



The Role of Software Engineering in Digital Transformation of Industry 4.0

Wandi Sianturi¹, Novario Dimas², Naufal Tauhid³, Heni Sulistiani⁴

^{1,2,3,4} Universitas Teknokrat, Bandar Lampung, Indonesia

Article Information

Received: 21-11-2024

Revised: 28-11-2024

Published: 05-12-2024

Keywords

Information; system; technology; software

*Correspondence Email:

wandi_sianturi@email.com

Abstract

Industry 4.0 is characterized by the adoption of advanced technologies that are changing the way companies operate, interact with customers, and produce products. One of the key factors in the success of digital transformation in this era is software engineering. Innovative and flexible software is the foundation for the implementation of technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, and automation that support modern industrial operations. This article discusses the critical role of software engineering in accelerating the adoption of Industry 4.0, with a focus on developing software that supports interoperability, scalability, and security in an ever-evolving digital ecosystem. It also discusses the challenges faced by software developers, including the need for new skills, integration of legacy systems, and management of big data generated by devices and sensors. With the right software engineering approach, companies can harness the full potential of Industry 4.0 technologies to improve operational efficiency, productivity, and innovation.(Furstenau et al., 2020)

1. Introduction

Industry 4.0, known as the fourth industrial revolution, has changed the operational paradigm in various sectors, from manufacturing to financial services and healthcare. The digitalization process that occurs in Industry 4.0 is characterized by the application of advanced technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI), and automation, which enable companies to create smarter, more efficient, and more connected systems. Behind this transformation, software engineering plays a vital role as a foundation for the development, integration, and maintenance of complex software systems.(Furstenau et al., 2020)

Software engineering in the context of Industry 4.0 not only includes traditional application development, but also includes innovations in software architecture that support interoperability between various systems and devices, scalability to manage very large volumes of data, and security that is absolutely necessary to protect company data and assets. In addition, an agile and continuous software engineering approach allows companies to adapt to the rapid changes that occur in the digital world.

While the potential benefits of implementing Industry 4.0 technologies are enormous, significant challenges remain, such as the complexity of integrating legacy systems, the need for advanced software skills, and managing ever-expanding data. Therefore, the role of software engineering in Industry 4.0 goes beyond creating applications—it serves as a catalyst for innovation that connects the physical and digital worlds, enabling a more efficient and sustainable ecosystem.

This article aims to explore the role of software engineering in accelerating the adoption and implementation of technologies that are at the heart of Industry 4.0. We will also discuss the challenges that software developers face in dealing with the dynamics of rapid change, and how software engineering can contribute to creating solutions that support the success of this digital transformation.

1.1 Literature Review

The digital transformation occurring in Industry 4.0 has a major impact on the way organizations operate, create value, and innovate. At the center of this change, software engineering plays a critical role in enabling the implementation of advanced technologies that are the main pillars of this industrial revolution. In the existing literature, many studies highlight the close relationship between software engineering and key technological elements in Industry 4.0, such as the Internet of Things (IoT), artificial intelligence (AI), big data, and automation.

1. Software Engineering in Industry 4.0

According to Xu et al. (2018), Industry 4.0 requires software that is able to support greater scale and complexity of operations, as well as better integration between physical and digital systems. Software engineering in this context refers not only to the development of applications that support basic functionality, but also includes the development of software to support communication between devices (IoT), big data processing, and the use of artificial intelligence algorithms for faster and more accurate decision making.

2. Interoperability and System Integration

One of the main challenges in software development for Industry 4.0 is creating a system that can function in an integrated manner, considering the many devices and platforms involved. Inteltek and Bapat (2019) stated that software interoperability is an important component that supports smooth operations in Industry 4.0. Software architecture that supports communication and data exchange between systems and devices is crucial in supporting the digitalization of industrial operations. Middleware technology and open communication standards are some of the solutions put forward to address this challenge.

