EasyChair Preprint

№ 14316

Intelligent Integration and Deployment Challenges in Industry 4.0: Insights from the TOE Framework

Thiago Augusto Aniceski Cezar, Lorene Thalia Pontes Miranda, Dalton Alexandre Kai, Thalinne Trindade Padilha, João Henrique Tomaz Dutra, Gabriel Lucas Bandeira and Guilherme Brittes Benitez

August 6, 2024

Intelligent Integration and Deployment Challenges in Industry 4.0: Insights from the Technology-Organisation-Environment Framework

Thiago Augusto Aniceski Cezar[1], Lorene Thalia Pontes Miranda[1], Dalton Alexandre Kai[1], Thalinne Trindade Padilha[1], João Henrique Tomaz Dutra[1], Gabriel Lucas Bandeira[1] and Guilherme Brittes Benitez[1]
[1] Industrial and Systems Engineering Graduate Program, Pontifical Catholic University of Parana, Curitiba PR, Brazil.
thiago.aniceski@pucpr.edu.br, guilherme.benitez@pucpr.br

Abstract

Companies are struggling to thrive in the evolving industry, marked by the Industry 4.0 revolution, driven by technologies such as the Internet of Things, Artificial Intelligence, Cloud Computing, Big Data, among others. The integration of these innovations is challenging due to internal and external barriers, such as budget constraints, employee resistance, technical skills gaps, and traditional organisational culture. The primary objective of the study is to analyse the barriers that companies face during the deployment of Industry 4.0 technologies and how these barriers impact the expected outcomes. It uses secondary data from a survey conducted by the Brazilian National Confederation of Industry (CNI) with 1,691 companies to establish a connection between these barriers and the Brazilian industrial landscape. The study provides insights into the challenges that hinder the progress of Industry 4.0 and informs strategic decision-making in the context of the Four Smarts: Smart Products, Smart Manufacturing, Smart Supply Chain, and Smart Working. It emphasises the importance of overcoming barriers for a successful adoption of Industry 4.0 and highlights the relevance of the TOE framework in analysing these issues.

Keywords: Industry 4.0; Four Smarts; Internal barriers; External barriers; TOE framework

1. Introduction

In recent years, the concept of Industry 4.0 (I4.0) has emerged as a revolutionary paradigm reshaping the global industrial landscape. This phenomenon represents the next stage in the evolution of manufacturing, driven by the convergence of cutting-edge technologies [1]. Companies have actively sought the adoption of I4.0 technologies due to the wide range of benefits and opportunities that this approach offers [2].

While I4.0 promises substantial technological advancement, companies encounter numerous barriers during its adoption and implementation [3] [4]. Notably, internal barriers pose significant challenges. One crucial concern is the organisational resistance to change, where employees may apprehend the replacement of human tasks with automation, leading to discomfort and uncertainty regarding the future of their roles [5].

At the same time, external barriers also pose challenges. Regulation and compliance with government standards can be an obstacle, especially in highly regulated sectors [6]. The need to adhere to stringent data security and privacy requirements can delay the implementation of innovative technologies [7]. Therefore, the presence of internal and external barriers can impact the realisation of the expected benefits of I4.0 technologies. According to [8], only four out of ten companies made good progress in moving towards Industry 4.0, and most companies either made no progress or had limited progress due to various challenges in implementing I4.0 technologies.

Despite ongoing debates on this topic, it is still unclear what the influence is when internal and external barriers are present in organisations that have adopted technologies related to the 'Four Smarts'.

Therefore, this study aims to examine how internal and external barriers affect organisations that have implemented I4.0 technologies focused on the 'Four Smarts' for distinct objectives. To achieve this purpose, our research focuses on the following question: What influence do internal and external barriers have on organisations that have adopted Industry 4.0 technologies, particularly concerning the Four Smarts, in achieving benefits related to environmental and social aspects, operational performance, and a higher degree of innovation?

To address this research question, we adopted the Technology-Organisation-Environment (TOE) framework as an analytical framework to explore the relationship between the deployment of I4.0 technologies and the presence of barriers, both internal (related to the organisation) and external (related to the environment). To do this, we used data from an extensive survey conducted by the Brazilian National Confederation of Industry (CNI) published in 2022, which focused on adopted I4.0 technologies and associated barriers in the Brazilian industry.

