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# A PDCA-Based Framework for Industry 4.0 Adoption: Enhancing Managerial Roles and Critical Success Factors in SMEs

Kurniawanti Kurniawanti[1,2], Andi Sudiarso[1], Muhammad Kusumawan Herliansyah[1*]

[1]*Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada (Indonesia)*
[2]*Department of Industrial Engineering, Faculty of Science and Technology, Universitas PGRI Yogyakarta (Indonesia)*

*kurniawanti@mail.ugm.ac.id, a.sudiarso@ugm.ac.id*
[*]*Corresponding author: herliansyah@ugm.ac.id*

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***Abstract:***

***Purpose:*** Many studies have addressed critical success factors (CSFs) in various industries and technology contexts in order to achieve successful adoption of Industry 4.0. However, there is still a gap in the literature that simultaneously examines managerial roles in digital transformation, especially in SMEs. This research aims to close that gap by creating a framework that integrates CSFs and managers' roles in digital transformation in the SME, using the Plan-Do-Check-Act (PDCA) approach.

***Design/methodology/approach:*** This research uses a systematic literature review approach based on PRISMA guidelines to identify CSFs using SCOPUS and IEEE databases.

***Findings:*** Sixteen CSFs were identified in this study. The study also found that the role of managers is critical in ensuring alignment between business strategy, resources, and technology and in overcoming resistance to change. The PDCA framework that was developed facilitates the transformation process through planning, execution, continuous evaluation, and innovation.

***Originality/value:*** This study makes a theoretical contribution by addressing a vacuum in the literature on the managerial role in Industry 4.0 adoption, particularly among SMEs. Practically, it offers managers solid direction on how to undertake digital transformation using an iterative, emphasizing the significance of leadership, communication, and ongoing adaptation to ensure transformation success in the dynamic SME environment.

***Keywords:*** managerial roles, industry 4.0 adoption, critical success factors, PDCA

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## 1. Introduction

The industrial sector has seen significant transformation as a result of Industry 4.0, which offers enhanced productivity, efficiency, and flexibility through the use of cutting-edge technologies like big data analytics, artificial intelligence (AI), and the Internet of Things (IoT). Although there is widespread recognition of this potential, it is difficult to put into practice, particularly for Small and Medium-Sized Enterprises (SMEs). A number of studies reveal that SMEs are often hampered by factors such as unclear regulations, inadequate workforce skills, limited funds, and a lack of understanding of new technologies (Lin, Ansell & Siu, 2020; Prause, 2019). In addition, SMEs' resistance to change, lack of digital culture, and weak organizational leadership further slow down digital transformation (Agostini & Filippini, 2019; Trstenjak, Opetuk, Cajner & Hegedić, 2022).

Managers have a vital role in the implementation of Industry 4.0 technologies since they are tasked with coordinating the technological transition throughout the organization (Brodeur, Pellerin & Deschamps, 2022). They are not only tasked with managing new technologies. However, they are also essential for fostering a culture of innovation, mitigating employees' mental resistance, and integrating technology with the organization's human resources and business strategy (Bellantuono, Nuzzi, Pontrandolfo & Scozzi, 2021). Current research has predominantly concentrated on the technical dimensions of Industry 4.0 adoption. However, the managerial role in SMEs, which is frequently vital for effective digital transformation, has received comparatively less attention (Mahmood, Ali, Nazam & Nazim, 2021). Large companies are usually more systematically and culturally prepared to adopt Industry 4.0 technologies, but SMEs still lag in digital culture (Cotrino, Sebastián & González-Gaya, 2020). In addition, management roles differ from those of large companies; SMEs have to take a more hands-on and integrated approach than large companies that have specialized departments. This suggests that SME managers should be more proactive and involved in the entire digital transformation process than managers of large companies, who may have greater structural support and resources (Martinsuo & Luomaranta, 2018). Given the critical role of managers in the success of digital transformation, this gap is important to address.

In recent times, numerous comprehensive literature review investigations have been carried out to investigate the potential directions regarding the adoption of Industry 4.0 (Battistoni, Gitto, Murgia & Campisi, 2023; Kamble, Gunasekaran & Sharma, 2018; Schneider, 2018), on preparedness and advancement (Amaral & Peças, 2021; Ansari, Barati, Sadeghi-Moghadam & Ghobakhloo, 2023; Antony, Sony & McDermott, 2023) and on obstacles and hindrances (Ghobakhloo, Iranmanesh, Vilkas, Grybauskas & Amran, 2022; Prause, 2019; Raj & Jeyaraj, 2023). Some studies have also focused on identifying the keys to success. These studies range from implementation frameworks to Critical Success Factors (CSF) that influence technology readiness and adoption. A CSF classification framework was built to help organizations measure their readiness to adopt a new-generation ERP system (Wong & Lane, 2023) and a CSF framework focusing on Industry 4.0 readiness and adoption intentions in the Indian manufacturing sector (Birajdar & Vasudevan, 2022). CSF focusing on the aerospace and defense sectors was also identified, emphasizing the factors of logistics development, intelligence, surveillance, and control (Khan, Elshennawy, Cudney & Furterer, 2024), and there was also one focused on the pharmaceutical industry (Debnath, Shakur, Mainul-Bari, Saha, Porna, Mishu et al., 2023). Some CSFs focusing on employability and specialized skills in the South Asian region, as well as artificial intelligence technologies, digital skills, and big data analytics in improving productivity and efficiency, have been investigated (Miah, Erdei-Gally, Dancs & Fekete-Farkas, 2024). Meanwhile, some focus on the type of technology, including CSF on Quality 4.0 implementation (Mahin, Kadasah, Alsabban & Albliwi, 2024), CSF on Lean Six Sigma in Quality 4.0 (Yadav, Shankar & Singh, 2021), on IoT in the digital supply chain (Samaranayake, Laosirihongthong, Adebanjo & Boon-itt, 2022), and Cloud ERP, specifically in India and the UK (Huang, Rahim, Foster & Anwar, 2021). In addition, Antony, Sony, Garza-Reyes, McDermott, Tortorella, Jayaraman et al. (2023) compared the benefits, challenges, and critical success factors in implementing Industry 4.0 across different continents and economies, where organizational efficiency and customer satisfaction varied between developing and developed countries, and employee resistance challenges were higher in developing countries. In the context of SMEs, the identification of CSFs focused on construction SMEs in the Middle East has also been researched (Sarvari, Chan, Alaeos, Olawumi & Abdalridah-Aldaud, 2021). Finally, the most common CSF research has identified

training and development, organizational culture, top management support, and organizational structure, which are important for Industry 4.0 implementation (Sahoo, Saraf & Uchil, 2022).

A critical investigation of these studies shows that, while many studies have highlighted CSF in various industries, areas, and technology contexts, the literature on CSFs that simultaneously examine the managerial role is still limited. There is still a gap in understanding how managers can lead digital transformation in a dynamic business environment, so a comprehensive framework is needed to ensure the success of digital transformation (Sahoo et al., 2022). This research aims to close the gap by creating a framework that integrates CSF and the role of managers in digital transformation in the SME sector using the Plan-Do-Check-Act (PDCA) cycle approach. Managers play a critical role in Industry 4.0 adoption, and the framework aims to address both internal and external elements that influence digital transformation. Specifically, this research will concentrate on how managers facilitate and lead the adoption process, ensure alignment with organizational goals, and overcome resistance to change. As such, we present several important research issues to close the current research gap: 1. What are the CSFs that influence Industry 4.0 adoption in the manufacturing sector? 2. Specifically, in the context of Industry 4.0, what is the role of managers in spearheading digital transformation based on the identified CSFs? 3. How can an Industry 4.0 implementation framework be created to help the industrial sector embrace it more successfully?

