El Colegio de la Frontera Norte
FRONTERA NORTE
e-ISSN: 2594-0260
Revista internacional de fronteras, territorios y regiones / International Journal of Borders, Territories and Regions

FRONTERA NORTE VOL. 37, ART. 01, 2025
e-ISSN 2594-0260 https://doi.org/10.33679/rfn.v1i1.2383

Are Maquiladora Localities Ready to Implement Industry 4.0?

¿Están listas las maquiladoras para implementar la Industria 4.0?

Eduardo Arriola Ruiz,[1] Redi Gomis Hernández,[2]
& Jorge Carrillo[3]

ABSTRACT
This article analyzes and compares the knowledge and implementation of Industry 4.0 (I4.0) technologies in maquiladoras in Tijuana and Ciudad Juárez through a descriptive quantitative approach. Online surveys were conducted with manufacturing sector workers to assess their familiarity with and practical application of 19 specific technologies. The results show that, while knowledge levels are moderate, practical adoption of these technologies remains limited, with Ciudad Juárez showing a slight advantage. The findings highlight the importance of improving I4.0 training to enable more effective implementation and support technological transformation in these border regions. Although the study's geographical scope is limited, it is recommended that future research encompass a wider diversity of industrial contexts. This research contributes to the understanding of the transition towards I4.0 and provides valuable insights for designing policies aimed at technological training in the sector.

Keywords: 1. Industry 4.0, 2. maquiladoras, 3. engineers, 4. Ciudad Juárez, 5. Tijuana.

RESUMEN
En este artículo se analiza y compara el conocimiento y la implementación de tecnologías de la Industria 4.0 (I4.0) en maquiladoras de Tijuana y Ciudad Juárez, mediante un enfoque cuantitativo descriptivo. Se realizaron encuestas en línea a trabajadores del sector manufacturero para evaluar su dominio y aplicación de 19 tecnologías específicas. Los resultados muestran que, aunque el conocimiento es moderado, la adopción práctica de estas tecnologías sigue siendo limitada, con un ligero avance en Ciudad Juárez. Los hallazgos destacan la importancia de mejorar la capacitación en la I4.0 para facilitar una implementación más efectiva y apoyar la transformación tecnológica en estas regiones fronterizas. Si bien el alcance geográfico del estudio es limitado, se recomienda que futuras investigaciones abarquen una mayor diversidad de contextos industriales. Esta investigación contribuye al conocimiento sobre la transición hacia la I4.0 y proporciona información útil para el diseño de políticas de capacitación tecnológica en el sector.

Palabras clave: 1. Industria 4.0, 2. maquiladoras, 3. ingenieros, 4. Ciudad Juárez, 5. Tijuana.

Received: February 13, 2024
Accepted: May 9, 2024
Available online: January 15, 2025

[1] Universidad Autónoma de Ciudad Juárez (https://ror.org/05fj8cf83), eduardo.arriola@uacj.mx, https://orcid.org/0000-0002-0037-0621

[2] El Colegio de la Frontera Norte (https://ror.org/04hft8h57), rgomis@colef.mx, https://orcid.org/0000-0002-1515-3929

[3] El Colegio de la Frontera Norte (https://ror.org/04hft8h57), carrillo@colef.mx, https://orcid.org/0000-0002-8533-2797

Frontera Norte is an annual digital journal edited by El Colegio de la Frontera Norte.
https://fronteranorte.colef.mx/

INTRODUCTION

This article analyzes and compares the expertise levels of manufacturing companies and their suppliers in Tijuana and Ciudad Juárez regarding Industry 4.0 (I4.0) technologies, as well as the degree of technological implementation achieved. The objective is to identify similarities and differences in these aspects between two major industrial hubs historically linked to the maquiladora industry.

Additionally, this study builds upon and complements previous research by Carrillo et al. (2020) and Arriola Ruiz (2022), which evaluated the expertise and adoption of I4.0 technologies in manufacturing companies in Tijuana and Ciudad Juárez, respectively. Additionally, it expands on the work of Arriola Ruiz and Carrillo (2022), which compared technological adoption and readiness in the auto parts industry across both cities.

This article goes beyond comparing the levels of expertise and readiness for I4.0 in a specific industrial sector. It explores current trends in the adoption of I4.0 technologies across manufacturing companies in all sectors in Tijuana and Ciudad Juárez. By doing so, it provides valuable insights into how these two key border cities are positioning themselves—whether in alignment or divergence—in the new industrial era. The study highlights the challenges and opportunities they encounter as they advance toward the digitalization and automation of industrial processes.

