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Research Article

The Role of Transformational Leadership in Leveraging Industry 4.0 Technologies: A Research Framework Grounded in Socio-Technical Systems Theory

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ABSTRACT

Industry 4.0 has catalyzed technological advancements, leveraging Artificial Intelligence (AI), the Internet of Things (IoT), and Data Analytics, thereby driving a pressing need for innovation within organizations. Transformational leadership plays a pivotal role in shaping organizational culture to adapt to socio-technical dynamics, effectively facilitating the adoption of emerging technologies. By synthesizing existing research on transformational leadership and socio-technical systems theory, this research elucidates the strategic role of transformational leadership in aligning employees, processes, and technological infrastructure, thus enhancing the adoption of Industry 4.0 technologies. Additionally, the research examines the critical role of organizational culture as a moderating factor, establishing a robust foundation for stability and innovation. The findings of this research provide a valuable theoretical framework for organizations to tailor their technology adoption strategies and strengthen their competitive advantage in an increasingly volatile business environment.

Keywords: Transformational Leadership, Socio-Technical Systems Theory, Industry 4.0 Technologies, Technology Adoption, Organizational Culture.

1. Problem statement

1.1. Research context

Industry 4.0 demands that global enterprises adopt advanced technologies such as Artificial Intelligence (AI), the IoT, Blockchain, and Data Analytics (Agarwal et al., 2022; Dai et al., 2022; Jagatheesaperumal et al., 2021; Javaid et al., 2021; Marinagi et al., 2023; T. Zheng et al., 2021). The integration of these technologies enhances organizational performance by optimizing production processes, improving security, transparency, and traceability (Mssassi & El Kalam, 2024), sustaining competitive advantage (Khan et al., 2022), and fostering sustainable development (Tsolakis et al., 2023). However, the adoption of these technologies poses significant challenges, particularly in developed economies, due to organizational cultures resistant to change (Roodt & Koen, 2020), employee readiness deficits (Draft, 2021), and inconsistent technical infrastructure (Shyle & Rruplli, 2024).

The socio-technical systems (STS) theory provides a robust theoretical foundation, emphasizing the interplay between social and technical components within organizations (Böhmann et al., 2014; P. Zheng et al., 2019). According to (E. L. Trist & Bamforth, 1951), organizations operate as open systems where social and technical factors interact, influencing one another (Appelbaum, 1997; E. Trist, 1981). This dynamic fosters equilibrium improves organizational performance, and enhances sustainability (Eijnatten, 1998; F. E. Emery & Trist, 1960). Successful implementation of new technologies requires comprehensively considering internal and external organizational factors (Da Silva et al., 2020; Sony & Naik, 2020).

Internal factors include investments in training and developing specialized human resources to address skill shortages (Jain et al., 2022; Veile et al., 2020; Vuksanović Herceg et al., 2020), financial resources, and technical infrastructure (S. Kumar & Bhatia, 2021; Moktadir et al., 2018; Vuksanović Herceg et al., 2020). An open

organizational culture and flexible structures enable employees to embrace new technologies swiftly (Ramadan et al., 2022; Veile et al., 2020). Strategic and decisive leadership can accelerate transitions and drive continuous improvement (Pozzi et al., 2023; Ramadan et al., 2022).

External factors, such as market pressures and technological advancements, compel organizations to innovate continuously to maintain competitiveness (S. Kumar & Bhatia, 2021). Customer trust in digital transactions also facilitates technology adoption (Jain et al., 2022; Müller et al., 2018). Additionally, organizations face regulatory and competitive pressures, requiring optimized processes and technology to comply with regulations and meet market demands (Müller et al., 2018).

Transformational leadership is pivotal in fostering an innovation-friendly organizational culture and encouraging employees to adapt to new technologies (Tănase, 2020). By creating empowering and creative work environments, transformational leaders drive organizational innovation (Afsar & Umrani, 2020; Ghasabeh et al., 2015; Jung et al., 2003; Le & Lei, 2019; Omaka et al., 2019; Sueb & Sopiah, 2023). They also promote learning and knowledge sharing, facilitating innovative employee behaviour (Afsar & Umrani, 2020; Le & Lei, 2019; Sueb & Sopiah, 2023). Coupled with cohesive organizational cultures, leadership support motivates employees to engage in innovative activities, establishing a creative work environment (Azmi et al., 2023; Jaskyte, 2004; Omaka et al., 2019).

However, examining transformational leadership through the lens of STS theory remains underexplored. This study addresses this gap by investigating how leaders can effectively integrate social and technical factors to enhance organizational performance through Industry 4.0 technologies adoption.

Additionally, a supportive organizational culture emerges as a critical factor for securing employee commitment and ensuring the successful implementation of Industry 4.0 technologies by fostering innovation and continuous learning (Ali & Xie, 2020; Liu et al., 2022). Organizational culture also supports strategic flexibility to adapt to new industrial contexts in rapidly evolving social environments through intermediary relationships, such as technological capabilities and market orientation (Kafetzopoulos & Katou, 2024). The integration of Industry 4.0 technologies not only transforms organizational behaviour and corporate culture but also enhances overall efficiency (Ali & Xie, 2020; Pol, 2022).

Nonetheless, overcoming cultural barriers, such as addressing skill gaps and transforming traditional business models, is essential for successful technology adoption (Agostini & Filippini, 2019). Therefore, the role of organizational culture in facilitating or hindering this process remains a crucial subject for further research. This study will explore how organizational culture influences the adoption of Industry 4.0 technologies, aiming to validate and differentiate its findings from prior research.

1.2. Research methods

This study employs a systematic literature review approach to ensure a comprehensive, scientific, transparent, and data-maximizing exploration of the topic by synthesizing all relevant studies on a specific subject (Askie & Offringa, 2015). The review focuses on examining relevant articles published within the past five years. The decision to include only recent publications is justified by the dynamic and continuously evolving nature of the field.