The next section discusses literature, such as the difficulties of SMEs in adopting Industry 4.0, the role of managers, the function of CSFs, and the PDCA approach (Section 2). Section 3 presents the research methodology. Section 4 discusses the results and discussions, which are complemented by the implications of this study. The next section is the conclusion (Section 5).

## 2. Theoretical Framework

This section develops the theoretical foundation of the study by synthesizing findings from previous literature on Industry 4.0 adoption, especially in manufacturing SMEs. Rather than merely reviewing existing studies, it aims to identify and organize key themes and critical success factors that form the conceptual basis for this research. The framework derived from this synthesis serves to guide the analysis and discussion in the subsequent sections.

### 2.1. Challenges of Industry 4.0 Adoption in SMEs

The implementation of Industry 4.0 in manufacturing SMEs is complex and challenging. This is due to the nature of the technological, organizational, and environmental changes required. This complexity is compounded by the constraints SMEs face, such as limited resources, lack of expertise, and the need for significant cultural change. In terms of technological challenges, SMEs face limitations in adequate infrastructure required for Industry 4.0, which requires seamless integration of various systems and technologies (Piat, Danjou, Agard & Beauchemin, 2023). Industry 4.0 also requires effective data management and security, but many SMEs still struggle with interoperability and data security issues (Fekrisari & Kantola, 2024). Many SMEs also operate with outdated machinery that lacks the computing and connectivity capabilities required for Industry 4.0 technologies, making the transition costly and technically challenging (Contieri, Hassui, Santa-Eulalia, Sigahi, Rampasso, Moraes et al., 2023).

Organizational and human resource barriers are also significant in SMEs. Lack of necessary skills and competencies or SMEs do not prioritize upskilling employees to support digital transformation (Hansen, Christiansen & Lassen, 2024). In addition, many SME leaders do not understand and know the benefits of Industry 4.0. Including the ability of organizations whose structures have not accommodated the adjustment of new technologies (Marrucci, Rialti & Balzano, 2023). Other challenges include implementation costs, environmental issues, cultural resistance, and lack of a clear roadmap (Kaya, Karaşan, İlbahar & Cebeci, 2023; Marrucci et al., 2023; Piat et al., 2023). While these challenges are significant, it is important to realize that the transition to Industry 4.0 also provides opportunities for SMEs to improve competitiveness and sustainability. If these challenges are addressed through appropriate strategies, it is expected that SMEs can successfully handle the complexities of Industry 4.0 implementation.

### 2.2. The Role of Critical Success Factors

Identifying the CSF in the implementation of Industry 4.0 is very important to help organizations achieve the success of the Industry 4.0 adoption process (Samaranayake et al., 2022). CSFs provide a structured approach to identify and address key aspects that significantly impact the success of digital transformation initiatives (Bhatia & Kumar, 2022). These factors help organizations navigate the complex Industry 4.0 landscape by aligning their strategic objectives with technological advances, ensuring that the transformation is effective and sustainable (Sahoo et al., 2022). One of the main benefits of identifying these CSFs is to mitigate the risks associated with implementing complex technologies (Moeuf, Lamouri, Pellerin, Tamayo-Giraldo, Tobon-Valencia & Eburdy, 2020). In addition, the identification of CSFs allows organizations to prioritize resources more effectively, which is especially important given the resource constraints often faced in the context of Industry 4.0 (Soltani, Alizadeh, Hao & Choo, 2023). For example, by understanding the critical role of management support and organizational culture, companies can allocate their resources more strategically, ensuring an efficient and effective implementation process (Brodeur et al., 2022). Furthermore, the recognition of these factors helps in creating a culture of innovation and adaptability, which facilitates a smoother transition to Industry 4.0 (Stocker, Rosenberger & Schmeja, 2021). In addition, these success factors can serve as benchmarks for organizations to measure their progress and performance in the implementation of Industry 4.0, allowing them to make the necessary adjustments to maintain long-term success in a rapidly evolving landscape (Masood & Egger, 2019).

### 2.3. Role of the Manager in Industry 4.0 Implementation

Managers play a key role in the successful implementation of Industry 4.0, as this digital transformation demands simultaneous changes to technology, organizational structure, processes, and skills (Schneider, 2018). This process often requires long-term commitment and large economic investments, making it prone to failure and difficult to reverse once started (Bellantuono et al., 2021). Research shows that the adoption of new technologies, particularly in the context of Industry 4.0, is often a slow and challenging process (Mahmood et al., 2021). In addition, due to the interpretive flexibility of new technologies, gaps between plans and actual practices often occur due to human involvement and the context of use (Virmani & Salve, 2023). Therefore, the implementation of such complex technologies requires a planned strategy, support from top management, and clear communication channels (Pihlajamaa, Malmelin & Wallin, 2023). Managers need to lead change by coordinating the efforts of change leaders across the organization to steer employee behavior in the desired direction (Sweeney, Nair & Cormican, 2023). However, while this leadership is critical, they must also be ready to adapt to influencing factors, such as local innovations and structural shifts that arise in response to unexpected events (Bellantuono et al., 2021). Several studies have also shown that organizational change does not always follow a rational model with clear goals and strategies; instead, many organizations may experience an ambiguous process characterized by fluid participation, inconsistent preferences, and unclear digital technologies (Nurbossynova, Sautbekov, Zholdaskhan, Abdallah & Shehab, 2021). These findings confirm that the implementation of Industry 4.0 creates tension between deliberate transformation practices and unexpected emergent change as actors seek to support or resist organizational efforts to replace existing digital platforms and infrastructure with new ones. To close the gap between managers' responsibilities for overseeing planned change and their handling of unforeseen difficulties that arise during the Industry 4.0 adoption process, more research is therefore required. This is particularly true for manufacturing SMEs, which are subject to different resource and flexibility constraints than larger corporations.

### 2.4. The Plan-Do-Check-Act (PDCA) Cycle in Industry 4.0

The Plan-Do-Check-Act (PDCA) cycle is a concept developed by Dr. Deming, an American quality management expert. This cycle aims for continuous improvement and plays an important role in facilitating digital transformation in the context of Industry 4.0. As digitalization rapidly transforms industries, the adaptive and iterative nature of the PDCA cycle helps organizations manage the complexity and speed of technological change (Mahnashi, Salah & Ragab, 2023). This model supports businesses in aligning their strategic goals with technological advancements, such as artificial intelligence (AI), cloud computing, and big data (Chiarini, Castellani & Rossato, 2020). PDCA enables structured management of these technologies, ensuring their integration into

existing processes while keeping a focus on long-term sustainability. In the planning stage, organizations leverage PDCA to identify current gaps in their technology infrastructure and anticipate future needs. This stage also includes foresight into emerging trends, which allows organizations to develop a technology transformation roadmap (Mahnashi et al., 2023). By aligning strategic goals with technological capabilities, companies can ensure that their digital transformation efforts are scalable and sustainable over time. The implementation of technological change, summarized in the "Do" phase, involves not only implementing new systems but also ensuring that employees are adequately trained to work with these technologies (Lima, Neto, Santos & Caiado, 2023).

