Research Article

Received: 9 April 2023 / Accepted: 12 June 2023 / Published: 5 July 2023

Technological Enablers and Prospects of Project Management in Industry 4.0: A Literature Review

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DOI: https://doi.org/10.36941/ajis-2023-0094

Abstract

This study provides an overview of the 'technological enablers,' which include technologies, methods, and organizational strategies, critical for transitioning to Industry 4.0. The shift is propelled by numerous challenges faced by modern companies, including global competition, economic inequality, and educational gaps, to name a few. To illuminate these complexities, we conducted a critical literature review, emphasizing perspectives related to industrial projects and 4.0 factories. This approach helped us identify notable trends within Industry 4.0 and discuss potential benefits and obstacles pointed out by various researchers in the field. This paper presents an updated summary of Industry 4.0 features, trends, and implementation factors, aiding readers to identify possible opportunities and challenges in their projects or work environments. As Industry 4.0 increasingly integrates companies with users across creative, design, and major business decisions, the need to adjust competitive strategies for gaining advantages becomes paramount.

Keywords: *technological enablers; industry 4.0; project management; competitive strategies; literature review*

1. Introduction

The term Industry 4.0 was initially coined in Germany in 2012, encapsulating a strategic initiative to leverage emerging technological advancements such as cyber-physical systems, the Internet of Things (IoT), future industries, real-time collaboration, and digitization of the manufacturing industry. This initiative heralded the onset of the Fourth Industrial Revolution or Industry 4.0. Enterprise Resource Planning (ERP) emerged as a core component of this revolution, with the concept of Future of Factories (FoF) encapsulating the technologies related to Industry 4.0.

Numerous studies have delved into the various facets of Industry 4.0. Jardim et al. (2016) identified the challenges and key innovations within the realm of intelligent industrial production. Concurrently, Haddara & Elragal (2015) assessed ERP systems' readiness for FoFs. Jin et al. (2017) contributed to the dialogue on process design management within the human resources sphere in the context of globalization. As a result, virtual spaces have arisen in workplaces for customer interaction, customizable on-demand manufacturing, and the circular economy. Industry 4.0 aspires to facilitate the integration and synergy of physical and virtual worlds. Ghobakhloo (2020) offered a comprehensive overview of Industry 4.0's constituent elements and their interrelationships, including smart project management, smart stakeholders, smart supplies, environmental sustainability, smart warehousing, smart products, smart customer integration, smart factories, and smart manufacturing (Valentin et al., 2018).

Kiraz et al. (2020) outlined nine factors shaping current Industry 4.0 trends, with market and consumer access being the most crucial. These factors encompass market and consumer access, data protection, processing and collective expertise, organizational culture, value chain and processes, IT architecture, risk and security, business models, products and services, data integration for analytics, leadership strategy, culture, and management. In today's fiercely competitive global environment, market and consumer access is regarded as the most significant factor.

Despite the existence of Industry 4.0 technologies, their implementation is contingent on various factors, paradigm shifts, and changes in approach. Unless sustainability is the driving force, the 4.0 revolution might lose direction and hasten environmental degradation and resource depletion. The true potential of Industry 4.0 can only be realized when supply chains, intelligent machines, and specialized human resources are interconnected within a single network, operating in real-time within a circular economy (Ghimire et al., 2017). Ozkan et al. (2020) shed light on the current challenges encountered during the transition to Industry 4.0. Majumdar, Garg, & Jain (2020) identified similar obstacles in the textile and apparel industry, such as lack of workforce training, insufficient understanding and commitment from top executives, inadequate government support and policies, research and development gaps, high implementation costs, fear of change and failure, and poor integration and incompatibility. Bag et al. (2020) collated the necessary adjustments for Industry 4.0 adoption (Figure 1). Ambitious initiatives like China's "Made in China 2025" seek to transition from mass-produced standardized goods to customizable, high-tech products. In Germany, sustainable energy use, energy auditing, management and monitoring systems, sales control, and energy integration in the Industry 4.0 environment are deemed crucial.