2. Theoretical background and hypotheses development

Using the TOE model as a reference, the factors influencing technology adoption in I4.0 can be categorised into three main domains: within the technological factors, the specific characteristics of the technology are considered, such as its complexity, compatibility with existing systems, perceived advantages, ease of use, and flexibility [9]. Organisational factors are related to the organisation's internal structure, including organisational culture, capacity for innovation absorption, supportive

leadership, availability of financial and human resources, and existing organisational processes [10]. Finally, Environmental factors encompass the organisation's external environment, such as government regulations, competitive pressures, customer and business partner expectations, and market trends [11]. We suggest that the TOE framework can serve as a theoretical framework to deepen our understanding of the factors constraining and influencing the industry's outcomes in a developing country like Brazil. This approach will enable us to examine the outcomes resulting from the barriers faced by organisations in the Brazilian industry that already adopted I4.0 technologies.

2.1 The Four Smarts of Industry 4.0 and Technology dimension

The 'Four Smarts' of Industry 4.0, encompassing the principles of Smart Manufacturing, Smart Products, Smart Supply Chain, and Smart Working, represent the essential foundations of contemporary industrial transformation [12]. Within the realm of Smart Manufacturing, advanced automation, the Internet of Things (IoT), and real-time data analytics play a central role in creating highly adaptable and interconnected production environments [1]. Concerning Smart Products, IoT sensors, artificial intelligence (AI), and machine learning converge, enabling data collection, learning usage patterns, and intelligent responses, resulting in customised and interactive products [13]. In the Smart Supply Chain context, technologies such as blockchain, IoT, and big data analytics are employed to establish transparent and efficient supply chains, allowing real-time tracking and optimised inventory management [14]. Finally, Smart Working utilises augmented reality (AR), virtual reality (VR), and advanced data analytics to create innovative and secure work environments, enhancing operational efficiency and ensuring safer and more productive workplaces [5]. These intricate interactions among technologies are pivotal in successfully implementing the 'Four Smarts', emphasising the significance and depth of digital transformation in Industry 4.0.

In TOE perspective, the technology dimension explains the characteristics of the technology itself, including its functionality, complexity, compatibility with existing systems that enables the 'Four Smarts' for organisations. Organisations must conduct a detailed analysis of specific technological characteristics in implementing these smarts, such as complexity, compatibility, perceived advantages, ease of use, and flexibility. This analysis is crucial to ensure the successful adoption and deployment of I4.0 technologies. This set of outcomes leads us to the hypothesis below:

H1. The adoption of Industry 4.0 technologies associated with Smart Products, Smart Manufacturing, Smart Supply Chain, and Smart Working led companies to achieve the following benefits: (a) Environmental and Social aspects, (b) Operational performance, and (c) Innovation.

2.2 Internal barriers for the Four Smarts and Organisation dimension

Research indicates that implementing Industry 4.0 is a complex process, and many companies in different countries face challenges due to various barriers [15]. Internal barriers within organisations constitute the obstacles, challenges, and resistances that arise within the company's structure during innovation processes or the

adoption of new technologies [16]. These barriers can manifest in various ways, including employee resistance, lack of skills or knowledge necessary for implementation, rigidity in organisational culture, ineffective leadership, and scarcity of financial or technological resources. When organisations face internal barriers such as employee resistance, lack of technical skills, traditional organisational culture, or lack of support from top management, adopting and deploying new technologies can be delayed or even halted.

The internal barriers organisations face is inherently connected to the organisational factors outlined by the TOE model. When a company encounters internal challenges in adopting and deploying technologies, these difficulties are often linked to its organisational structure, culture, resources, and existing processes [17]. Implementing a new technology often requires a complete overhaul of organisational processes. If leaders do not demonstrate commitment or do not emphasise the importance of innovation, employees lack motivation to accept new technologies.

H2. The presence of internal barriers associated with Lack of infrastructure and knowledge, Economic aspects, and Cultural factors hampers the deployment of Industry 4.0 technologies and consequently their outcomes: (a) Environmental and Social aspects, (b) Operational performance, and (c) Innovation.