Once the new technology has been implemented, the "Check" phase of the PDCA cycle is crucial for evaluating its effectiveness, enabling real-time monitoring of project quality and efficiency, ensuring continuous improvement and adaptation to new challenges (Sun, Zhou & Wang, 2024). The final phase, "Act," ensures that feedback from the evaluation phase is used to make the necessary adjustments. This phase is critical to ensure that the digital transformation process is adaptive and responsive to emerging challenges and opportunities (Peças, Encarnação, Gambôa, Sampayo & Jorge, 2021). The integration of Industry 4.0 technologies in the PDCA cycle further increases its relevance. In the PDCA 4.0 concept, PDCA cycles are used to improve production processes with real-time data (Peças et al., 2021). In conclusion, the PDCA cycle provides a structured yet flexible framework that supports continuous improvement in the context of Industry 4.0 (Silva, Borges & Magano, 2022).

## 3. Methodology

The study adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology to ensure a transparent and reproducible literature review process. The literature search was conducted on September 17, 2024, using two major academic databases: Scopus and IEEE, which are known for their comprehensive coverage of peer-reviewed research. The Boolean search strategy is used by using the following keywords:

("Success factors" OR "Implementation success" OR "Adoption factors") AND ("industry 4.0" OR "IoT" OR "smart factory" OR "cloud computing" OR "big data" OR "artificial intelligence" OR "data-driven" OR robotics OR "augmented reality" OR digitalization OR "cyber-physical systems") AND ("manufacturing" OR "manufacture").

The search is limited to peer-reviewed journal articles published in English between 2013 and 2024. This time frame was chosen to capture the most relevant and current developments in Industry 4.0 adoption, particularly in the context of Small and Medium Enterprises (SMEs). The inclusion criteria are set as follows:

- Documents with search terms included in titles, abstracts, and/or keywords
- A paper explaining the adoption of Industry 4.0 in the manufacturing sector, both for large companies and SMEs
- A paper describing the successful implementation of industrial 4.0 technology and technologies related to digital transformation
- It is accessible in full text form and written in English.

Exclusion criteria include:

- Papers that do not specifically address digital transformation or the industrial 4.0 adoption process
- Papers that mention Industry 4.0 but do not address the essential elements or success factors that are essential for effective adoption
- Non-empirical or non-conceptual work (e.g., book chapters, notes, editorials)
- Duplicates, inaccessible papers, and publications outside of the selected time frame.

The initial search yielded a total of 16,225 papers (16,176 from Scopus and 49 from IEEE). Subsequently, only articles and proceedings were selected, resulting in 13,732 papers. Of these, 143 papers were not in English, and 8,222 were not accessible, leaving 5,367 papers. The screening process also took into account publication years

between 2013 and 2024, with 75 papers excluded and 4,027 duplicate papers removed, resulting in the remaining 1,265 papers. Next, through title and abstract screening based on purpose, topic, and keywords, 1,000 papers were eliminated, leaving 265 papers. The final stage in screening involved assessing the quality of the papers by reading the full text, of which 227 did not meet the criteria, leaving 38 documents to be synthesized in this SLR. Figure 1 shows the flowchart of the systematic review using PRISMA.

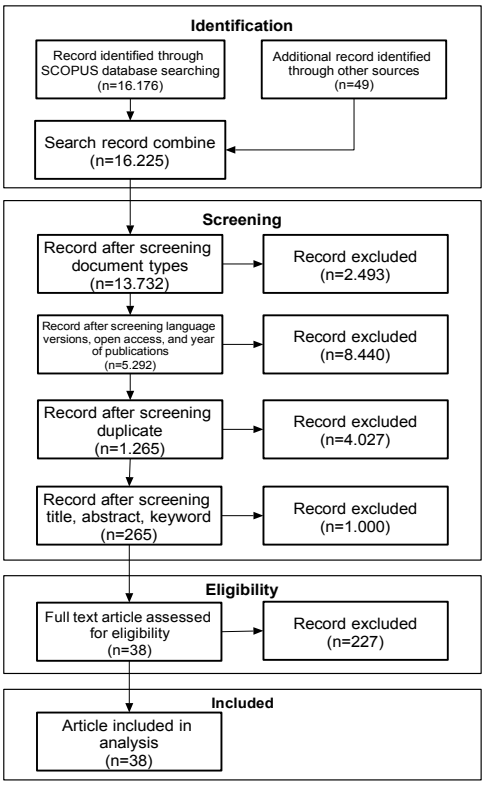


Figure 1. Flowchart of search and selection criteria based on PRISMA

## 4. Results

### 4.1. Critical Success Factors (CSF) for Industry 4.0 Implementation

The results of the SLR on CSF for Industry 4.0 deployment are presented in this section. Table 1 presents the important findings of the CSF. The authors have found sixteen CSFs related to Industry 4.0 adoption. The selected literature was then analyzed and classified into sixteen CSFs. In this subchapter, the author describes them in detail.

The main factor that organizations must have in planning the implementation of Industry 4.0 is that they must have a vision and strategy. Having a clear vision and a solid strategy is essential to maintain the direction of digital transformation. Continuous strategic planning allows managers to adapt to changes in the business environment and ensure the transformation process is in line with the company's long-term goals (Brodeur et al., 2022). Not only that but an innovative vision and digital strategy aligned with business processes are essential to creating sustainability in digital transformation (Hakim, Singgih & Gunarta, 2023).

The next must-have for organizations is technology technology infrastructure. It is the backbone of a successful Industry 4.0 implementation. Therefore, technology readiness, scalability, and system compatibility are essential factors in overcoming the increasing data complexity (Dora, Kumar, Mangla, Pant & Kamal, 2022). The system must be designed to be easy to use (trialability) and have high service quality to maintain operational performance. Proper system configuration and technology compatibility with business processes are crucial, where system suitability and scalability greatly affect usability (Masood & Egger, 2019).

The next factor that influences successful implementation is employee training and development. Management needs to invest in employee training to ensure they are prepared for broader and more complex roles (Adebanjo et

al., 2023). Employees must be equipped with relevant knowledge and skills to support the digital transformation process (Brodeur et al., 2022). In addition, synergy between technical training and soft skills is necessary to create a work environment conducive to sustainable digital transformation (Majid & Ariffin, 2021). Forms of soft skills training, such as how employees can adapt interpersonally, crisis adaptation, and problem-solving abilities (Sony & Mekoth, 2022).