Additionally, the research framework was developed by integrating insights from seminal works, including those by Trist and Bamforth (1951), Trist (1981), and Bass (2006), alongside other relevant contributions. Following the recommendations of (Palmaccio, M., Dicuonzo, G., & Belyaeva, Z. S., 2021), the systematic review process consists of four key stages: (1) Defining objectives and planning the review; (2) Selecting relevant studies; (3) Analyzing and synthesizing data; (4) Discussing analytical results. Through a rigorous process of screening and evaluating the relevance of the literature to the topic, a total of 27 articles were selected for further analysis and synthesis.

To enhance the depth of the review, the author conducted searches for English-language studies in the Scopus database using the keywords “TL” and “transformational leadership.” Bibliometric analysis was performed using VOSviewer software to identify research trends, focus areas, and concentrated regions of study. This process aids in uncovering theoretical gaps and generating actionable implications to address them.

2. Theoretical basis

2.1 Concept of Industry 4.0

Industry 4.0 encompasses advanced technologies such as the IoT, AI), Data Analytics, and Cyber-Physical Systems (CPS), which are integrated into production and management processes (Duman & Akdemir, 2021; Haseeb et al., 2019; Klingenberg et al., 2021). The adoption of these technologies represents not merely the implementation of innovative tools but also a comprehensive transformation in how businesses are structured and operated, spanning design, supply chains, manufacturing, distribution, and customer service (Mohelska & Sokolova, 2018). Industry 4.0 significantly enhances efficiency and productivity through automation and process optimization, improving both

production processes and product quality (Duman & Akdemir, 2021; Haseeb et al., 2019; Klingenberg et al., 2021). CPS and robotics automate complex tasks, reducing reliance on manual labour while improving precision (Bajic et al., 2020; Duman & Akdemir, 2021; Mohelska & Sokolova, 2018). Additionally, technologies such as 3D printing and Augmented Reality (AR) enable cost-effective customization of products within shorter timeframes (Choi et al., 2022; Duman & Akdemir, 2021; Klingenberg et al., 2021). These capabilities enhance organizational competitiveness by offering personalized products and services that meet customer demands swiftly. Moreover, Industry 4.0 fosters sustainable development by promoting efficient resource management and minimizing environmental impacts (Haseeb et al., 2019; Morawiec & Sołtysik-Piorunkiewicz, 2023).

However, the successful implementation of Industry 4.0 technologies requires businesses to undertake significant organizational and managerial changes. Enterprises must develop new employee skill sets, restructure organizational frameworks, and cultivate an innovation-driven and creative organizational culture (Cimini et al., 2020; Mohelska & Sokolova, 2018; Obermayer et al., 2022). This transformation extends beyond technological adoption, necessitating adaptation in management and human resource practices to fully harness the benefits of Industry 4.0.

2.2 Transformational Leadership in the Context of Industry 4.0

Burns (1978) first introduced the concept of transformational leadership, which was later expanded by Bass & Bass Bernard (1985). Bass emphasized the critical role of leaders in driving organizational change by inspiring and motivating employees to transcend personal interests and pursue collective goals (Bass & Bass Bernard, 1985).

In the context of Industry 4.0, the advancements brought by technologies such as IoT, AI, and CPS have challenged the efficacy of traditional business models and leadership styles (Ivanov et al., 2019). This necessitates the development of novel approaches to managing the complexities introduced by Industry 4.0 technologies (Vlasov & Chromjaková, 2018). Conventional leadership models often fail to adapt to the intrinsic technological advancements and far-reaching impacts of Industry 4.0, which extend beyond individual operational levels (Xu et al., 2018). Consequently, leaders must embrace the core principles of Industry 4.0, including digitalization, flexible production model redesign, and sustainable market strategies (Schlaepfer et al., 2015).

Transformational leadership, characterized by idealized influence, inspirational motivation, intellectual stimulation, and individualized consideration (Bass & Avolio, 1994), is well-suited to fostering readiness for Industry 4.0. Such leaders provide ethical guidance, articulate a compelling vision, and enhance organizational performance (Northouse, 2021). They align teams, unify organizational goals, and encourage innovation while promoting skill development among employees (Ghasabeh et al., 2015; Schein, 2010). Roux's Leadership 4.0 model highlights transformational leadership as a viable framework for Industry 4.0 integration, emphasizing employee empowerment through clear focus and specific objectives (Roux, 2020).

2.3 Socio-Technical Systems Theory

In the context of Industry 4.0, where emerging technologies such as automation, IoT, and AI are continuously evolving, organizational adaptability and self-regulation are critical for sustainable development (Appelbaum, 1997). The STS theory provides an effective analytical framework for optimizing the interplay between technical and social factors to achieve high performance in the Industry 4.0 environment (E. Trist, 1981). Technical systems encompass technological infrastructure and procedural processes, while social systems involve human elements such as workforce skills, organizational culture, and employee engagement in continuous improvement efforts (E. L. Trist & Bamforth, 1951). A harmonious balance and coordination between these elements are essential for organizations to maximize operational efficiency and fully leverage the benefits of advanced technologies (Eijnatten, 1998; F. E. Emery & Trist, 1960).

Additionally, external pressures, such as market demands, often require organizations to be flexible, responsive to change, and innovative in addressing customer needs (Baxter & Sommerville, 2011; Ng et al., 2011). External support, including government policies and partnerships, also plays a pivotal role in enabling organizations to access new technologies and enhance their competitive capabilities (Sony & Naik, 2020).

STS theory emphasizes that the interaction between external and internal organizational factors is crucial for the successful implementation of new technologies (Davies et al., 2017). While focusing on external elements enhances an organization's ability to respond to market dynamics and capitalize on external resources, internal factors, including social and technical systems, are instrumental in supporting and accelerating technological transitions (Mohamad & Songthaveephol, 2020).

2.4. Previous research works

Using a systematic literature review method, the author has undertaken the task of collecting studies related

to the topics of transformational leadership and the STS as follows:

(1) In this study, Appelbaum et al. (1997) investigated the relationship between organizational development (OD) and the integration of technology to enhance operational efficiency within the coal mining industry in the United Kingdom, drawing upon survey data from Fortune companies and Fortune Service. Specifically, the implementation of self-managed work teams was seen as an effective approach to support technological tasks, thereby optimizing overall performance. The findings recommended the application of STS theory in organizational change strategies. However, due to the reliance on Woodward's classification framework and its limitation to the manufacturing sector, the research suggested expanding the scope of STS application and examining the impact of technology across different industries or organizational contexts for a more comprehensive understanding (Appelbaum, 1997).