2.3 External barriers for the Four Smarts and Environment dimension

The external barriers in organisations consist of elements derived from the external environment that can either facilitate or hinder the deployment of new technologies. These barriers are rooted in factors coming from the external environment, encompassing government regulations, public policies, market competition, customer expectations and demands, social acceptance, and economic conditions. Government regulations can impose specific restrictions on the type of technology a company can adopt, while market competitive pressure encourages organisations to embrace innovations to maintain their relevance and competitiveness [11].

The external barriers organisations face can be analysed through the environment dimension of the TOE framework. In this context, the external environment encompasses various elements such as government regulations, market competition, customer expectations, social acceptance, and economic conditions. When an organisation encounters challenges in these areas, it hampers the adoption and deployment of new technologies.

H3. The presence of external barriers associated with technical norms, lack of partnerships and support, and lack of infrastructure and skills hampers the deployment of Industry 4.0 technologies and consequently their outcomes: (a) Environmental and Social aspects, (b) Operational performance, and (c) Innovation.

3. Research method

Our study utilises secondary data from a Special Survey on Industry 4.0 organised by the Brazilian National Confederation of Industry [18]. CNI serves as the primary representative body for the Brazilian industry, advocating and promoting

public policies that support entrepreneurship and industrial production. It represents 27 state federations of industry and 1,280 trade unions, with almost 700 thousand companies affiliated. This extensive survey was conducted five years after Special Survey No. 66, which in 2016 gathered data concerning the expected benefits of Industry 4.0 for the Brazilian industry. The survey population comprises exclusively companies engaged in production activities, encompassing transformation and extractive sectors. CNI collected 1,691 responses from enterprises, with 40.46% classified as small, 35.89% as medium, and 23.65% as large industrial companies across 27 sectors in Brazil.

The survey questionnaire comprises four main groups of questions: (i) Adoption of Industry 4.0 Technologies, encompassing a list of 18 digital technologies; (ii) Achieved Benefits, featuring a list of 11 benefits derived from the adoption of digital technologies; (iii) Internal Barriers, including a list of eight barriers associated with technology adoption; and (iv) External Barriers, incorporating a list of seven barriers associated with technology adoption.

4. Results and Discussion

We adopted the TOE framework as a theoretical lens to elucidate the relationship between deploying I4.0 technologies and the internal (organisational) and external (environmental) barriers. Our principal finding highlights that for enterprises that have already embraced I4.0 technologies to enable the 'Four Smarts', internal barriers exert a more pronounced influence on their pursuit of benefits. This finding is particularly promising, suggesting that external barriers are more challenging for companies that have not yet adopted I4.0 technologies.

In essence, organisations already equipped with I4.0 technologies are not significantly swayed in their outcomes by external barriers related to technical norms, the absence of partnerships and support, and deficiencies in infrastructure and workforce skills. This observation reflects prior I4.0 and sociotechnical systems research [19] [20], which underscored the pivotal role of the external environment in influencing the decision to adopt or forgo technologies. However, as articulated by [21] [22], when companies have already integrated I4.0 technologies, the deployment phase appears relatively impervious to these external barriers. In essence, this implies that enterprises equipped with I4.0 technologies have effectively addressed external factors that could impact their outcomes, and these are not decisive factors in impeding their technology deployment. Conversely, when confronting internal barriers, companies face challenges during the deployment phase, which directly influences their outcomes.

Furthermore, our study unveiled a direct negative association with Smart Manufacturing, which can be attributed to companies' tendencies to concentrate on operational improvements such as productivity, quality, lead time, and takt time [1][23].

Moreover, our research revealed a negative association with cultural factors, implying that organisations with rigid organisational cultures or challenges in integrating new technologies do not represent significant obstacles to achieving environmental and social outcomes. This suggests that companies may have effectively surmounted this obstacle when adopting I4.0 technologies, rendering it a less critical determinant of

their sustainable outcomes. The negative association of external barriers, such as the lack of partnerships and support, indicates that companies focusing on Smart Products solutions are less likely to have their sustainable outcomes undermined by this barrier. [24] elucidate that Smart Products solutions facilitate companies' interactions with internal and external customers, rendering the company more responsive and efficient in its processes, enhancing sustainable outcomes. Finally, although concerns and benefits may exhibit similarities, small enterprises may encounter additional challenges, such as higher implementation costs relative to their scale and limited resources to invest in Industry 4.0 technologies, such as smart supply chains. However, through appropriate strategies and collaborative partnerships, small businesses can harvest the expected benefits within the context of Industry 4.0 [25] [26] [27] [28] [29].