| Authors | Critical Success Factors | Technology |
|---|---|---|
| Adebanjo, Laosirihongthong, Samaranayake & Teh (2023) | HR development related to skills, attitudes, and ethics | Industry 4.0 |
| Baier, Lockl, Röglinger & Weidlich (2022) | Strategy, organization structure, culture, people, process, project management, technology | Industry 4.0 |
| Brodeur et al. (2022) | Vision and strategy, leadership, alignment of hierarchical lines, communication management, project management, evaluation, training and knowledge management, teamwork, culture, change management | AI |
| Debnath et al. (2023) | Financial aspect, digital product monitoring and traceability, solid research and development team | AI |
| Deepu & Ravi (2021) | Top management commitment and support, short-long term planning, financial aspect, interconnectivity between factors | Digital twin |
| Dora et al. (2022) | Security and privacy, perceived advantages/benefits, infrastructure, data complexity, competitive pressure, regulation, demand volatility, institution-based trust, security system, customer satisfaction, information exchange and communication between partners, employee training, job security, clarity of vision and strategy, expert commitment and support. | AI |
| Eampoonga & Leelasantith (2023) | Business and technical skills; business process alignment, training and education; continuous planning; infrastructure readiness, system characteristics, financial aspect, organizational culture, employee trust; government support, consultant knowledge, audit system, business competition | Hybrid cloud ERP |
| Ghadimi, Donnelly, Sar, Wang & Azadnia (2022) | Risk identification, mitigation strategy | Industry 4.0 |
| Gupta & Misra (2016) | Regulatory compliance, network, security | Cloud ERP |
| Hakim et al. (2023) | The financial aspect, ideas and innovation, market trends, operations, human resources, management, regulation, resources and technology | IoT |
| Hamad, Yassin & Okour (2022) | Technology competence, management support, organizational culture, system characteristics | Cloud ERP |
| Intalar, Chumnumporn, Jeenanunta & Tunpan (2021) | Top management support, alignment of digital strategy with business strategy, work environment, external collaboration, project management, knowledge and technology transfer, visible benefits, individual buy-in | IoT, image processing |
| Jayashree, Reza, Malarvizhi, Gunasekaran & Rauf (2022) | Technological competence, IT managerial and technical competence, manager understanding, decision-making accuracy, financial aspects, leadership and teamwork, innovative vision, networking and collaboration, market and competitor, vendor support expert institutions | Industry 4.0 |
| Jo (2022) | User satisfaction includes system quality, information quality, service quality | Smart factory |
| Khan, Singh, Haleem, Dsilva & Ali (2022) | Top management support, alignment of digital strategy with business strategy, technological infrastructure, availability of technological infrastructure, financial aspects, training and education, research environment | Logistic 4.0 |
| Leyh, Koppel, Neuschl & Pentrack (2021) | Data security, IT infrastructure availability, top management support, organizational culture, digital understanding | DT |

| Authors | Critical Success Factors | Technology |
|---|---|---|
| Majid & Ariffin (2021) | Adequate technology availability and security, good and documented processes, technical and soft skills, top management support | Cyber security |
| Masood & Egger (2019) | System configuration, technology readiness, technology compatibility, organizational fit, user interface design, tracking accuracy, ergonomics | Augmented reality |
| Naveed, Islam, Qureshi, Aseere, Rasheed & Fatima (2021) | Top management support, security, implementation strategic management, network latency and infrastructure, relative advantages | Cloud ERP |
| Nurbossynova et al. (2021) | Management support, knowledge and innovation, strategic planning and goals, business process reengineering, team competencies, culture, communication, financial aspects, government support, unified standards and rules, collaboration, customer needs, operational transparency, technology infrastructure readiness and reliability | Industry 4.0 |
| Raut, Gardas, Jha & Priyadarshinee (2017) | Technology experience and competences, knowledge and training, government support, innovation, organization size, security and privacy, ease of use and convenience, ecological sustainability, observability, competitive advantage | Cloud computing |
| Sony & Mekoth (2022) | Interpersonal adaptability, problem-solving skills, training and continuing education, stress management skills, teamwork adaptability | Industry 4.0 |
| Wang & Meckl (2022) | Monitoring and coordination, organizational responsibilities and legal framework, production processes and procedures, emergency plans, maintenance, ergonomics, platform standardization and quality, audit processes, top management and employee involvement, internal integration, data security | Autonomou s driving |
| Zhang, Xu & Ma (2022) | Technology competency, digital strategy, top management support, employee skills, government support, partnerships | Industry 4.0 |
| Stocker et al. (2021) | Organizational culture, adaptability, user persuasion, stakeholder involvement, management support, understanding current state, challenges, target setting | Industry 4.0 |
| Withanaarachchi & Silva (2023) | Financial aspects, technology-oriented organizational strategy, digital expertise, dynamic organizational culture, top management involvement, and IT infrastructure availability | Industry 4.0 |
| Bhatia & Kumar (2022) | Data usage, regulation, collaboration and teamwork, IT infrastructure, employee engagement | Industry 4.0 |
| Pawar, Misra & Singh (2020) | Organizational performance, availability of on-demand products and services, competitive advantage, time to market, customer satisfaction, integration of design and manufacturing services, competitive pressure | Cloud technology |
| Uchihira (2022) | Clear goals and vision, digital knowledge and leadership, trial and error with in-house optimization systems, plant floor engagement, digital culture | Smart factory |
| Jung, Kim & Shin (2023) | Top management support, technology infrastructure, ability to manage change, maintain communication and coordination. | Smart factory |
| Kumar, Bhamu, Goel & Singh (2024) | Organizational culture, top management commitment, and workforce skills | Industry 4.0 |
| Sweeney et al. (2023) | Infrastructure costs, security system, recertification requirements, validation, and quality and procedures | AI |
| Albayrak & Erkayman (2023) | Leadership, digital skills, IT infrastructure, strategic integration, cooperation, project management, cybersecurity, data management, financial resources. | Industry 4.0 |
| Zhou, Zhou, Nie & Zheng (2024) | Top management support, technological competence, supplier support, and pilot projects | Industry 4.0 |
| Singh, Mohanty, Mangla & Agrawal (2023) | Speed-tailored production, continuous production, flexible manufacturing systems for complex products, production standardization, digital skills and technological infrastructure | AM |

| Authors | Critical Success Factors | Technology |
|---|---|---|
| Solaimani & Swaak (2023) | Performance expectations, top management support, technical competence and resources, ease of use, organizational fit, and trading partner influence | AI |
| Mir, Sharma, Kar & Gupta (2020) | Data and hardware, devices, capital and labor, organizational hierarchy, and governance | AI, robotics |
| Moeuf et al. (2020) | Training, project studies, regular use of data, communication culture, alignment of hierarchical lines, cooperation between managers, top management support, continuous improvement | Industry 4.0 |

Table 1. Existing CSF for the implementation of Industry 4.0

Implementation of Industry 4.0 cannot be accomplished without top management support. According to Intalar et al. (2021), top management support includes not only resource allocation but also ensuring the alignment of digital strategy with business objectives. Top management must establish a clear vision and strategic goals aligned with Industry 4.0 principles. This alignment ensures that technological advances are integrated into the business model, driving innovation and competitiveness (Deepu & Ravi, 2021). In addition, adopting Industry 4.0 requires transdisciplinary competencies that combine technical, social, and human aspects. This integration supports informed decision-making by ensuring that all relevant factors are considered to lead to more effective and innovative solutions, which can only be done by top management (Jayashree et al., 2022; Nurbossynova et al., 2021). While the strategic role of top management is critical, it also plays a role in managing the challenges and risks, as well as the changes that may occur in the Industry 4.0 adoption process (Stocker et al., 2021).

Communication and cooperation are other CSFs that help successful implementation. Organizations can ensure seamless information flow across functions and process alignment by implementing effective communication management and collaboration. The significance of communication management in fostering stakeholder collaboration (Brodeur et al., 2022). Through the sharing of resources, external collaboration can also foster innovation and increase efficiency (Intalar et al., 2021). Strong communication and operational transparency foster confidence and promote cross-functional cooperation (Nurbossynova et al., 2021). This openness lowers operational risk and fosters an environment of accountability. Furthermore, maintaining uniformity and coordinating organizational objectives requires the integration of internal procedures. Wang and Meckl (2022) emphasize that to guarantee efficient Industry 4.0 management, coordination and oversight within the legal framework are crucial. The long-term viability of organizations is impacted by this strategic collaboration and communication (Moeuf et al., 2020; Uchihira, 2022).