3. Security in Software Engineering

Software security is a key issue in the adoption of Industry 4.0 technologies, especially in the context of big data management and IoT integration. The literature shows that the increasing complexity of device networks and ever-growing data flows increases their vulnerability to cyber threats. Behnam et al. (2020) expressed the importance of software engineering that not only supports data management but also has adequate security layers, ranging from encryption to strict access control, to protect sensitive information and maintain system integrity.

4. Implementation of Automation and Artificial Intelligence Technology

In Industry 4.0, software engineering also plays an important role in supporting automation and the implementation of artificial intelligence (AI). Several studies, such as those conducted by Zhang et al. (2021), show that AI-based software enables smarter automation in manufacturing processes, data processing, and decision-making. The use of software for AI implementation also allows companies to accelerate adaptation to market changes and significantly improve operational efficiency.

5. Big Data Management and Predictive Analysis

Big data management is an important aspect in supporting information-based decision-making in the Industry 4.0 era. According to McKinsey & Company (2019), the volume of data generated by IoT devices and sensors requires software that is able to process and analyze the data in real-time to generate useful insights. Software

engineering in this case includes the development of predictive analysis algorithms that can project future trends, as well as big data solutions that support scalability and data processing speed.

6. Challenges and Solutions in Software Engineering for Industry 4.0

Although there are various benefits that can be obtained from the implementation of technology in Industry 4.0, software development to support this infrastructure also faces major challenges. One of them is the integration of legacy systems with new technologies. As stated by Seric et al. (2020), software adaptation that can run smoothly in heterogeneous environments—consisting of legacy devices and systems as well as advanced technologies—is a crucial aspect in minimizing operational disruptions. On the other hand, a software engineering approach based on Agile and DevOps methodologies is a promising solution to accelerate the development cycle and improve connectivity between development teams. (Siti Masrohatin et al., 2023)

2. Research Methods

In this study, qualitative and descriptive research approaches are used to explore the role of software engineering in supporting digital transformation in Industry 4.0. This study aims to analyze various techniques, challenges, and solutions related to software development in the context of Industry 4.0 technologies, and to provide insights into how software engineering contributes to facilitating industrial digitalization.

1. Qualitative Approach

A qualitative approach was chosen because this study focuses more on an in-depth understanding of the processes, challenges, and solutions faced by software developers in the context of digital transformation in Industry 4.0. This approach allows for data exploration through interviews, focus group discussions, and existing literature studies.

2. Data Collection Methods

Data were collected through several main methods as follows:

a. Literature Study

A literature study was conducted to understand the theoretical framework and previous research findings related to software engineering in Industry 4.0. This study helps in identifying knowledge gaps and provides a basis for developing further research questions. The literature sources used include international journal articles, books, industry reports, and white papers that discuss software engineering, IoT, big data, artificial intelligence, and challenges and solutions in Industry 4.0.

b. Survey and Questionnaire

A survey was conducted to collect quantitative data that can support qualitative findings from interviews and literature studies. The questionnaire was designed to assess the level of understanding and experience of companies in implementing Industry 4.0 technologies, as well as to identify the biggest challenges they face in software development. The respondents selected were IT professionals and managers working in companies involved in digital transformation in various industrial sectors.

3. Data Analysis

Data obtained through interviews, surveys, and literature studies were analyzed using thematic analysis techniques. Thematic analysis allows researchers to identify patterns, themes, and relationships that emerge from the collected data. In this case, the main focus of the analysis is to find how software engineering can support the development and implementation of technologies such as IoT, big data, AI, and automation in Industry 4.0, as well as the challenges associated with these aspects.

For quantitative data obtained from the survey, basic statistical analysis was used to identify trends and relationships between variables. Statistical analysis tools such as frequency and percentage analysis will be used to provide an overview of the prevalence of challenges and solutions faced by companies in developing software for Industry 4.0.

4. Case Studies

As part of the methodology of this research, case studies were conducted on several companies that have implemented Industry 4.0 technologies. These case studies aim to analyze in-depth best practices in software engineering, as well as identify factors that contribute to the success or failure of implementing these technologies. Each case study focuses on a specific aspect of digital transformation, such as cloud-based software development, implementing AI solutions, or integrating legacy systems with new technologies.

