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Smart Technologies for Sustainable Industry: Digital Strategies to Reduce Waste and Boost Productivity

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Abstract. In recent years, the rapid advancement and widespread adoption of digital technologies have profoundly reshaped various sectors of the economy and society. Increasingly, organizations are moving their operations into digital realms, resulting in significant reductions in transaction costs and a notable expansion of economic activity. The internet has facilitated the creation of an enormous, virtually boundless market characterized by global competition and remarkable dynamism across companies, products, and consumers. In this context, the capacity to handle and analyze vast amounts of data emerges as a crucial competitive advantage. The ability to swiftly respond to evolving customer demands and swiftly introduce new products and services through online channels now plays a pivotal role in determining the sustainability and growth prospects of businesses, far outpacing the capabilities of previous decades. Today, the market value of many companies is heavily influenced by their "digital assets," such as the size and engagement of their online audience, brand recognition, and reputation in cyberspace.

1 Introduction

The engineering industry is rapidly embracing innovative technologies for production, a trend that has roots dating back to the Industrial Revolution. As we move into the fourth industrial revolution, the digitization of processes is becoming crucial for managing the increasing complexity of manufacturing systems. Traditional production planning and control systems are evolving to integrate various functions efficiently.

As manufacturing systems grow in complexity, mathematical and simulation methods are indispensable for planning and analysis. Mathematical models are designed to optimize

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production execution, while simulation models offer a detailed representation of manufacturing systems, often including 2D or 3D graphical elements. Simulation provides invaluable insights, allowing experimentation with new strategies and concepts without physical alterations.

In the context of Industry 4.0, advanced simulation plays a pivotal role. It is the primary approach for designing and analyzing manufacturing systems, offering a range of methods and technological tools. These tools enable experimentation, verification, and prediction of production system performance in a controlled environment.

The rise of digitalization has expanded access to simulation tools for manufacturing processes and systems. Digital simulation technologies facilitate the creation of realistic models, visualization of production systems, and real-time processing of big data. These tools emulate the characteristics and behaviors of production system components, aiding in better decision-making and optimization.

Simulation, visualization, and digitization are distinct concepts, often confused. Simulation involves generating data, while visualization entails graphically representing that data. 3D visualization makes elements appear real, while simulation technology makes them function as if real.

Digitization encompasses various forms, including the integration of digital tools, workflows, and approaches into activities across industries. In manufacturing, digitization includes digital tools for production planning, among other aspects.

Digital manufacturing is a comprehensive approach integrating digital technologies for planning, preparation, quality management, cost control, material movement, and production operations. It enables manufacturers to optimize their production systems using digital technology.

In manufacturing, digital technologies like communication tools, connectivity mechanisms, and data analysis capabilities are widespread, enabling leaner, more profitable, and data-driven processes. This document identifies digital tools for production planning and showcases their practical applications through case studies.

2 Research methodology

Despite the multifaceted nature of the concept, the theoretical and analytical exploration of digital transformation is ongoing in both academic and business circles. In scholarly literature and various analytical publications, digital transformation is examined from different perspectives, with authors attempting to forecast its implications and long-term outcomes. Most studies revolve around several key inquiries [4]: What constitutes digital transformation and what are its boundaries? What are its principal characteristics? What are the driving forces behind it? What are its objectives and consequences?

In leading nations, digital transformation entails a cross-industry approach to supporting the adoption of new technologies. Programs and initiatives can be structured to focus on implementing a specific set of promising technologies across multiple sectors or, conversely, on digitally transforming a particular industry through the rapid deployment of diverse technological solutions tailored to its needs in the economy or society. For instance, Singapore's artificial intelligence (AI) development program encompasses five sectoral initiatives: intelligent cargo transportation planning, seamless public service delivery, early

diagnosis and prediction of chronic illnesses, personalized educational pathways, and streamlining migration procedures.

3 Results and Discussions

Regardless of how we define digital transformation, it's evident that most industries have experienced similar evolutionary stages over recent decades. These stages include the adoption of computers for industrial tasks in the 1950s-1960s, the automation wave of the 1970s-1980s, the rise of personal computers in the 1980s-1990s, and the development of the internet in the 2000s-2010s. These transitions significantly altered economic and social landscapes and fostered the emergence of new sectors, notably information and telecommunications technology [7].