Because it creates an atmosphere that encourages employee adaptation, preparedness, and acceptance, a change-friendly organizational culture is essential to reducing resistance to the adoption of new technology (Intalar et al., 2021). Not only are cooperation and collaboration crucial cultural elements to guarantee the effective implementation of Industry 4.0 (Brodeur et al., 2022), but a dynamic and collaborative culture will also enhance employee involvement in the digital transformation process (Hakim et al., 2023). The operational performance and responsiveness that are necessary for a successful digital transition are influenced by these cultural factors (Bhatia & Kumar, 2022).

Adopting Industry 4.0 necessitates managing several organizational changes. Most people call this phrase "change management". It is necessary to effectively manage and address some variables of change management in the context of new technical developments. Organizations are more inclined to embrace change if they can immediately see the benefits of innovation, which is why the idea of perceived benefits to innovation helps them get over their reluctance (Naveed et al., 2021). The difficulties posed by new technology and process adaptation are additional factors associated with change management. To avoid operational disruptions, organizations are expected to manage and respond to difficulties (Stocker et al., 2021). Although management's adoption of new technology is a concern, ecological sustainability still requires consideration of the effects on the environment (Raut et al., 2017). Change management, according to some other viewpoints, is about handling new things that can come up during the technology adoption process, such as recertification and quality, which means that it needs to go by relevant industry standards and laws (Jung et al., 2023; Sweeney et al., 2023). Innovation, process adaptation, sustainability,

and organizational issues are all included in the broad category of change management in the digital transition. Organizations can guarantee alignment with strategic goals, minimize technology benefits, minimize resistance, and preserve ecological sustainability through efficient change management.

Government, financial resources, organizational structure, standardization of procedures, and security systems all prove to be important success factors. Cybersecurity is essential to defend systems and data from outside threats. To increase the efficacy of technology adoption, Gupta and Misra (2016) underline the need for network security management and compliance with data security laws. Furthermore, a good security system should take into account both operational and physical security, as they are the cornerstones of an organization's successful digitization (Leyh et al., 2021). Nonetheless, financial resources are necessary for Industry 4.0 to be implemented successfully (Debnath et al., 2023). Investments in technology, staff development, and innovation are financially supported (Solaimani & Swaak, 2023; Withanaarachchi & Silva, 2023). When resources are scarce, it is important to prioritize the efficient use of the budget for personnel training and technology investment. Long-term planning should also take this into account to ensure the success of digital transformation projects (Deepu & Ravi, 2021). Financial resources can be obtained from external sources, such as the government, to support the implementation of digital transformation, thereby reducing the problem of budget restrictions faced by SMEs (Nurbossynova et al., 2021). Not only support financial aid, the government also plays a role in offering supportive risk-related rules and regulations (Birajdar & Vasudevan, 2022). Governments should develop regulations to assist businesses in managing the risks involved in introducing new technologies (Ghadimi et al., 2022).

Standardization of procedures is crucial for many aspects of operations and data collection. By implementing consistent procedures in manufacturing and product delivery, standardization helps organizations achieve increased efficiency (Baier et al., 2022; Hakim et al., 2023; Wang & Meckl, 2022). Furthermore, the establishment of uniform platforms and frameworks guarantees connections among various systems and technologies, facilitating smooth integration within complex production settings (Singh et al., 2023). Transparency and trust in operational procedures are ensured even by explicit norms in the collection and use of valuable data (Dora et al., 2022), which also helps in decision-making (Bhatia & Kumar, 2022). Thus, standardization of processes guarantees uniformity, effectiveness, and conformity to regulations, which enables organizations to function more efficiently and adaptively.

A flexible organizational structure is also necessary to enable Industry 4.0 to be implemented successfully (Nurbossynova et al., 2021). Companies need to provide a framework that encourages employee autonomy and gives them more opportunities to participate in the digital transformation process (Adebanjo et al., 2023). When implementing new technologies, a flexible organizational structure will maximize resource utilization and encourage departmental collaboration (Brodeur et al., 2022). An efficient organizational structure enables better communication and unambiguous coordination to achieve hierarchical alignment, and the stability of the organizational structure offers a solid foundation for operational efficiency (Moeuf et al., 2020). Furthermore, the size of a firm impacts how it modifies its organizational structure; larger businesses require more elaborate structures to manage a wider range of tasks (Birajdar & Vasudevan, 2022).

Organizations that successfully survive in market competition are due to their competitive advantage factors. Concerning Industry 4.0, competitive advantages are how well companies can utilize new technologies to improve their competitiveness. Several factors, such as institutional trust, product availability, time-to-market, and sustainable production, are part of the competitive advantages that support the success of such transformation. Institution-based trust creates stability and strong relationships between customers and business partners, which is critical in Industry 4.0 (Dora et al., 2022). The speed with which organizations respond to the market and integrate design with manufacturing services directly affects performance and competitiveness in the digital age (Pawar et al., 2020; Raut et al., 2017). In addition, supplier support strengthens the supply chain (Zhou et al., 2024), and sustainable production helps companies stay relevant in a market that is increasingly concerned with environmentally friendly practices being a factor under consideration (Singh et al., 2023). Supplier support strengthens the supply chain as reliable and efficient suppliers ensure timely supply of quality materials and components, which is key in Industry 4.0. With advanced technologies such as IoT and big data, good integration with suppliers enables automation, real-time visibility, and faster decision-making in the supply chain (Zhou et al.,

2024). This reduces disruptions, improves operational efficiency, and enables companies to respond more quickly to market demands. Meanwhile, sustainable production helps companies stay relevant as more consumers and business partners care about environmentally friendly practices. In the context of Industry 4.0, technology enables resource optimization, waste reduction, and more efficient energy use, supporting sustainability efforts (Singh et al., 2023). Companies that implement sustainable production not only meet the demands of environmental regulations but also gain market trust and maintain reputation, which is essential for long-term success in an increasingly competitive industrial ecosystem.

The last factors that support transformation success are competitive pressure, customer focus, and human-centric design. To maintain an advantage over rivals, businesses must improve operational effectiveness, speed digital transformation, and optimize supply chains (Debnath et al., 2023). Companies are under pressure to adopt modern technology to maintain their competitive edge quickly, and this pressure is further heightened by market volatility (Jayashree et al., 2022). A further layer of competitive pressure is created by customer expectations for high-quality products with shorter lead times, which drives businesses to innovate constantly (Solaimani & Swaak, 2023). The requirements and satisfaction of the customer should be at the center of any strategy for digital transformation. Businesses can guarantee that digital solutions closely correspond with market expectations by giving clients priority (Dora et al., 2022). Businesses can react quickly to changing client preferences by exchanging data efficiently and by understandably communicating with customers. Real-time data gathering and analysis are made possible by technologies like IoT, big data, and AI, which enable businesses to predict shifts in consumer trends and behavior (Pawar et al., 2020). Customers can receive individualized and pertinent goods and services because of this responsiveness, which also boosts competitiveness and speeds up innovation.

Ensuring the efficiency, acceptability, and effective utilization of Industry 4.0 technologies by human resources is just as crucial as their acceptance. To make Industry 4.0 technologies user-friendly and reduce additional workloads for employees, an ergonomic user interface tailored to the application context is essential (Masood & Egger, 2019; Wang & Meckl, 2022). The use of design aspects that promote comfort and trust in the system can increase staff support for its adoption and create individual acceptance and trust in the new technology (Eampoonga & Leelasantitham, 2023; Intalar et al., 2021).