(2) Sawyer et al. (2003) employed STS theory to analyze the relationship between technical and social factors, such as institutional regulations and individual behaviours, within the rapidly evolving context of broadband technology development. Through the STS lens, the research offers a comprehensive perspective on broadband and mobile technology, while highlighting the challenges associated with upgrading connectivity. The research proposes policies and strategies to optimize the use of broadband networks, emphasizing the importance of job design that aligns with both technical and social systems to enhance performance. However, the research did not delve deeply into the limitations of applying STS in different organizational contexts and suggests directions for future research to improve the effective utilization of broadband networks (Sawyer et al., 2003).

(3) Geels et al. (2004) expanded the analytical framework of STS theory by focusing on four key aspects: (1) shifting from sectoral innovation systems to STS; (2) clearly distinguishing between systems, actors, and institutions; (3) exploring in-depth the role of institutions; and (4) examining the processes of transition between STS. This analytical framework integrates sociology, institutional theory, and innovation studies to better understand the long-term dynamics and co-evolution between technology and society. The findings from an investigation of self-managed work teams as an application of STS in organizational development demonstrated that these teams can enhance productivity and employee satisfaction. However, the research lacked an analysis of the dynamics and transition processes between STS systems and suggested that future research should adopt a multi-level perspective to gain a deeper understanding of the dynamics of transformation and to support policies that foster effective (Geels, 2004).

(4) Gumusluoglu et al. (2009) examined the impact of transformational leadership on organizational innovation and analyzed the moderating roles of internal and external support factors. Based on data analysis from 163 R&D employees and managers across 43 small and medium-sized software development companies in Turkey, the research found that transformational leadership had a significant positive effect on organizational innovation capabilities. External support, such as technical and financial assistance, was found to be more influential and impactful than internal support in fostering innovation. However, due to the cross-sectional design limitations, the research could not account for temporal fluctuations or the high correlations among variables. As a result, the authors recommended future research to adopt a longitudinal design and explore additional mediating factors to better understand the relationship between transformational leadership and organizational innovation (Gumusluoglu & Ilsev, 2009).

(5) Davis et al. (2014) extended the STS theory by proposing an analysis beyond emerging technologies and design sectors, focusing on complex and global challenges such as crowd management and environmental sustainability while encouraging forward-looking research. A case study approach was employed to demonstrate the application of STS in new domains, emphasizing the clear distinction between systems, actors, and institutions. The findings indicated that STS is effective in analyzing and addressing complex issues, thereby expanding the theory's influence and contributing to solving significant societal challenges. However, the research called for further research to develop specific methodologies for applying STS in various new fields, in order to optimize the potential of this theory (Davis et al., 2014).

(6) Van Dun et al. (2017) integrated STS theory with transformational leadership to emphasize the balance between technical and social factors in examining the impact of lean management on enhancing customer value. A combination of interviews, surveys, and video analysis was employed to identify the values and behaviours of middle managers implementing lean initiatives in small and medium-sized enterprises (SMEs) in the Netherlands. The findings indicated that successful lean managers typically prioritize altruistic values and openness to change, demonstrating behaviours that foster positive relationships and continuous improvement. However, the research was limited by sample size and geographic scope, suggesting

opportunities for future research to expand across different countries and industries, while also exploring the role of values and behaviours at various management levels (Van Dun et al., 2017).

(7) Rossini et al. (2019) explored the relationship between the adoption of Industry 4.0 technologies and lean production (LP) practices in relation to the operational performance of 108 manufacturing companies across Europe. Using a quantitative approach with multivariate analysis techniques, the research examined contextual factors such as company size, experience with LP implementation, ownership structure, and business operations. The findings revealed a positive correlation between the degree of Industry 4.0 adoption and the implementation of LP practices. Conversely, limited process design effectiveness and a lack of continuous improvement culture were identified as potential barriers to the readiness for technological adoption. Due to limitations in sample size and geographic scope, the research suggested expanding future research to further investigate the relationship between LP and Industry 4.0 (Rossini et al., 2019).

(8) Mohelska et al. (2018) applied STS theory to assess organizational culture and identify appropriate management approaches that support innovation in the context of Industry 4.0 in the Czech Republic. Using a quantitative method, the research collected data from 1,547 employees through the Organizational Culture Index (OCI) survey developed by Wallach, which classifies organizational culture into bureaucratic, innovative, and supportive types. The results indicated that bureaucratic culture predominated, followed by supportive and innovative cultures, with no significant changes observed between 2013 and 2017. The research emphasized the need to foster an innovative culture to align with the demands of Industry 4.0 and proposed expanding the sample size and conducting deeper analyses of the relationship between organizational culture and operational performance in future research (Mohelska & Sokolova, 2018).

(9) Birkel et al. (2019) developed a comprehensive risk framework for Industry 4.0 in relation to the three pillars of sustainability: economic, ecological, and social. The research conducted 14 interviews with senior managers representing 13 different industries, varying in size and scope. The findings revealed six primary risk categories: economic, environmental, social, technical, information technology, and legal-political. Among these, the adoption of Industry 4.0 was associated with risks such as inefficient investments, increased energy consumption, job losses, and data security concerns. The research contributes to validating the relationship between Industry 4.0 and sustainable development, emphasizing the importance of appropriate risk management to ensure the sustainable growth of businesses. However, due to the small sample size and limited geographic scope, the research suggested expanding future analyses to further investigate the severity of each risk category (Birkel et al., 2019).

(10) Qureshi et al. (2019) assessed the mediating role of social, environmental, and technical systems in the relationship between managerial support and sustainable manufacturing performance in large manufacturing plants in Malaysia. Using structural equation modelling (SEM) with survey data from 299 employees, the research found that managerial support had a significant positive effect on sustainable manufacturing performance through the mediating factors of social, environmental, and technical systems. Management support was found to promote employee empowerment and involvement in sustainability initiatives, while also improving the efficiency of advanced environmental and technical systems. However, the research faced limitations related to sample size and geographic scope, and it suggested that future research should expand the analysis to further explore these relationships (Qureshi et al., 2019).