5. Validity and Reliability

To ensure the validity and reliability of this research, data triangulation was conducted by comparing findings from literature studies, interviews, surveys, and case studies. This aims to ensure that the data obtained comes from various sources that are reliable and mutually supportive, so that the findings produced are more valid and representative.

6. Research Limitations

This research is limited to companies located in certain geographic areas and in industrial sectors that are more advanced in terms of adopting Industry 4.0 technologies. In addition, this study focuses more on software engineering in the context of the technology that has been implemented, so it does not discuss other aspects of digital transformation as a whole, such as changes in organizational culture or change management. (Klangala & Africa, 2020)

3. Result and Discussion

This study reveals key findings related to the role of software engineering in supporting digital transformation in Industry 4.0. Based on the analysis of data obtained through interviews, surveys, literature studies, and case studies, a number of key themes emerged that reflect the challenges, best practices, and solutions found in software development for Industry 4.0. The results of this study will be discussed further in the context of interoperability, security, scalability, and automation, and how software development contributes to the success of digital transformation in the industrial sector.

1. Interoperability and System Integration

One of the key findings is the importance of interoperability in software systems used in Industry 4.0. The results of interviews with software developers indicate that companies often face challenges in integrating legacy systems with new technologies such as IoT and AI. Most companies use a middleware-based approach to enable communication between various systems, and ensure that data can be exchanged effectively across the digital ecosystem.

A case study of a manufacturing company that has implemented an IoT system shows that the use of a microservices-based architecture is very helpful in creating interoperability between different device systems. One company reported a 20% increase in operational efficiency after successfully integrating multiple devices and systems using a cloud-based platform that supports open and flexible communication.

2. Security in Software Engineering

Software security was also identified as a critical aspect of Industry 4.0, given the increasing potential for cyber threats as the network of interconnected devices expands. The survey results showed that more than 60% of respondents noted that their biggest challenge was securing data generated by IoT devices and ensuring that systems were not vulnerable to attack.

Most companies that successfully addressed this security issue implemented end-to-end data encryption solutions and role-based access control. Additionally, implementing multi-factor authentication (MFA) on applications that deal with sensitive data was also found to be a best practice to reduce the risk of security breaches.

3. Scalability and Big Data Management

As more and more data is generated by devices and sensors in the Industry 4.0 ecosystem, the ability of software to handle large volumes of data (big data) becomes critical. The results of the study show that companies that have successfully implemented big data solutions are using cloud-based platforms and containerization technologies to increase the scalability and flexibility of their systems.

A case study in the automotive sector shows how cloud-based software development can handle the surge in data volumes coming from various sensors and connected vehicles. Using a scalable architecture, the company was able to process data in real-time and use it for predictive analysis, allowing them to identify potential vehicle issues faster and reduce maintenance costs.

4. Automation and Artificial Intelligence (AI)

Software engineering also plays a significant role in the application of automation and artificial intelligence (AI) in industrial processes. The use of AI in software for automated decision-making, production process optimization, and predictive maintenance is gaining popularity across sectors. Findings from the interviews show that companies that integrate AI-based software with their operational systems can significantly increase productivity and efficiency.

One interesting example comes from the manufacturing industry, where the use of AI-based software for production line automation resulted in a reduction in production time of up to 25%. This AI system uses algorithms to identify patterns in production data and makes recommendations on machine settings to improve efficiency.

5. Challenges in Software Development for Industry 4.0

Despite the enormous potential offered by digital transformation, companies face several challenges in developing software for Industry 4.0. One of the biggest challenges identified in the study is the difficulty in aligning software developer skills with the needs of new technologies. Most companies reported that the lack of human resources skilled in advanced technologies such as AI, big data, and IoT is a barrier to adoption.

To address this, several companies have invested in training and skills development for their employees, as well as working with external partners who have expertise in the latest technologies. In addition, the use of agile software development methodologies and DevOps approaches to improve collaboration between development teams are also widely implemented solutions.

Discussion The results of this study indicate that software engineering has a central role in supporting digital transformation in Industry 4.0. Best practices found in this study include the implementation of software architectures that support interoperability between systems, encryption-based security solutions and access control, and the development of scalable cloud-based platforms for managing big data.