### 4.2. Developing a Framework to Guide Managers in the Adoption of Industry 4.0

Based on scientific studies that the successful implementation of Industry 4.0 cannot be separated from the role of managers in its implementation (Schneider, 2018; Sweeney et al., 2023). The purpose of this study is to investigate in further detail the strategic role that managers play in the process of digital transformation. The main focus of this research is to identify the managerial skills needed and the strategic decisions that must be made in adopting Industry 4.0 technology based on CSFs that have been identified in advance through literature studies. Using the PDCA cycle approach can clarify the role of managers in each PDCA phase to guarantee Industry 4.0's successful deployment. This reasoning is illustrated in Figure 2, which offers a framework of managerial responsibilities in relation to the crucial success elements of Industry 4.0 implementation through the use of PDCA.

At the Plan stage, managers need to establish a vision, strategy, and organizational structure that supports the successful implementation of Industry 4.0. Planning can be in terms of human capital development, which includes training and skills development before embarking on digital transformation (Adebanjo et al., 2023). This includes an initial competency evaluation to ensure that HR is ready for change. Brodeur et al. (2022) also suggest strategic planning that includes aligning the organization's vision and structure with the company's long-term goals. In this context, planning should include well-thought-out technology, process, and project management strategies to ensure readiness and success. In addition to internal planning, external support should also be considered. Government regulations must be considered to ensure that the planning is done according to existing rules and to see other positive potentials that can support the technology transformation process (Ghadimi et al., 2022). Another important thing to do in this stage is to assess the competitive advantages owned and those to be achieved to align technology with strategic goals. This assessment helps understand the organization's current position,

identify areas of improvement, and leverage Industry 4.0 technologies to improve the organization's market competitiveness (Pawar et al., 2020).

The next stage, the Do stage, focuses mainly on implementing the planned strategy. Financial resources are allocated to invest in relevant technologies, and training is carried out. On transformation activities, the corporate culture needs to be aligned, such as giving more autonomy to employees after training to ensure they can play an active role in the digital transformation process (Adebanjo et al., 2023). This allows employees to use their problem-solving abilities and adaptation skills in dealing with new technologies. In addition, good project management and communication among line management, as well as internal and external stakeholders, are essential for successful implementation (Brodeur et al., 2022). Close collaboration between departments should be established to facilitate vertical and horizontal integration of production systems connected with Industry 4.0 technologies (Bhatia & Kumar, 2022).

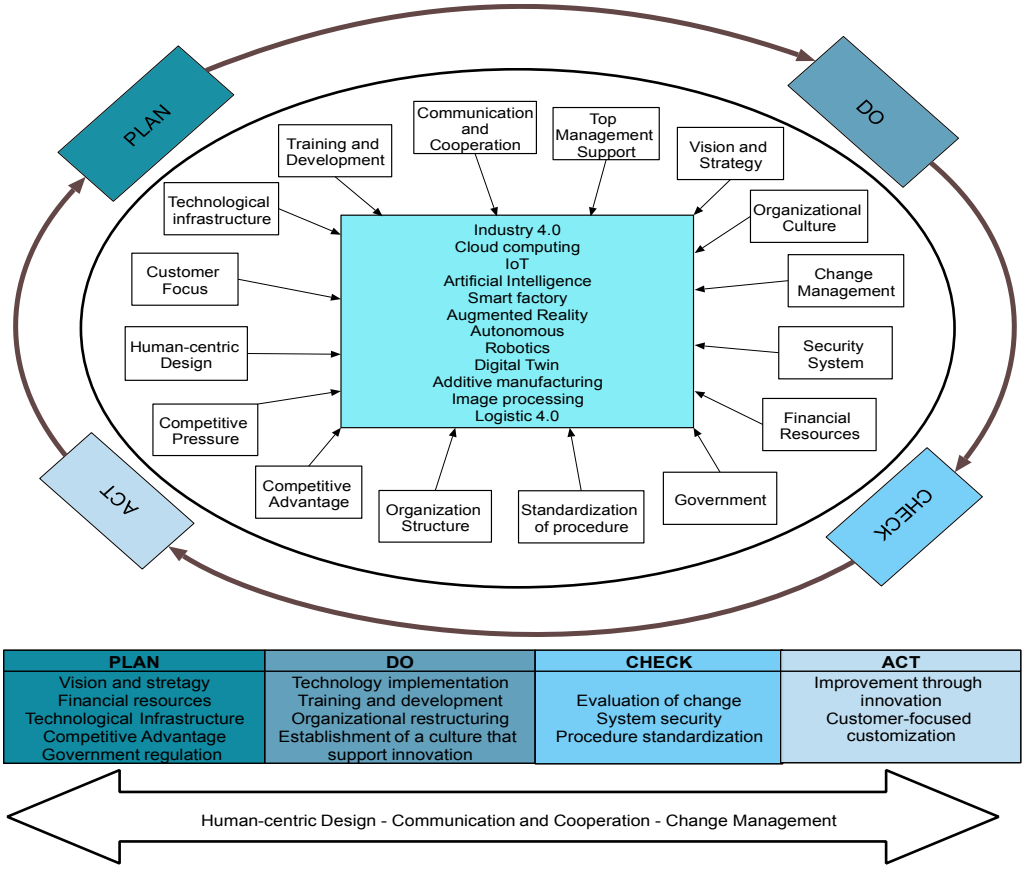


Figure 2. Managerial role framework in industry 4.0 implementation based on PDCA

In the Check stage, managers must monitor and evaluate the results obtained from the implementation. Evaluation is carried out to see the relationship between various critical factors, such as financial performance and technological efficiency, to ensure the sustainability of the digital transformation process (Deepu & Ravi, 2021). Another purpose of evaluation is to assess the conformity of the implementation with the initial plan and ensure that all technological, organizational, and external aspects are well-integrated (Eampoonga & Leelasantitham, 2023). Evaluation also includes retraining and updating employee skills as needed. Another activity that needs to be done at this stage is monitoring the security and privacy aspects during the implementation of Industry 4.0 technology (Gupta & Misra, 2016). Regular monitoring of cybersecurity systems and network reliability should be carried out to ensure that company data and information are well protected from external threats.

The Act stage involves corrective actions based on the evaluations that have been made. Managers must make adjustments to strategies, human resources, and operational policies (Hakim et al., 2023). Continuous innovation is

also needed to maintain the company's competitiveness in the face of market trends and changing customer expectations (Nurbossynova et al., 2021). These initiatives are carried out by gathering consumer input regarding implemented goods and services to determine which era has to be enhanced and what insights relate to consumer happiness (Dora et al., 2022). Managers should ensure employees are involved in the continuous innovation and development process through cross-departmental collaboration (Hakim et al., 2023). In addition, risk mitigation and adaptation to the external environment must be integrated to ensure long-term success in Industry 4.0 implementation (Ghadimi et al., 2022).

The roles and activities of managers have been identified in each PDCA cycle. However, three key factors apply throughout the PDCA phases of Industry 4.0 implementation: human-centric design, communication and cooperation, and change management. Human-centric design ensures that all implemented technologies and processes meet the needs and expectations of users (employees). Managers can engage users in the design process of new products or systems to get direct feedback on their needs and preferences. Managers also need to regularly evaluate and refine designs based on user feedback to ensure that services remain relevant and functional. Likewise, communication and cooperation factors, where managers need to create clear and open communication channels, including regular meetings, digital platforms for discussion, and structured feedback. Meanwhile, change management serves as a framework that helps organizations overcome the challenges they face. By planning carefully, implementing effectively, conducting in-depth evaluations, and taking necessary corrective actions, managers can ensure that digital transformation is smooth and sustainable while maximizing the benefits to the organization.