(11) Agostini et al. (2020) evaluated the impact of financial investment in advanced manufacturing technologies (AMT) and social capital (SC), including both internal and external relationships, on the level of Industry 4.0 (I4.0) adoption in SMEs in Central Europe. Analysis of data from 163 manufacturing SMEs revealed that firms with strong social capital tended to adopt I4.0 technologies at higher levels. Furthermore, support from top management and absorptive capacity were found to strengthen the positive relationship between social capital and I4.0 adoption. However, managerial support was found to diminish the impact of AMT investment in manufacturing and internal absorptive capacity on the intensity of I4.0 implementation. The research emphasizes the importance of combining social capital and technological investment, along with managerial support, to enhance the effective implementation of Industry 4.0 in SMEs. Nonetheless, the research is limited by its geographic scope and did not consider other potential factors such as employee technical skills and government support policies (Agostini & Nosella, 2020).

(12) Chonsawat et al. (2020) developed a set of indicators to assess the readiness of SMEs for adopting Industry 4.0 (I4.0). Using a bibliometric analysis combined with the VOS (Visualisation of Similarities) technique, the research analyzed 1,541 academic papers from the Web of Science and Scopus databases to identify key aspects

of I4.0. These aspects were categorized into five main themes: organizational adaptability, infrastructure systems, production systems, data transformation, and digital technologies. The results led to the development of 23 readiness indicators, which were piloted with SMEs to evaluate their readiness and assist decision-making in the process of transitioning to I4.0. While the research did not validate the practical effectiveness of the indicators or consider sector-specific factors, it successfully developed a practical quantitative set of indicators that can help managers identify areas for improvement (Chonsawat & Sopadang, 2020).

(13) Adebanjo et al. (2021) explored the key technological factors influencing the adoption of Industry 4.0 (I4.0) in SMEs in Thailand, an emerging economy. Using a mixed-methods approach, the research identified and prioritized 19 enablers of I4.0 adoption, grouping them into six main categories through the Analytic Hierarchy Process (AHP). The findings revealed that human capital was the most critical factor, followed by data interaction and processing capabilities, while hardware and technology-related factors, such as data security and technological infrastructure, were rated lower. The research emphasized the importance of human factors and organizational culture in driving I4.0 adoption and recommended expanding future research across various industries and countries to enhance the generalizability of the results (Adebanjo et al., 2021).

(14) Ukobitz et al. (2021) analyzed the factors influencing the decision to adopt 3D printing technology (3DP) in organizations. The research reviewed 29 selected studies from reputable scientific databases using a semi-systematic approach that combined bibliometric and content analysis. The findings indicated that the primary drivers for adopting 3DP technology were benefits such as reduced time to market and simplified supply chains. Factors such as technological readiness and skilled human resources were also found to play significant roles, while factors like pressure from business partners and government support were less frequently addressed in the existing literature. The research highlighted a gap in research regarding the impact of environmental and serendipitous factors on the decision to adopt 3DP. However, it noted limitations in the content analysis methodology, particularly the reliance on the frequency of occurrence of factors, which did not allow for an assessment of the actual impact of each factor on 3DP adoption decisions (Ukobitz, 2021).

(15) Lee et al. (2022) evaluated the impact of quality management (QM) activities and the STS on employee experience and organizational performance in healthcare facilities in South Korea. Using structural equation modelling (SEM) with data from 239 employees, the analysis revealed that QM activities positively influenced components of STS, thereby enhancing employee experience and organizational performance. The components of STS played a significant mediating role in the relationship between QM and operational performance. A novel aspect of the research was the consideration of internal customer experience as a mediating factor linking QM, STS, and organizational performance. However, the research was limited by its geographic scope and did not provide a detailed analysis of different types of QM activities. The authors recommended expanding the survey to other healthcare organizations and integrating data from both employees and customers to offer a more comprehensive evaluation (Lee & Lee, 2022).

(16) Marcon et al. (2022) analyzed the complex relationship between socio-technical system (STS) factors and the level of Industry 4.0 (I4.0) adoption in small and medium-sized enterprises (SMEs) in Denmark. The research combined cluster analysis to categorize companies based on their level of technology adoption, and linear regression analysis to identify the role of STS factors. Survey data from the European Manufacturing Survey (EMS) in 2016, involving 231 SMEs, revealed that companies focusing on the development of STS tended to adopt I4.0 technologies at higher levels. Key factors such as clear manufacturing strategies, workforce development, and work processes and policies were found to have significant impacts. Limitations of the research include its geographic scope and the use of outdated data, suggesting the need for future research to expand the survey and update the influencing factors. Nonetheless, the research provided a comprehensive application of the STS lens to explain differences in I4.0 adoption levels, contributing to filling the research gap regarding the role of human and social systems in Industry 4.0 (Marcon et al., 2022).

(17) Kumar et al. (2022) applied the socio-technical systems theory (TSTT) and social cognitive theory (SCT) to analyze the social factors influencing the acceptance of Industry 4.0 (I4.0) in digital manufacturing in India. Utilizing bibliometric analysis and exploratory factor analysis on data from 121 responses from manufacturing units, the research identified seven main factor groups: safety, psychological, behavioural, compliance, culture, employees, and market. The results highlighted that "security breaches" and "data theft" were the most critical factors impacting I4.0 acceptance. This research contributes to the development of TSTT and SCT, providing practical insights for managing I4.0 technology in digital manufacturing by emphasizing the need to improve safety and data security factors to foster successful adoption and implementation of Industry 4.0. However,

the research was limited by its geographic scope and industry focus, suggesting the need for future research to expand across various sectors and regions to enhance the generalizability of the findings (A. Kumar et al., 2022).