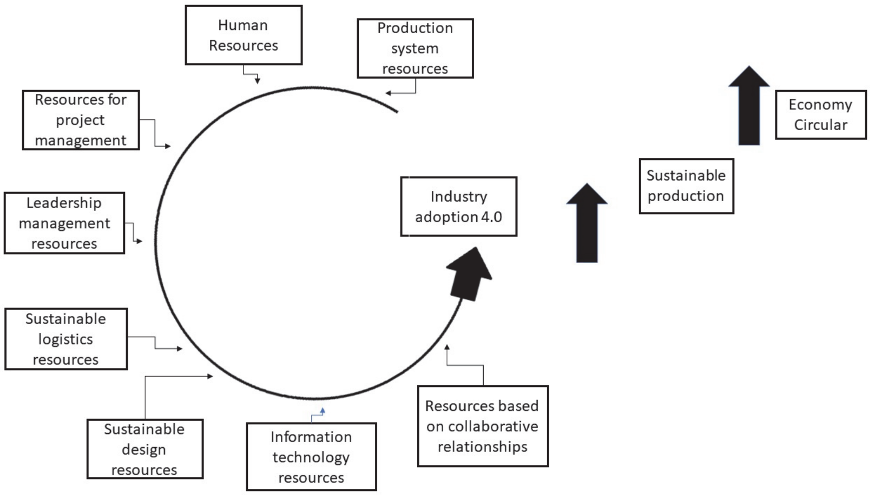

Figure 1. Adjustment elements for adopting Industry 4.0, leading to sustainable production (Bag et al., 2020).

The aim of this paper is to offer an all-encompassing overview of the characteristics and emerging trends of Industry 4.0, focusing on factors related to its implementation, and identifying both potentials and challenges. Understanding how to navigate this intricate landscape is essential, given the complexities in implementing Industry 4.0 (Zhu & Mostafavi, 2017). This paper also scrutinizes the project management approach in engineering and explores various technological tools for its implementation and integration. The successful transition to Industry 4.0 depends on numerous variables, each posing its unique set of challenges and opportunities. Recognizing these factors can better equip industries to prepare for this transformative shift, leading to enhanced efficiency, productivity, and sustainability (Benešová et al., 2019). The insights and strategies derived from this research review can serve as valuable guidelines for enterprises aiming to navigate the transition to Industry 4.0 successfully.

2. Methodology

For this review, we consulted bibliographic sources dating from 2010 to 2021. These were primarily obtained from respected databases such as IEEE, ScienceDirect, Springer, Wiley, and Taylor & Francis, which publish some of the most influential journals in the field of engineering. Additional articles were selected from the Google Scholar search engine, given its broad coverage of pertinent sources. The research was conducted in English, given its status as the predominant language of scientific discourse and its comprehensive source availability.

Our initial search used the keywords "Project Management" and "Industry 4.0". Subsequently, related topics were identified from the collected articles, which included: digital twins, system of systems, frameworks, supply chain, smart manufacturing, digitalization, big data, customization, complex systems, management methods, future trends, automation, Internet of Things (IoT), and more (Zhu & Mostafavi, 2017). Further keywords were derived from these articles, such as cobots, smart factories, smart cities, smart manufacturing, sustainability, circular supply chain, agile project management, dynamic systems, global supply chain, energy management, device integration, cyber-physical systems, cloud computing, real-time operations, multitasking learning, product development, blockchain, e-robotics, intelligent systems, virtual testbeds, real-time simulation, product lifecycle management, product-service system, virtual organizations, Industry 4.0 skills, and socio-economic modeling, among others (Scholz et al., 2020; Wang et al., 2018). Following this extensive search, 81 articles that met the specified criteria were chosen and reviewed. Subsequent analysis was conducted from the perspective proposed in this study, identifying pertinent topics and structuring the review by clustering common elements.