### 4.3. Framework Implementation in SMEs

The framework's proof case was conducted in an SME of agricultural equipment machinery, plantations, livestock, and food processing in Indonesia, which has 47 employees. ERP technology has been successfully applied by developing the system independently and will be developed to Cloud ERP. The testing process was conducted through semi-structured interviews with company managers, resulting in an analysis of the framework's strengths in supporting success and some future improvements.

1. In the Plan stage, the company has established a clear vision of resource management through information systems, which is aligned with the content elements and strategies of the PDCA framework. This has proven to help the company set directions and plans that support the development of Cloud ERP. Cooperation with external parties (universities) is also carried out in developing technology and infrastructure. Not only that but adequate budget planning and human resource development are also prepared at this stage.
2. The Do stage, which is the development of an ERP system independently with external support, shows that the company has successfully implemented technology infrastructure and elements of communication cooperation. The company also implemented cross-department collaboration with a little organizational restructuring, namely by forming and appointing a special IT team. Then, the technology implementation process was carried out through trials and gradual steps to overcome the employee resistance that emerged. This shows the implementation of good change management.
3. In the Check stage, the company also conducts an evaluation at the beginning of implementation (1-3 months), then periodically every 3 months. The evaluation elements are related to employee responses, whether there are disruptions or errors, and employee work efficiency. This ensures that the process runs according to plan and problems can be identified early. The decision to formally implement ERP through a Decree shows the company's commitment to standardizing procedures, which is another element in the framework.
4. In the Act stage, the company forms an R&D team. It creates a system innovation plan, which shows the implementation of technological innovation development elements leading to the production process (production floor) to meet customer needs. It should be noted that the company's production system is based on customer orders from both industry and government. Although this team has not been running optimally, this step shows an effort to make continuous improvements. The company is also still

collaborating with universities by accepting interns as a form of information sharing and identifying innovation opportunities.

In the transformation process, the company faced several challenges. Employee resistance to new technology and organizational culture issues are the main challenges. So, based on the framework that has been built, the solution provided for the company is to strengthen the training and communication elements, especially in building a culture that supports digital transformation. More intensive training programs based on real-world applications can help overcome resistance, in addition to encouraging active employee participation and change. Another issue identified was concerns related to data security; employees and companies are very concerned about this issue, causing companies to refrain from collaborating with the government or using more sophisticated technology. Companies assume that the government has not played a significant role in supporting their specific needs. Therefore, this problem can be an improvement for the framework to prioritize security systems as the main thing considered by companies before implementing advanced technology, especially Industry 4.0.

In addition, a solution that can be provided to the framework is to include advocacy strategies and active collaboration with the government, specifically voicing the unique needs of SMEs and adjusting regulations to be more relevant. Other issues also include the management of sustainable innovation. Despite the existence of RnD teams, sustainable innovation is still difficult to optimize. This could be strengthened by a framework with more emphasis on innovation management systems, which support more systematic product and process development and more structured resource allocation. High maintenance costs are also a constraint faced, so it is advisable to pay attention to cost management, such as maintenance costs and other costs that will arise (employee training costs, unexpected costs). This element should be included in the long-term financial plan so that the company can plan the budget more effectively to maintain the system. The human-centric design factor is not really considered in this case study; the reason is that the type of technology does not require major interaction with employees. It is different if the type of technology is related to the production process on the factory floor; maybe this factor will have a significant influence. A good communication and cooperation system throughout the phases also contributed to the success of the technology transformation process.

The PDCA framework for the implementation of new technology has proven to support digital transformation in machining SMEs. However, there are still challenges in several aspects that make the input for improvement of the framework to be more effective in its application. Figure 3 is an improved framework that is tailored to the conditions of SMEs.

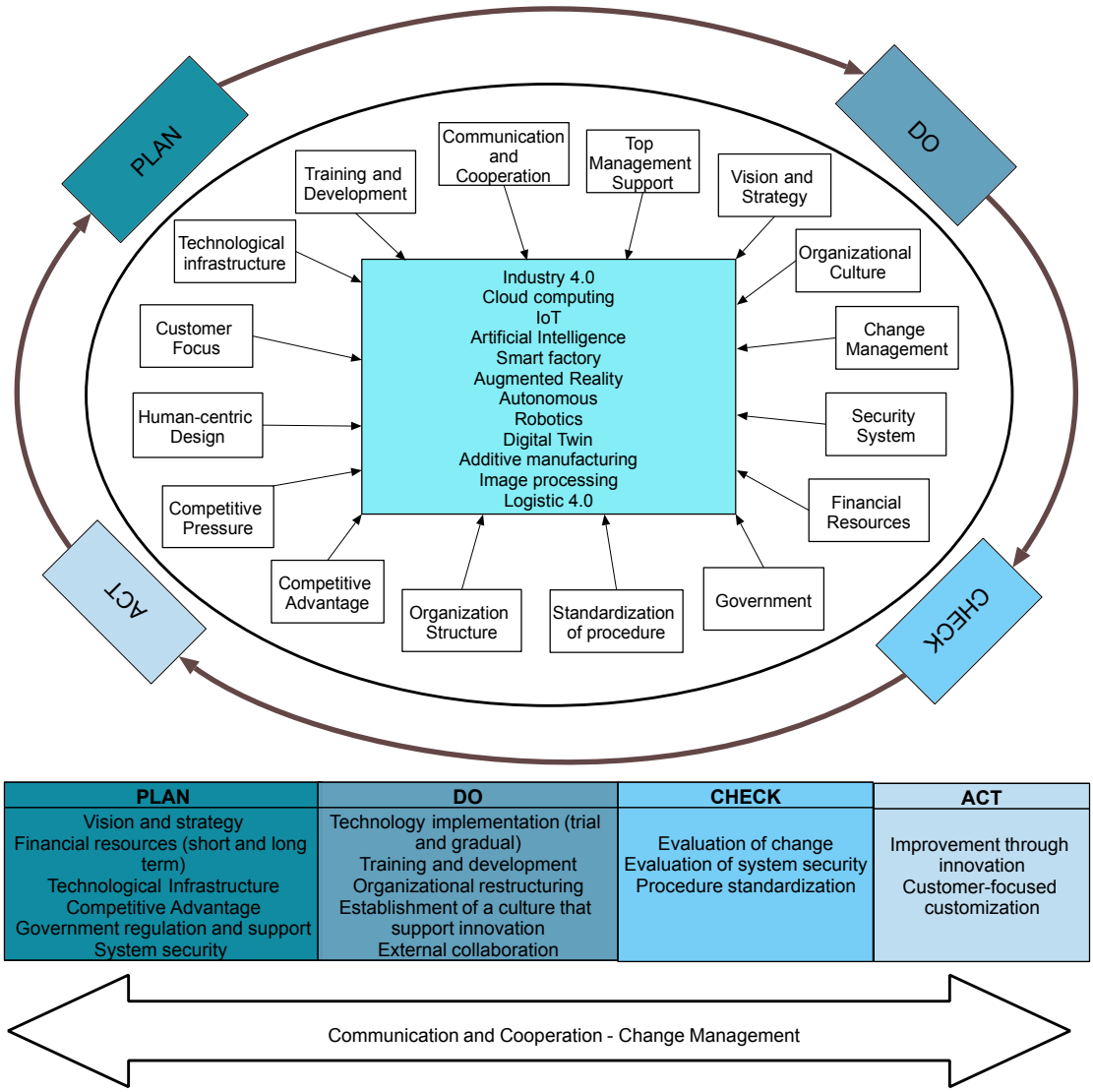


Figure 3. Improvement of Managerial Role Framework in PDCA-Based Industry 4.0 Implementation