(18) Liu et al. (2022) explored the essential role of organizational culture in enhancing service management efficiency within the context of Industry 4.0. Grounded in the STS and social cognitive theory (SCT), the research analyzed the interaction between digital technology, people, and organizations using a combined approach of Su-Field TRIZ and PLS-SEM, based on data from 239 employees in globally competitive industrial manufacturers in Taiwan. The findings revealed that organizational culture positively impacts service management, with leadership, employee motivation, and commitment playing pivotal roles in driving the successful implementation of Industry 4.0. Although the research is limited by its geographical scope and does not provide an in-depth analysis of quality management activities or employee reactions during technology adoption, it contributes by integrating TRIZ and PLS-SEM to develop a service management model tailored for Industry 4.0. Additionally, it clarifies the significant role organizational culture plays in service management effectiveness (Liu et al., 2022).

(19) Bag et al. (2022) explored the relationship between Industry 4.0 (I4.0), sustainable manufacturing, and the circular economy, with the aim of developing an integrated research framework for supply chain management. Grounded in the Resource-Based View (RBV) theory, the research emphasized the role of tangible resources and workforce skills in driving I4.0 adoption and enhancing sustainable manufacturing and circular economy capabilities. The methodology included a literature review and proposed an integrated framework linking I4.0 with AI and Data Analytics. The findings revealed a positive relationship between institutional pressures, resources, workforce skills, I4.0 adoption, sustainable practices, and the circular economy. However, since the research methodology was solely based on literature and limited by its geographical scope, the authors recommended expanding the research to include more industries and countries in order to enhance the comprehensiveness and practical application of the research framework in real-world supply chain management, particularly in the interaction between I4.0, sustainable manufacturing, and the circular economy (Bag & Pretorius, 2022).

(20) Erboz et al. (2022) applied the Resource-Based View (RBV) theory to analyze the impact of Industry 4.0 (I4.0) on Supply Chain Integration (SCI) and Supply Chain Performance (SCP) in manufacturing companies. Data collected from 212 employees in manufacturing firms in Turkey were analyzed using Structural Equation Modeling (SEM). The results showed that I4.0 had a significant positive impact on both SCI and SCP, with SCI playing a mediating role in this relationship, thus enhancing SCP in modern manufacturing environments. However, the research was limited by the sample scope, which was confined to a single developing country, and future research should expand to other countries to confirm the generalizability of the findings (Erboz et al., 2022).

(21) Münch et al. (2022) focused on identifying the essential capabilities for the digital servitization process to support manufacturing firms in implementing smart product-service systems (PSS). Based on the STS, the research emphasized the relationship between people, technology, and the environment within service systems. Using a multi-case study approach with 18 semi-structured interviews from four manufacturing firms and six supporting experts, the research identified 46 essential capabilities, categorized into six groups: Objectives, People, Culture, Processes, Technology, and Infrastructure. The results indicated that each group encompassed both internal and external capabilities of the firm. While the research focused on large enterprises, limiting its applicability to SMEs, it contributed to the development of a comprehensive framework that helps managers better understand the critical factors in digital service transformation. The research also suggests expanding research to various industries and company sizes to increase the generalizability of the findings (Münch et al., 2022).

(22) Tortorella et al. (2023) used the STS to assess the moderating role of leadership behaviours in the relationship between the maturity level of Industry 4.0 (I4.0) and operational performance in manufacturing organizations. A multivariate data analysis method was applied to data collected from 189 leaders of manufacturing organizations in India and Brazil to test the hypotheses. The results revealed that leadership behaviours focused on task execution and driving change had a significant positive impact on the relationship between technological digitalization and operational performance. In contrast, leadership styles that emphasized relationship-building and fostering change were found to have a negative impact on I4.0 development and digital culture. Due to limitations related to the geographic scope and sample size, the research suggests

expanding future research to better understand the role of leadership in the organizational digitalization process (Tortorella et al., 2023).

(23) The research by Van Dun et al. (2023) draws upon the Unified Theory of Acceptance and Use of Technology (UTAUT) and Social Exchange Theory (Blau, 1964) to explore the impact of transformational leadership on the adoption of Industry 4.0 (I4.0) technologies in manufacturing firms. Employing a case study approach, the research involved field visits and semi-structured interviews with leaders and management personnel from two manufacturing companies based in the Netherlands. The findings indicate that transformational leadership significantly facilitates the adoption of I4.0 technologies through the leaders' organizational leadership style and emotional intelligence. Specifically, the research highlights that leadership behaviours focused on task-oriented goals and fostering change positively influence the acceptance of I4.0, while emotional intelligence enhances interpersonal relationships and organizational support for technological innovation. However, the study's limited geographical scope—restricted to only two companies—prevents the generalization of the results. Therefore, the authors advocate for further research that integrates social factors into the technology acceptance framework to enhance the effectiveness of I4.0 implementation across diverse organizational contexts (van Dun & Kumar, 2023).

(24) The research by Gillani et al. (2024) aims to identify digital transformation (DT) archetypes in organizations while exploring the associated capabilities and value creation. Using the Resource-Based View (RBV) and Sociotechnical Systems (STS) theories, the research proposes an analytical framework encompassing support factors, characteristics, interactions, operational capabilities, and value generation in the context of digitalization. The research employs a combination of literature review and in-depth case analysis of 16 companies, providing valuable insights into the DT process. The findings reveal that key support factors, such as technology, data, human capital, processes, and organizational structure, complement each other in driving digital transformation. Three DT archetypes: (1) process efficiency, (2) responsiveness, and (3) strategic agility—reflect a unique technical-social configuration that enhances business processes and creates value. Although limited by sample size and scope, the research contributes to the development of digital archetypes linking technical-social components, operational capabilities, and business objectives (Gillani et al., 2024).

(25) Thomas et al. (2024) applies the Sociotechnical Systems (STS) theory to explore the key drivers of Knowledge Management (KM) in the context of digital transformation. The research adopts a qualitative research approach, conducting in-depth interviews with nine senior KM experts. Using NVivo 12 software for thematic analysis, the research identifies four key pillars of KM: motivation, technology, human interaction, and organizational factors. From an STS perspective, these elements are interdependent and play a critical role in the effective design of KM in the digital era. While the research is limited by its qualitative approach and small sample size, it provides a relatively comprehensive conceptual framework, emphasizing the integration of both technical and social factors for effective KM implementation during digital transformation (Thomas, 2024).