The results of this review are divided into three primary sections: first, we introduce the technologies and technological enablers of Industry 4.0, supported by various examples and experiences drawn from the literature review. Second, we discuss models of engineering project management and factors associated with the implementation of 4.0 technologies. Finally, we examine the most significant aspects identified, and pinpoint the key trends and tools required for the transition to Industry 4.0.

3. Results and Discussion

3.1 Industry 4.0 Enabling Tools and Technologies

Integration/Interconnection: New devices and software applications allow for extensive interconnection of devices through standardized protocols (Berteaux & Javernick-Will, 2015). This integration spans human talent and autonomous systems such as autonomous transport vehicles, intelligent robots, and collaborative robots (cobots), enabling high-resolution coordination across all components of the production model.

Internet of Things (IoT): As a novel technological paradigm, the IoT envisions a global network of work systems, employees, machines, and devices capable of interacting with each other. This network is gaining recognition as a key component in many industries. Table 1, from Lee & Lee (2015), outlines some of the major enablers of IoT. The table provided offers an insightful view of the evolution of technology pertaining to the Fourth Industrial Revolution, or Industry 4.0, across different aspects: network, software and algorithm, hardware, and data processing. This evolution showcases a shift from relatively simple, isolated technologies to complex, integrated, and autonomous systems. Overall, this table effectively maps out the progression of key technological aspects associated with Industry 4.0. It underlines the increasing complexity, sophistication, and autonomy of these technologies, reflecting the transformative potential of the Fourth Industrial Revolution. However, it also underscores the escalating challenges in terms of managing and securing these technologies, a theme that is central to discussions on Industry 4.0.

Table 1. Evolution of revolution 4.0 technologies (Lee & Lee, 2015)

	Before the 2010	**2010 - 2015**	**2015 -2020**	**After the 2020**
Network	Networked sensors	Self-aware and self-organizing networks; transparent location; transparent location of sensor networks; hybrid network technologies	Context-aware networks	Knowledge networks; Networks Autonomous, (self-learning and self-repair).
Software and algorithm	Relational database integration; BDR; IoT oriented to BDR management systems; event-based event-driven platforms; Networked sensor middleware; Proximity/location Proximity/location	Open software language modules; Combinable algorithms; IoT in social software; IoT in enterprise IoT in social software; IoT in enterprise software	Goal-oriented software; distributed intelligence, problem solving; Collaborative environments between objects (Things to Things)	Goal-oriented software; distributed intelligence, problem solving; Collaborative environments between objects (Things to things)

	Before the 2010	2010 - 2015	2015 -2020	After the 2020
Hardware	RFID tags (bar codes) and sensors; Mobile devices with sensors; Cell phones with NFC tags; SMEM (micro-electro-mechanical (micro-electro-mechanical systems) smaller and cheaper	Multi-protocol, multi-standard standard; New sensors and actuators Tags with higher security, lower price	Sensors sensors (biochemical); New sensors and actuators	Nanotechnology and new materials
Data processing	Serial data processing; Parallel data processing; Quality of service	New energy and spectrum signal and electromagnetic spectrum electromagnetic spectrum; Context-aware data processing	Conscious and in-context data processing in context, and response data	Cognitive processing and optimization

Big Data Analytics: With the rise of the internet, a vast amount of information is readily available. In the industrial sector, this data, when analyzed using advanced technologies, can inform intelligent decision making. Big data analytics enable companies to access valuable customer statistics and formulate effective action plans, thereby enhancing customer satisfaction and loyalty (Singh, 2020).

Cyber-Physical Systems: These autonomous devices are controlled or monitored through software algorithms. In the context of Industry 4.0, IoT allows these devices to be integrated into complex system managers, leading to the development of a smart factory (Zhu & Mostafavi, 2017). Advancements in intelligent cyber-physical system design are explored in Peralta & Soltero's work (2020).

