing area of the industry. However, because research and development are not utilised to the same degree in the

V4 nations as they are in Western Europe, their impact reaches somewhat low levels. According to research on digital readiness and component use, social networks and data sharing are where major organisations are seeing the most digitalization. In the analysis of the combined components, it can be argued that the Czech Republic and Slovakia have the best strategy for a successful digital revolution; however, this will all depend on the future actions taken by these nations. The emphasis should be primarily on improving educational procedures, optimizing legislative management, and increasing spending on research and development to produce high-added-value products in these economies. It is critical to shift Slovakia's focus to producing electric vehicles and their associated batteries. This assertion is supported by the DESI index, which also emphasises how poorly prepared the public is for the massive shift to a digital world.

This study has several limitations, primarily as only four nations were included in the analysis (Slovakia, Czech Republic, Poland, and Hungary). Further research is needed to define Industry 4.0-based manufacturing systems for these nations' industries, taking into account self-driving cars in relation to smart transportation and network connectivity systems, deep learning object detection and collision avoidance technologies, geospatial data visualisation tools, and trajectory planning and sensor fusion algorithms.

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