(26) Hien et al. (2022) investigated the correlation between organizational culture, transformational leadership, and the quality of accounting information systems (AIS) in enterprises under the Ministry of Defense in Vietnam. Drawing on the foundations of the Useful Information Theory, Psychological Theory, and the Benefit-Cost Relationship Theory, the research highlights the critical role of these two factors. A qualitative research approach was employed, including literature synthesis and an analysis of the current state of defence enterprises. The results indicate that organizational culture, with shared values and norms, along with transformational leadership capabilities, positively influences the quality of AIS. Although the research primarily relied on qualitative methods, lacked quantitative data, and had a limited scope, it provides valuable insights into this relationship in the specific context of defence enterprises. The research underscores the significance of organizational culture and transformational leadership in enhancing AIS quality within these organizations (Hien & Phuong, 2022).

(27) Based on the theories of organizational culture, transformational leadership, and the competitive advantage framework, Duc et al. (2024) evaluated the impact of organizational culture and transformational leadership on the competitive advantage of universities in Vietnam. The research collected data from 321 faculty members in Hanoi and Ho Chi Minh City, which was analyzed using SmartPLS software. The findings revealed that both organizational culture and transformational leadership positively influence competitive advantage, with transformational leadership playing a mediating role between organizational culture and competitive advantage. Although the research scope was limited to Hanoi and Ho Chi Minh City, and the sample size was relatively small, the research provides empirical evidence on the role of these two factors in enhancing

competitive advantage within Vietnamese universities. The research emphasizes the importance of fostering a positive organizational culture and developing transformational leadership to improve competitive advantage for universities (Duc & Mui, 2024).

A synthesis of related studies indicates a gap in the development of a comprehensive research framework addressing the factors influencing the adoption of Industry 4.0 technologies in enterprises, particularly the role of transformational leadership within both technical and social elements. Therefore, this study proposes a new research framework aimed at providing a more comprehensive perspective for researchers, business leaders, and relevant authorities, tailored to specific application contexts.

3. Proposed research framework and research hypotheses

3.1 Proposed Research Framework

After reviewing previous studies by the authors Appelbaum et al., 1997; Sawyer et al., 2003; Geels et al., 2004; Gumusluoglu et al., L., & Ilsev, A., 2009; Davis et al., 2014; Bagga et al., 2024; Van Dun, 2017; Rossini et al., 2019; Mohelska et al., 2018; Birkel et al., 2019; Qureshi et al., 2019; Agostini et al., 2020; Chonsawat et al., 2020; Adebanjo et al., 2021; Ukobitz et al., 2021; Lee et al., 2022; Marcon et al., 2022; Kumar et al., 2022; Liu et al., 2022; Bag et al., 2022; Erboz et al., 2022; Münch et al., 2022; Tortorella GP et al., 2023; van Dun et al., 2023; Gillani et al., 2024; Thomas et al., 2024; Hien et al., 2022; Duc et al., 2024, the author has summarized the factors affecting the application of Industry 4.0 in the following table:

Table 1: Summary of factors from previous studies and proposed research factors

Reseach	Market Pressure (MP)	External Support (EX)	Employee Engagement (EP)	Process/ Procedure (PP)	Technology Infrastructure (TI)	Organizational Culture (OC)	Transformational Leadership (TL)
1.	X	X	X		X	X	X
2.	X	X	X	X	X		
3.	X	X	X	X	X	X	
4.		X				X	X
5.		X	X	X	X	X	
6.							X
7.		X	X	X	X		
8.						X	
9.	X	X			X	X	X
10.	X	X	X	X	X	X	
11.		X	X	X	X	X	X
12.			X	X	X	X	X
13.		X	X	X	X		
14.	X	X	X		X	X	
15.	X		X	X			X
16.			X	X	X	X	
17.	X	X	X		X	X	
18.	X					X	X
19.	X	X	X	X			
20.			X		X	X	
21.		X	X	X	X	X	
22.					X		X
23.			X		X		X
24.			X	X	X	X	
25.	X	X	X		X	X	X
26.						X	X
27.						X	X
28. Author's recomm	X-new	X-new	X-new	X-new	X-new	X-new	X-new

Reseach	Market Pressure (MP)	External Support (EX)	Employee Engagement (EP)	Process/ Procedure (PP)	Technology Infrastructure (TI)	Organizational Culture (OC)	Transformational Leadership (TL)
endation							

(Source: Author's synthesis)

3.2. Research hypotheses

Market pressure refers to the external environmental forces that compel organizations to continuously innovate and adapt in order to maintain competitiveness. This includes fluctuations in customer demand, market trends, competitive pressures, and technological advancements (Mustafa et al., 2023). Under market pressure, organizations must not only react swiftly but also develop creative processes and solutions to meet the complex demands of the business environment (Ng et al., 2011). Market pressure plays a crucial role in encouraging organizations to invest in advanced technologies associated with Industry 4.0 to achieve higher efficiency and optimize processes (Zhong & Moon, 2023). As competition intensifies, organizations are compelled to seek innovative solutions to enhance their competitive advantage, improve technical capabilities, and boost digital transformation to meet customer expectations (Gangwani & Bhatia, 2024; Sony & Naik, 2020). Therefore, environmental pressures can influence technology strategies by requiring the rapid deployment of advanced technologies, such as AI and the IoT, thereby accelerating technological integration (Baxter & Sommerville, 2011; Li et al., 2020). In general, organizations that successfully adopt Industry 4.0 in response to market pressures tend to gain sustainable competitive advantages, providing a foundation for long-term development. Based on this, the author proposes the following research hypothesis:

Hypothesis H_1: Higher market pressure will promote the adoption of Industry 4.0 technologies.