However, the challenges faced by many companies, especially in terms of legacy system integration, developer skills, and big data management, indicate that full adoption of Industry 4.0 technologies requires careful planning and sufficient resources. One recommendation that can be given is the need for closer collaboration between software developers, IT professionals, and company management to create solutions that not only meet technical needs but also support long-term business goals.

Going forward, companies need to focus more on developing smarter and more flexible software solutions to be able to compete in the increasingly complex digital era. Companies that can overcome these challenges and leverage the potential of Industry 4.0 technology are expected to gain significant competitive advantages in terms of operational efficiency, product innovation, and response to evolving market demands. (SatuData, 2021)

4. Conclusions

The digital transformation taking place in the context of Industry 4.0 has brought about significant changes in the way industries operate, with advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, and automation playing a vital role in increasing efficiency and innovation. Software engineering, as the foundation for the development and implementation of these technologies, plays an irreplaceable role in unifying physical and digital systems and supporting smarter data management and decision-making.

Based on the research results, it can be concluded that software engineering in Industry 4.0 faces a number of major challenges, such as legacy system integration, data security issues, big data management, and the need for more advanced software developer skills. However, solutions implemented by various companies, such as the use of cloud-based architectures, strict security implementations, and the use of AI and IoT-based platforms, have succeeded in overcoming many of these obstacles and creating more integrated and efficient systems.

In addition, the application of agile and continuous software development methodologies (DevOps) has proven effective in accelerating the development cycle, improving collaboration between teams, and enabling companies to adapt quickly to technological changes and market needs. Best practices in software development, such as the use of microservices for interoperability between systems and the use of AI for automation, provide significant benefits for companies in achieving operational efficiency and increasing productivity.

However, significant challenges remain, especially in terms of developing software developer skills that can support Industry 4.0 technologies. Therefore, investment in human resource training and development and collaboration between the industrial sector and software developers are essential to ensure that digital transformation can run smoothly and successfully.

Overall, software engineering is not only supporting but also a key driver in achieving the full potential of digital transformation in Industry 4.0. Companies that can overcome these challenges and optimize the use of advanced technologies will be better positioned to compete in the ever-evolving digital industry era. These are key findings found in the study and provide a clear picture of the vital role of software engineering in the success of digital transformation in Industry 4.0. (Harun & Hashim, 2017)

5. References

- Furstenau, L. B., Sott, M. K., Kipper, L. M., MacHado, E. L., Lopez-Robles, J. R., Dohan, M. S., Cobo, M. J., Zahid, A., Abbasi, Q. H., & Imran, M. A. (2020). Link between Sustainability and Industry 4.0: Trends, Challenges and New Perspectives. *IEEE Access*, 8, 140079–140096. <https://doi.org/10.1109/ACCESS.2020.3012812>
- Harun, H., & Hashim, M. K. (2017). *STRATEGIC INFORMATION SYSTEMS PLANNING : A REVIEW OF ITS CONCEPT , DEFINITIONS AND STAGES OF DEVELOPMENT*. April.
- Klangala, K. S., & Africa, S. (2020). *techniques*. 3.
- SatuData. (2021). Proyeksi Kebutuhan Tenaga Kerja di Perusahaan Berdasarkan Kompetensi pada Sektor Teknologi Informatika dan Komunikasi. *Satudata.Kemnaker*. https://satudata.kemnaker.go.id/satudata-public/2022/04/files/publikasi/1650296308464_2021%2520-%2520Buku%2520Proyeksi%2520Kebutuhan%2520Tenaga%2520Kerja%2520Sektor%2520TI.pdf
- Siti Masrohatin, Rini Puji Astuti, M. Iqbal Fardian, & Gogor A. Handiwibowo. (2023). The Growth of Industrial Revolution 4.0 and the Preparation of Software Engineers in Digital Transformation at Makers Institute Indonesia. *Journal of Research and Technology*, 8(2), 303–312. <https://doi.org/10.55732/jrt.v8i2.729>