However, the current phase of digital transformation exhibits distinct characteristics:

1. New Technological Advancements: The latest phase is propelled by advancements in technologies such as AI, robotics, blockchain, and virtual/augmented reality. These innovations offer unprecedented opportunities, including precise forecasting, data-driven decision-making, cost reductions, and enhanced consumer experiences. Consequently, investments are increasingly directed towards these advanced digital technologies, with their share in total spending projected to reach 23.4% by 2023. The COVID-19 pandemic accelerated this trend, with a notable shift towards investments in advanced technologies while traditional ICT spending decreased.

2. Surging Demand for Digital Technologies [8]: There's an unprecedented surge in demand for digital technologies, fueled by their increasing simplicity and intuitiveness. Managers in both Russian and global organizations are keen on expanding their use of digital technologies, reflecting a broader trend of growing interest and investment. Global spending on digital technologies has consistently risen by 10-15% annually over the past decade, reaching significant proportions of GDP in many countries.

3. Shortening Technology Life Cycles: The heightened demand has accelerated the transition of advanced technologies from the laboratory to practical applications. Quantum technologies, for instance, are progressing rapidly, promising breakthroughs in computation and data transfer speeds. Examples such as cloud quantum computing being utilized for COVID-19 research in Canada highlight the swift adoption of cutting-edge solutions to address pressing challenges. Future technological progress hinges on the ability to cultivate and leverage unique knowledge at the intersection of fundamental research and applied development, particularly in the realm of DeepTech.

Digital tools and simulation play integral roles in the concept of the digital factory, aiding in the design and analysis of complex systems. Computer models are constructed to make decisions about these systems, and experimentation on these models informs decision-making processes.

The case studies outlined in the paper illustrate various applications of digitization and simulation in production planning decision-making. In one case, the implementation of digital records enhanced warehouse processes and resource management in production. Another case demonstrated how simulation identified potential improvements in the layout of assembly workstations, leading to time and cost savings in material flow. Additionally, a third case highlighted how digital tools optimized workforce utilization. These studies

underscore how digitization and simulation contribute to systematic decision-making in production planning and process optimization.

The benefits of using digital tools are evident, as they offer cost-effective, efficient, and safe implementation without disrupting real production systems. Simulation enables testing of multiple scenarios, allowing for anticipation of system behavior and preemptive mitigation of shortcomings. However, accurately describing the behavioral model of the system in simulation is crucial for obtaining relevant results, a topic for future research.

Further investigation is needed to define advanced simulation and digital twin concepts, as well as to devise strategies for collecting real-time data from production systems and utilizing digital twins alongside machine learning systems for production process optimization. These areas warrant exploration in future studies to enhance the efficacy of digital tools in manufacturing.

The COVID-19 pandemic has spurred significant shifts in global technology trends, driving further digitalization. The evolving needs of industries and populations have led to the emergence of new applications (CovidTech) and a reassessment of digital technologies' role in everyday life. The pandemic accelerated the adoption of mature technologies, resulting in a leap in digitalization comparable to several years' worth of progress within a few months. The convergence of digital and physical realities, termed the "phygital" concept, has gained traction, offering consumers a wide array of services even during lockdowns. Advanced digital solutions, from AI-powered pandemic monitoring to drone-based biomaterial delivery, have played a crucial role in navigating the challenges posed by the pandemic.

4 Conclusions

In today's world, digital tools play a key role in optimizing production processes and reducing resource consumption. These tools provide businesses with the opportunity to increase the efficiency of their operations, minimize costs and reduce their negative impact on the environment. In conclusion, we can highlight the following main advantages of digital tools in this area:

1. Optimize Manufacturing Processes: Digital technologies enable businesses to monitor and control their manufacturing operations in real time, identify bottlenecks, and optimize workflows to improve productivity.

2. Reduced resource consumption: Digital monitoring and control systems make it possible to use energy, water and other resources more efficiently, optimizing their consumption and minimizing losses.

3. Analytics and Forecasting: Using digital tools, businesses can analyze large amounts of data about their operations, identify trends and predict future needs, which helps them make more informed strategic decisions.

4. Improving product quality: Digital technologies make it possible to automate production processes, which reduces the likelihood of errors and product defects, and also ensures stable quality of products.

5.Sustainability Compliance: The use of digital tools helps businesses meet sustainability and environmental responsibility requirements, leading to cleaner, more sustainable operations.

Thus, digital tools represent a powerful tool for optimizing production processes and reducing resource consumption, providing businesses with a competitive advantage and contributing to their sustainable development.

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