Support from stakeholders helps organizations optimize their digital transformation processes, thereby minimizing risks and costs when implementing Industry 4.0 technologies (Sony & Naik, 2020). Additionally, varying demands from stakeholders have driven companies to enhance the quality of their products and services (Abdullah et al., 2022). For example, pressure from stakeholders and the green marketing trend not only improve financial performance but also enhance environmental efficiency when new technologies are adopted (Ijaz Baig & Yadegaridehkordi, 2023). Collaborating with research institutes and universities allows companies to strengthen their technological capabilities and access new knowledge, while support from organizations in establishing international standards encourages businesses to participate in global value chains (Fedyunina et al., 2024). Furthermore, external support such as information and technical consulting, financing, and legal frameworks play a critical role in the successful deployment and integration of new technologies, helping to reduce investment risks and costs, while also enhancing competitiveness (Avis, 2018; Baxter & Sommerville, 2011; Li et al., 2020; Mohamad & Songthaveephol, 2020; Ng et al., 2011) in the context of Industry 4.0. Therefore, the author proposes the following research hypothesis:

Hypothesis H_2: External support positively impacts the adoption of Industry 4.0 technologies.

Due to their ability to inspire and motivate innovation, transformational leadership is considered a critical factor in driving employee engagement in the adoption of Industry 4.0 technologies (Bohari et al., 2024; van Dun & Kumar, 2023). By fostering an open culture and encouraging empowerment, transformational leaders not only reduce resistance but also increase employee responsibility and commitment to technological initiatives, thereby enhancing job performance and satisfaction (F. Emery, 1993; E. L. Trist & Bamforth, 1951). Support from senior management enables employees to engage in strategy development, continuous learning, and the acquisition of relevant digital skills, optimizing the effectiveness of technology implementation and contributing to the sustainable development and competitiveness of the organization (Mohamad & Songthaveephol, 2020; Zhong & Moon, 2023). The alignment of technical and social elements ensures long-term success in Industry 4.0 (Belak & Ušljebrka, 2014). Therefore, the author proposes the following research hypothesis:

Hypothesis H_3: Transformational leadership positively influences employee engagement in the adoption of Industry 4.0 technologies.

Internal processes and procedures play a crucial role in the ability and speed of adopting Industry 4.0 technologies, directly influencing an organization's competitive drive (Zhong & Moon, 2023). These processes and procedures must be flexible and adaptive to fully leverage advanced technologies such as automation, AI, and Data

Analytics (Li et al., 2020; Sony & Naik, 2020). Transformational leadership is pivotal in restructuring organizational processes and enhancing flexibility, and adaptability to meet the rapid pace of technological advancements, thus creating an environment conducive to continuous improvement and innovation, consistent with the STS (E. L. Trist & Bamforth, 1951; W. Zheng et al., 2010). Strategic orientation and encouragement of cross-functional collaboration from leadership not only promote innovation but also ensure the effective deployment of new technologies (Birasnav, 2014). Support from senior management in investing in research and development and applying lean processes ensures that the organization possesses the necessary resources and strategic alignment to implement Industry 4.0 effectively (Yüksel, 2022). Therefore, the author proposes the following research hypothesis:

Hypothesis H_4: Transformational leadership positively influences processes and procedures in the adoption of Industry 4.0 technologies

The technical infrastructure is a critical foundation for the successful deployment of Industry 4.0 technologies, ensuring connectivity and integration across processes, departments, and devices (Avis, 2018; Baxter & Sommerville, 2011). It not only enhances operational efficiency but also strengthens security and risk management, thus ensuring long-term competitiveness in a digitized environment (Sony & Naik, 2020). A robust infrastructure with secure data storage is essential for maintaining data integrity and availability, and supporting big data analytics and artificial intelligence in decision-making processes (Li et al., 2020; Nzumile et al., 2024). Leadership must assess the compatibility between existing infrastructure and new technological demands, creating an optimal technical environment that supports and sustains effective technology implementation. Transformational leadership plays a strategic role in optimizing technical infrastructure through investment decisions, ensuring compatibility with new technologies, promoting workforce training, improving processes, and driving sustainable development, thereby achieving strategic goals (Akçay Kasapoglu, 2018; Balahurovska, 2023; Behie et al., 2023; Blaginin et al., 2018). Therefore, the author proposes the following research hypothesis:

Hypothesis H_5: Transformational leadership positively influences technological infrastructure in the adoption of Industry 4.0 technologies.

Organizational culture refers to the shared values, beliefs, and norms that shape behaviour and guide activities within an organization. In the context of Industry 4.0, organizational culture plays a crucial role in achieving employee commitment and ensuring effective technology adoption (Liu et al., 2022). A flexible and open culture enables companies to rapidly adapt to new technologies, foster creativity, and promote continuous learning, thereby enhancing competitiveness and work performance (Durana et al., 2019; Kafetzopoulos & Katou, 2024). Organizational culture influences employee participation, commitment, and satisfaction, reduces resistance to change, and facilitates the successful implementation of new technologies (Niemetz et al., 2013; Okatan & Alankuş, 2017; Research, 2014). The alignment between organizational culture and digital strategy helps organizations overcome challenges in technology integration, ensuring sustainable development and adaptability in a dynamic business environment (Veile et al., 2020; Villena-Manzanares et al., 2020). Therefore, establishing a culture that supports innovation and flexibility is essential for success in the era of Industry 4.0 (Chonsawat & Sopadang, 2020; McCunn & Gifford, 2014). Based on this, the author proposes the following research hypothesis:

Hypothesis H_6: Organizational culture positively influences the adoption of Industry 4.0 technologies.

The STS theory emphasizes the importance of organizational culture in aligning social, technical, and work environment elements to achieve higher levels of Industry 4.0 technology adoption (Marcon et al., 2022). For example, in educational settings, cultural incompatibility has led to failures in adopting new technologies (Steven, 1996). A flexible and open organizational culture fosters collaboration and creativity, reducing resistance to change and enhancing the effectiveness of technology implementation (Veile et al., 2020). Therefore, organizational culture not only supports but also moderates the relationship between technological infrastructure and Industry 4.0 adoption, ensuring the optimization of technological potential and maintaining competitiveness (Liu et al., 2022). Based on this, the author proposes the following research hypothesis:

Hypothesis H_{7a}: Organizational culture moderates the relationship between technological infrastructure and the adoption of Industry 4.0 technologies.