5. Conclusion

The study delves into the challenges companies face in deploying Industry 4.0 (I4.0) technologies associated with the 'Four Smarts'. Employing the Technology-Organisation-Environment perspective as the theoretical framework, the research examines the technology (T), organisation (O), and environment (E) dimensions. By scrutinising the implications of these technologies for pursued benefits, particularly in the face of internal and external barriers, this study contributes to ongoing discussions on technology integration. However, it's important to note that using CNI data may constrain the outcomes to the specific context of the Brazilian industry. While the CNI data offers industrial national representativeness, caution should be exercised when attempting to extrapolate the findings to other countries. There is significant potential for future research to expand upon this study. For instance, exploring strategies to overcome the challenges associated with deploying the 'Four Smarts' amidst barriers could be a fruitful area of investigation. Additionally, studying the synergy among the 'Four Smarts' to overcome such obstacles and implement human-centric systems presents another promising avenue for inquiry.

References

1. Frank, A. G., Dalenogare, L. S. and Ayala, N. F. 2019. “Industry 4.0 technologies: Implementation patterns in manufacturing companies”. *International Journal of Production Economics* 210: 15–26.
2. Machado, C. G., Winroth, M. P. and Ribeiro da Silva, E. H. D. 2020. “Sustainable manufacturing in Industry 4.0: an emerging research agenda”. *International Journal of Production Research* 58 (5): 1462–1484.
3. Senna, P. P., Ferreira, L. M. D., Barros, A. C., Roca, J. B. and Magalhães, V. 2022. “Prioritizing barriers for the adoption of Industry 4.0 technologies”. *Computers and Industrial Engineering* 171.
4. Benitez, G. B., Ghezzi, A. and Frank, A. G. 2023. “When technologies become Industry 4.0 platforms: Defining the role of digital technologies through a boundary-spanning perspective”. *International Journal of Production Economics* 260: 108858.
5. de Assis Dornelles, J., Ayala, N. F. and Frank, A. G. 2022. “Smart Working in Industry 4.0: How digital technologies enhance manufacturing workers’ activities”. *Computers and Industrial Engineering* 163.

6. Mathivathanan, D., Mathiyazhagan, K., Rana, N. P., Khorana, S. and Dwivedi, Y. K. 2021. “Barriers to the adoption of blockchain technology in business supply chains: a total interpretive structural modelling (TISM) approach”. *International Journal of Production Research* 59 (11): 3338–3359.
7. Horváth, D., and Szabó, R. Z. 2019. “Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?”. *Technological forecasting and social change* 146: 119-132.
8. Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A. B. L. and Rajak, S. 2020. “Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective”. *International Journal of Production Economics* 224.
9. Tabim, V. M., Ayala, N. F. and Frank, A. G. 2021. “Implementing Vertical Integration in the Industry 4.0 Journey: Which Factors Influence the Process of Information Systems Adoption?” *Information Systems Frontiers*.
10. Rahman, M., Kamal, M. M., Aydin, E. and Haque, A. U. 2022. “Impact of Industry 4.0 drivers on the performance of the service sector: comparative study of cargo logistic firms in developed and developing regions”. *Production Planning and Control* 33 (2–3): 228–243.
11. Nayernia, H., Bahemia, H. and Papagiannidis, S. 2022. “A systematic review of the implementation of industry 4.0 from the organisational perspective”. *International Journal of Production Research* 60 (14): 4365–4396.
12. Meindl, B., Ayala, N. F., Mendonça, J. and Frank, Ag. G. 2021. “The four smarts of Industry 4.0: Evolution of ten years of research and future perspectives”. *Technological Forecasting and Social Change* 168.
13. Porter, M. E. and Heppelmann, J. E. 2014. How smart, connected products are transforming competition. *Harvard business review*, *92*(11), 64-88.
14. Lerman, L. V., Benitez, G. B., Müller, J. M., de Sousa, P. R. and Frank, A. G. 2022. “Smart green supply chain management: a configurational approach to enhance green performance through digital transformation”. *Supply Chain Management: An International Journal* 27 (7): 147–176.
15. Benitez, G. B., Ayala, N. F. and Frank, A. G. 2020. “Industry 4.0 innovation ecosystems: An evolutionary perspective on value cocreation”. *International Journal of Production Economics* 228.
16. Parente, S., L. and Prescott, E. C. 1994. “Barriers to Technology Adoption and Development”. *Journal of Political Economy* 102 (2): 298–321.
17. Ghobakhloo, M. 2020. “Determinants of information and digital technology implementation for smart manufacturing”. *International Journal of Production Research* 58 (8): 2384–2405.
18. CNI - Confederação Nacional da Indústria, 2022. Industry 4.0: Five Years Later. Available at: https://static.portaldaindustria.com.br/media/filer_public/e6/84/e6846537-db7b-4694-b031-cf9ed814f6e1/special_survey_industry_40_april2022.pdf
19. Marcon, É., Soliman, M., Gerstlberger, W. and Frank. A. G. 2022. “Sociotechnical factors and Industry 4.0: an integrative perspective for the adoption of smart manufacturing technologies”. *Journal of Manufacturing Technology Management* 33 (2): 259–286.
20. Almeida, R. P., Ayala, N. F., Benitez, G. B., Kliemann Neto, F. J., and Frank, A. G. 2023. How to assess investments in industry 4.0 technologies? A multiple-criteria