Supply Chain Management (SCM): Industry 4.0's promise of sustainability relies on optimizing supply chains. Various studies have explored this, with authors like Shao et al. (2021) and Birkel & Müller (2021) proposing smart SCM models and demonstrating improvements with Industry 4.0 technologies. Moreover, Mastos et al. (2020) investigated how IoT can make SCM in the metallurgy and scrap reuse industry more sustainable. Esmaelian et al. (2020) delve further into concepts like smart logistics and transportation, smart business models, environmentally responsible practices, and a product lifecycle view in SCM. They highlight that the transition towards Industry 4.0 is most noticeable in economically robust and technologically advanced countries.

Transportation Routes: These play a crucial role in SCM. For route development, factors like biodiversity, ecosystems, communities, soil composition, climate variation, and weather conditions must be considered. Using high-resolution data about these factors can result in real-time adjustments (Ghimire et al., 2017). Furthermore, the maritime industry and ports are undergoing digital transformations, with an emphasis on system and information integration, sensor technologies, security, cybersecurity, and process and weather simulation (Ekeocha et al., 2018; Rumeser & Emsley, 2018).

Digital Twins (DGs): DGs have emerged as a powerful tool for managing engineering processes across various domains and complex tasks, Figure 2. They replicate a physical system or process in a virtual environment, enabling simulation-based testing and effective real-world decision-making (Rumeser & Emsley, 2018). A detailed review of DGs is provided by Wagg et al. (2020).

Research reveals an increasing trend in the application of Digital Twins (DGs). For example, Dahmen & Rossmann (2018) showcased the use of DGs and a Virtual Test Bench (VTP) in a space project. Other notable applications encompass resource optimization in engineering projects, real-time DG interface for equipment maintenance optimization, real-time patient monitoring or specific medical condition modeling, and advanced learning of employee or user personality characteristics for improved communication (Sun et al., 2020). Essentially, modeling and simulation provide a platform for testing, optimization, verification, and validation of solutions in the virtual twin. This process minimizes risks and critical errors, or simply boosts the performance of the real twin

(Rumeser & Emsley, 2018). When applied to product design, the DG model aids the product refinement process, facilitating progress step by step (Figure 3). Schluse et al. (2018) provide a detailed graphical synthesis of the opportunities that DG technology offers across various knowledge domains. This includes the challenges and potentials in high-technology product development, further highlighting the value of DGs.

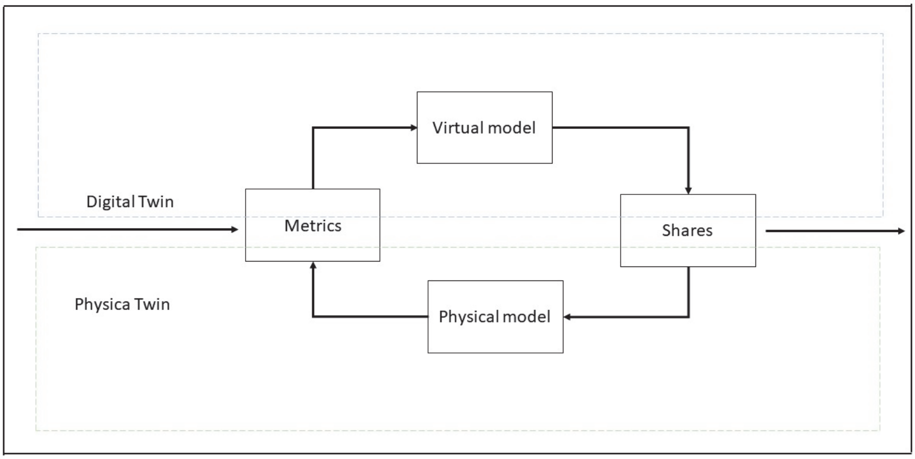

Figure 2. General model of a DG (Twinning cycle) (Jones et al, 2019)