Additionally, organizational culture influences processes and procedures, directly affecting performance, flexibility, commitment, and change management within an organization (Agostini & Filippini, 2019). A positive organizational culture can facilitate the implementation of Industry 4.0 by aligning internal processes and fostering an environment conducive to technological advancement (Piyathanavong et al., 2024). The alignment between cultural values and the principles of Industry 4.0 helps optimize process efficiency and encourages continuous innovation (Grau & Moormann, 2013; Liu et al., 2022). Therefore, recognizing and adjusting organizational culture

is a crucial strategy to ensure success, consistency, and alignment in organizational processes. Based on this, the author proposes the following research hypothesis:

Hypothesis H_{7b}: Organizational culture positively impacts the relationship between processes/procedures and the adoption of Industry 4.0 technologies.

Furthermore, organizational culture significantly moderates the relationship between employee engagement and commitment to the adoption of Industry 4.0. A positive, flexible, and open organizational culture fosters active support and involvement from employees in implementing new technologies (Agostini & Filippini, 2019; Liu et al., 2022). Social responsibility and employee skills are also crucial for Industry 4.0, as they enable individuals to play a central role in the adoption of technology, guiding technological progress within organizations (De Camargo et al., 2023). Organizational culture supports collaboration, and knowledge sharing, and promotes creative thinking, creating a favourable environment for innovation and adaptation to digital demands (Baxter & Sommerville, 2011; Belak & Ušljebrka, 2014). Therefore, developing and maintaining a strong organizational culture is vital to optimize employee engagement and ensure success in the adoption of Industry 4.0 technologies (Sony & Naik, 2020). Based on this, the author proposes the following research hypothesis:

Hypothesis H_{7c}: Organizational culture positively impacts the relationship between employee engagement and the adoption of Industry 4.0 technologies.

The author has reviewed and synthesized relevant studies to explore the factors influencing the adoption of Industry 4.0, particularly focusing on the impact of transformational leadership on elements of the STS framework in the context of Industry 4.0 adoption, with organizational culture acting as a mediating factor. From this synthesis, the author proposes a conceptual model illustrating the impact of the seven key factors in driving the acceptance and implementation of Industry 4.0 technologies, as shown in the following figure (Figure 1).

(Source: Author's construction)

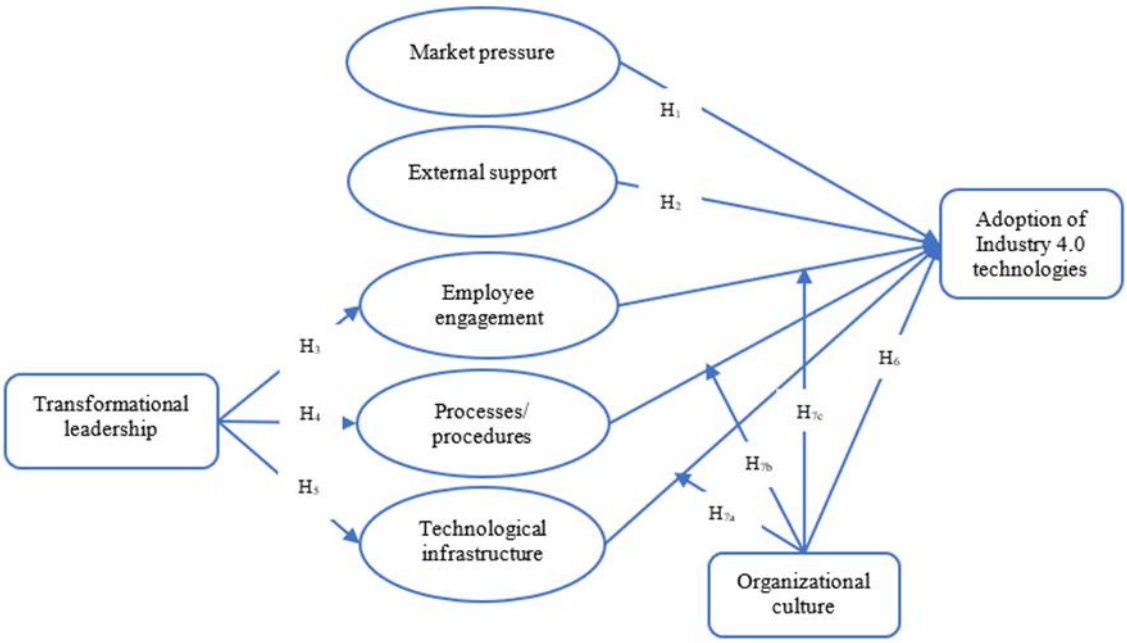

Figure 1: Proposed research framework

4. Conclusion and future research directions

In the context of the rapid technological advancements today, organizations face intense competitive pressures that necessitate the integration of advanced technological infrastructures to sustain and enhance their competitive advantage (Schwab, 2016). The implementation of Industry 4.0 involves not only investment in technology but also requires a fundamental transformation in operational processes and active participation from employees at all levels within the organization (Lassi & Sonnenwald, 2013). According to the STS, the interaction between social and technical elements is a prerequisite for success (E. L. Trist & Bamforth, 1951).

Transformational leadership plays a crucial role in guiding this change, having a profound impact on both the social and technical systems, thereby fostering innovation and enhancing organizational performance (Bass,

2006). This leadership style focuses not only on improving processes but also on inspiring employees to actively engage in the digital transformation process (Northouse, 2021), aligning personal values with organizational goals, and creating a flexible and creative work environment (Liaqat & Ullah, 2024). Furthermore, external factors such as market pressures and external support influence an organization's strategy in adopting Industry 4.0 technologies. Organizational culture serves as a regulating mechanism, ensuring alignment between social and technical components to achieve common objectives (Schein, 2010).

This research model demonstrates that successful implementation of Industry 4.0 requires a harmonious system between organizational leadership, technology, and social factors. Transformational leadership leverages the organization's STS framework to improve processes in adopting advanced technologies. However, further research is needed to explore the long-term impact of transformational leadership on technology adoption and process improvement, particularly regarding employees' adaptability and resilience to rapid technological changes (Norman & Pahlawati, 2024). Future studies should focus on examining the interactive relationship between transformational leadership, organizational culture, and employees' adaptive capacity to ensure sustainable success in the digital.

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