framework for economic, financial, and sociotechnical factors. *Production Planning & Control*, 34(16): 1583-1602.

21. da Silva, V. L., Kovaleski, J. L., Pagani, R. N., Silva, J. D. M. and Corsi, A. 2020. "Implementation of Industry 4.0 concept in companies: empirical evidences". *International Journal of Computer Integrated Manufacturing* 33 (4): 325–342.
22. Kamble, S. S., Gunasekaran, A. and Sharma, R. 2018. "Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry". *Computers in Industry* 101: 107–119.
23. Tardio, P. R., Schaefer, J. L., Nara, E. O. B., Gonçalves, M. C., Dias, I. C. P, Benitez, G. B. and de Castro, A. 2023. "The link between lean manufacturing and Industry 4.0 for product development process: a systemic approach". *Journal of Manufacturing Technology Management*.
24. Biondo, D., Kai, D. A., Pinheiro de Lima, E., and Benitez, G. B. 2024. The contradictory effect of lean and industry 4.0 synergy on firm performance: a meta-analysis. *Journal of Manufacturing Technology Management*, 35(3), 405-433.
25. da Silva, N. A., Abreu, J. L., Orsolin Klingenberg, C., Antunes Junior, J. A. V., and Lacerda, D. P. 2022. "Industry 4.0 and micro and small enterprises: systematic literature review and analysis". *Production & Manufacturing Research*, *10*(1), 696-726.
26. Benitez, G. B., Lima, M. J. D. R. F., Lerman, L. V., and Frank, A. G. 2019. "Understanding Industry 4.0: Definitions and insights from a cognitive map analysis", *Brazilian Journal of Operations & Production Management* [recurso eletrônico]. Rio de Janeiro, RJ. Vol. 16, no. 2 (June 2019), p. 192-200.
27. Kai, D.A., Jesus, É.T.D., Pereira, E.A.R., Lima, E.P.D., Tortato, U. 2017. Influence of organisational characteristics in sustainability corporate strategy. Int. J. Agile Syst.Manag. 10(3–4): 231–249.
28. Kai, D.A., de Jesus, É.T., Pereira, E.A., de Lima, E.P., Tortato, U. 2016. Influence of organizational characteristics in the sustainability strategy. In: ISPE TE, 176–185.
29. Kai, D.A., de Lima, E.P., Cunico, M.W.M., da Costa, S.G. 2016. Additive manufacturing: a new paradigm for manufacturing. In: Proceedings of the 2016 Industrial and Systems Engineering Research Conference, Availability, Development, 14: 102.