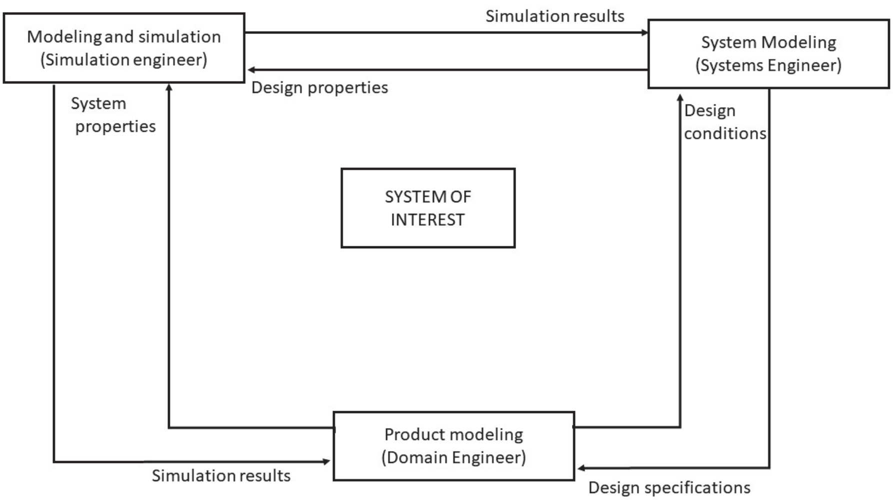

Figure 3. Modeling and simulation in engineering projects (Dahmen & Rossmann, 2018).

It's crucial to clarify that the term "model" can assume different meanings based on its application. For example, a System Model depicts a data repository detailing interconnected system specifications such as requirements, behaviors, structure, etc. The Product Model outlines the physical details and specifications of realized product components, and the Simulated Model represents a digital code executing specific simulations that integrate data from the product model and system model

(Rumeser & Emsley, 2018). From a project management and business organization perspective, DGs can revolutionize decision-making processes, with applications extending to ergonomics, physical and mental health, employee personalities, interpersonal relationships, teamwork, effective communication, leadership, risk prevention and mitigation, and cybersecurity.

Real-time Solutions: Real-time solutions, facilitated by the integration of control mechanisms in information networks, intelligent automatic systems, process synchronization, and human capital expertise (Ghimire et al., 2017), are now feasible in Industry 4.0.

Interfaces and Semantics: Semantics, denoting the meanings of language expressions, assumes critical importance in the realm of future technologies. This significance becomes even more apparent as communication extends to the Internet of Things, technological devices and equipment, artificial intelligence, and human understanding.

3.2 Organizational Models

Project Management in Industry 4.0: When considering the technological enablers for the implementation of Industry 4.0, it's apparent that some traditional industries grapple with significant hurdles, including constrained investment capacity for new technologies, limited research and development, and inflexible production models. While traditional project management (PM) generally adheres to the PMBOK guide, several authors propose alternative methods better attuned to Industry 4.0, such as Scrum and Agile project management (Scholz et al., 2020).

Table 2. Comparison of project management models versus key aspects (Engelhardt, 2019).

Subject	**Traditional dp**	**Agile pd**
Paradigm	Fully specified and predictable systems	Continuous design improvement based on feedback and rapid changes
Address	Command and control	Leadership and collaboration
Knowledge	Explicit	Tacit
Communication	Formal	Informal
Model	Life Cycle	Evolutionary, iterative
Organization	Large, mechanistic	Small, organic
Quality control	Intensive planning, late intensive testing	Continuous control of requirements and continuous testing.

This table provides a succinct yet comprehensive comparison between traditional and Agile project management models across several key aspects, including paradigm, leadership style, knowledge base, communication, model type, organization, and quality control. Each of these models has its strengths and weaknesses and is more suited to certain types of projects. Traditional project management often works well for projects with a well-defined scope and stable requirements. Agile project management is often better for projects where the product is not fully defined, and requirements are likely to change throughout the project, which is often the case in software development.

Human Resources and Organizational Culture: The evolution of project management incorporates new theories, techniques, and processes to refine organizational strategy, simultaneously harnessing information technology (IT) to support social processes and collaborative work (Vila et al., 2017).