## 5. Discussion

### 5.1. Comparison with Previous Studies

The study identified 16 CSFs for Industry 4.0 adoption in the context of SMEs, where top management support and technology infrastructure were found to be the most influential factors. These findings are in line with studies by Črešnar and Nedelko (2020), as well as Ghobakhloo and Iranmanesh (2021), which emphasizes that strategic leadership has a direct influence on an organization's readiness to face digital transformation. Similarly, Brodeur et al. (2022) states that technological readiness is a prerequisite for the successful implementation of Industry 4.0. However, in contrast to this approach that often puts technology at the center, this study emphasizes the importance of a balance between technological readiness and organizational capacity, especially in the context of resource-constrained SMEs.

In addition, the study found that employee resistance and lack of digital skills are the dominant challenges in the technology adoption process. This is supported by the findings of Miah et al. (2024), which identify a lack of skilled labor and digital literacy as the main obstacles in the South Asian region. The study also confirms that the development of job skills that include technical, communication, and leadership skills is an integral part of successful transformation. This puts the human factor at the center of the digitalization strategy, different from the previous approach as conveyed by Lykourentzou, Apostolopoulos, Dabić, Liargovas and Tekavčič (2025), which

positions the human factor as an element of moderation. Therefore, this study's approach supports the need to reposition human factors as a key dimension in the success of SME digital transformation.

The study also developed a Plan-Do-Check-Act-based framework that aims to provide iterative guidance for managers in managing the digital transformation process. This approach is consistent with the framework developed by Mahnashi et al. (2023), which emphasizes the importance of continuous improvement processes in a rapidly changing business environment. However, the PDCA framework in this study has a practical advantage because it directly integrates the CSF into the SME operational management cycle, allowing for flexible adjustments to market dynamics and internal constraints.

When compared to the technology transfer framework developed by Alkhazaleh, Mykoniatis and Alahmer (2022), there are fundamental differences in approaches. Alkhazaleh emphasizes the interaction between key actors (agents, receivers, media, and transfer objects), with support from external ecosystems such as government incentives and modern legal frameworks. The focus of the model lies on the external structure and dynamics in the success of technology transfer, not on internal implementation that is managerial. In contrast, the PDCA model in this study focuses on strengthening the organization's internal processes—specifically strategic planning, implementation, outcome evaluation, and continuous improvement—which makes it more applicable and directly usable in the context of SME operations. The SEI (Skill–Enabler–Impact) framework was developed by Miah et al. (2024) focuses on workforce readiness and the influence of external enablers such as education, public policy, and cross-sectoral cooperation. SAI's main focus is to create an adaptive, highly digitally literate workforce capable of operating Industry 4.0 technology productively. This framework is useful at the systemic level, but it does not meet the practical needs of managers in managing transformation at the organizational level as PDCA does. Thus, this study complements Miah's macro approach with relevant micro contributions to daily decision-making at the SME level.

One of the other important contributions is the introduction of two factors that have rarely been explicitly discussed in the previous literature, namely human-centric design and customer focus. These findings are in line with Alkhazaleh et al. (2022), who emphasized the importance of user involvement in technology transfer, and Götz (2021), which shows that customer orientation is a key driver of digital innovation in the SME sector. However, such reviews by Sahoo et al. (2022) or Khan et al. (2024) generally still places these aspects as additional factors, not as the core of the adoption strategy. Therefore, this study contributes a new dimension to CSF by placing people and customers as the main focus of sustainable innovation.

In terms of managerial strategy, this study found that a top-down approach alone is not enough. A flexible, participatory, and learning cycle-based management system is needed. This approach contrasts with overly structured and hierarchical management models, such as those in the study of Khan et al. (2024), which is more suitable for large organizations with high complexity. In the context of SMEs, PDCA demonstrates excellence because it offers simple processes that remain systematic, allowing managers to respond quickly and efficiently to change.

Finally, this study confirms that the successful adoption of Industry 4.0 in SMEs depends on the synergy between internal factors, such as organizational readiness, leadership, and innovation culture, and external factors such as regulation, technology support, and institutional collaboration. This is in line with Succurro and Donati (2025), who stated that the success of SME digitalization in Europe is largely determined by the clarity of regulatory frameworks and adaptive technology standards. In the context of this study, the role of policies that have not addressed the specific needs of SMEs is a real obstacle, especially related to data protection and technology adoption incentives. Overall, the study reinforces important findings from the previous literature, but also offers a new contextual and applicative approach through integration between CSF and the PDCA cycle. Comparison with the framework of Alkhazaleh et al. (2022) and Miah et al. (2024) shows that the PDCA approach is able to bridge the gap between macro strategies and micro-implementation, as well as make a significant theoretical and practical contribution to accelerating digital transformation among SMEs.

### 5.2. Implications

This study adds to the understanding of Industry 4.0 adoption in SMEs by creating a CSF and PDCA framework that demonstrates the importance of managerial leadership. The iterative PDCA framework allows for ongoing review and modification, aligns with SME dynamics, and advances theory by adapting the continuous improvement model to digital transformation. This study also bridges the theory-practice gap in Industry 4.0 research by providing a framework that can be readily applied by SMEs. This study demonstrates how leadership influences the success of digital transformation by incorporating managerial functions into implementation. The PDCA framework serves as both a theoretical model and a practical guide for implementation.

Practical implications are recommended for managers to align technology implementation with business strategy and resources and ensure that each phase of transformation is guided by a clear vision. Managers should also address obstacles that arise during the transformation process through effective change management. By combining planning, implementation, evaluation, and feedback, the framework allows for continuous adaptation and improvement. In addition, SME managers should adjust their innovation strategies to meet the unique needs of their organizations. This study supports the idea that a flexible approach to innovation produces more successful outcomes, helping managers overcome resource constraints and regulatory challenges. Practical implications for the government are also indicated, namely that the government, in setting policies, must be more specific, especially to answer the unique needs of SMEs. Data security and privacy issues are major considerations for SMEs to adopt industry 4.0 technology. It is hoped that the government can really guarantee this security with clear and definite policies.

## 6. Conclusion

This study aims to answer key questions about CSF and managers' roles in leading Industry 4.0 digital transformation in SMEs by developing a CSF and PDCA-based framework. This study fills a gap in the CSF-related literature, which generally does not focus on the role of managers in the digital transformation process. The developed PDCA framework offers a systematic approach that assists managers in planning, execution, evaluation, and continuous innovation so that SMEs can better face the challenges of digital transformation. The findings of this study show that strong managerial leadership, adequate technological resources and infrastructure, and external collaboration are able to help SMEs achieve successful adoption of new technologies, supported by appropriate strategies for facing challenges and obstacles. However, this study has limitations, such as a small sample and a focus on specific sectors, so that the results may lack generalizability. Recommendations for future research include cross-industry exploration and deeper evaluation of the role of government policies and cultural factors in supporting Industry 4.0 adoption in SMEs.

## Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication

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