Human Capital Training: The advent of digital factories revolutionizes manufacturing, necessitating employees equipped with the necessary qualifications and competencies to implement and operate new technologies.

Transformation of Workspaces (Framework 4.0): In the context of the fourth industrial revolution, employees are expected to be highly skilled and specialized, making their well-being a primary consideration in workspace design.

3.3 Industry 4.0 Trends

Our findings emphasize the increasing trend of digital initiatives that merge Industry 4.0 technologies like Digital Twins and Blockchain. By evaluating the scope of these technology enablers, we can contribute to the evolution of administrative practices and the creation of solutions and technologies that cater to user expectations. However, with the onset of the Fourth Industrial Revolution, substantial disparities exist among countries. Our case studies suggest that industries with implemented Enterprise Resource Planning (ERP) systems are better prepared for the shift towards future-oriented production models.

Management difficulties and team collaboration challenges demand the use of simulation models throughout all development stages to mitigate risks. Agile models offer more flexibility and allow real-time process intervention through disruptive technologies, a cornerstone of Industry 4.0. Nonetheless, no single approach is a cure-all since every project is unique and can benefit differently from each method (Ghimire et al., 2017; Wang et al., 2018).

3.4 What's Next?

Allam & Jones (2021) discuss digital twins on larger scales, such as entire cities, and anticipate that 6G technology will become the technological standard, with Digital Twins of system of systems and neural interfaces for immersion at its core. The future workspace of industries is expected to take on the form of a Human-Technology-Organization trident. Schumacher (2020) conceptually develops this model for designing industrial production systems (Figure 4).

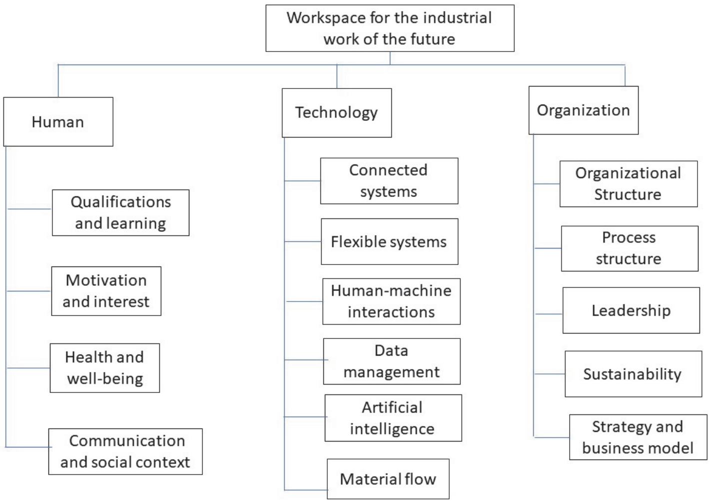

Figure 4. Workspace for the industrial work of the future, elements of the first level (Schumacher (2020).

Simulation is now widely used in a broad array of technological solutions and intelligent systems with intuitive interfaces. As a result, management structures consistently using simulation to respond effectively to problematic scenarios throughout a project's life cycle are essential.

4. Conclusions

This work offers an updated overview of the characteristics and emerging trends of Industry 4.0 and associated factors of its implementation. This allows readers to recognize the potentials and challenges within their work environment or specific project types, pinpointing key elements for distinct engineering projects and connecting various technological tools to their implementation and integration.

4.1 Future lines of research

Future research should focus on evaluating the impact of integrating different Industry 4.0 enabling tools and technologies on project management performance and efficiency, and the role of semantics and user interfaces in enhancing communication and collaboration in Industry 4.0 project management. Other worthwhile explorations include assessing the effectiveness of traditional project management approaches compared to Agile and Scrum methodologies and examining the transformation of workspaces and the impact of Industry 4.0 technologies on employee well-being and productivity. The implications of real-time solutions for decision-making and risk management in Industry 4.0 project management should also be studied, as well as the effectiveness of Digital Twins in optimizing engineering processes and project management across various domains and complex tasks.

5. Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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