This study also contributes to explaining the factors involved in the adoption of I4.0 in border regions, providing valuable insights into these two industrial hubs. By examining workers' knowledge and readiness to integrate I4.0 into production processes, it brings a crucial human perspective to the conversation on digitalization and automation in manufacturing—an often-overlooked dimension. Furthermore, the study highlights the unique challenges maquiladoras face in adopting I4.0, offering a foundation for developing strategies to address these barriers. This information is particularly relevant for policymakers, educators, and business leaders aiming to promote the adoption of I4.0 technologies in the manufacturing sector.

Baja California and Chihuahua boast a strong industrial tradition, with maquiladoras playing a pivotal role in their regional economies. In Baja California, manufacturing companies contribute 10% of the national output, with Tijuana responsible for over 70% of this total (Index Zona Costa BC, 2023). Similarly, in Chihuahua, manufactured exports account for approximately 12% of the national total, with Ciudad Juárez as the primary contributor, generating nearly 80% of the state's output (Asociación de Maquiladoras, A. C. [AMAC]-Index Juárez, 2023). Combined, these two regions represent over 20% of the national manufacturing industry.

The maquiladora industry is currently undergoing a shift toward the Industry 4.0 (I4.0) production model, also known as the Fourth Industrial Revolution. In this context, companies are adopting strategies focused on technology integration and digitalization to harness the competitive advantages offered by emerging technologies. This transformation highlights the essential role of I4.0 in today's manufacturing landscape.

Industry 4.0 is characterized by the integration of the value chain through cyber-physical systems (CPS) within manufacturing processes (Arvind, 2016). This model incorporates technologies such as big data, artificial intelligence (AI), simulation, digitalization, and robotics, utilizing information and communication technologies (ICT) to connect all members of the production network. Operating in a decentralized manner with a high degree of autonomy, I4.0 enhances resource efficiency, promotes economies of scale, and enables flexible production (Wang & Wang, 2016; Kinzel, 2017). Matus (2022) emphasizes that the transition to this new industrial paradigm is driven by the digitalization of processes and the adoption of I4.0-specific technologies.

In Mexico, various stakeholders involved in industrial development—such as suppliers, local companies, academics, and government institutions—have invested resources to understand and adapt to the I4.0 model (Carrillo et al., 2020). However, limited research has been conducted on the transition of Mexican companies to this model, and the existing literature presents conflicting findings. Some authors suggest that Mexico is falling behind in adopting I4.0 (Riquelme, 2019; AXIS Centro de Inteligencia Estratégica, 2019), while other studies point to significant progress (International Data Corporation [IDC], 2017), with some even reporting that small and medium-sized enterprises (SMEs) in Mexico are outpacing their German counterparts. These discrepancies highlight the need for further investigation into the I4.0 implementation processes occurring in Mexican companies.

This article is structured into four main sections, in addition to the introduction. The first section provides background on the key factors driving the transition to I4.0, identifying both the advantages and challenges. The second section outlines the methodological approach, with an emphasis on data collection and analysis. The third section presents the empirical analysis and discussion of the data obtained. Finally, the last section offers a comparative study and concludes the work.

DETERMINANTS AND CHALLENGES OF TECHNOLOGICAL IMPLEMENTATION IN COMPANIES

Throughout history, technological advancements have provided significant benefits to companies, workers, and society at large, primarily through increased productivity and reduced production costs. Today, the I4.0 model introduces innovations that go beyond the incremental changes typically associated with technological evolution. This section explores the factors motivating companies to adopt I4.0 technologies and examines the key challenges and obstacles they encounter during the technological transition process.

Motivations for the Adoption of I4.0

Various authors have identified key factors related to the implementation of I4.0 in companies. Sampietro-Saquicela (2020), in a study of Argentine companies, found that these companies have benefited from their ability to quickly adapt to demand fluctuations, supported by flexible and modular production. The author also highlights that the significant reduction in costs and non-productive time has facilitated the adoption of new technologies.

On the other hand, Raso Delgue (2018), in his research on industries in Mexico, Chile, and Brazil, found that the adoption of I4.0 technologies fostered the development of cognitive skills and enhanced labor inclusion, particularly by providing more opportunities for women. This was due to the reduced physical demands of certain tasks and the increasing need for advanced cognitive skills. Moreover, the implementation of new technologies created jobs in areas such as artificial intelligence, robotics, and the software industry.

Various studies have shown that information technologies (IT) act as catalysts for the digitalization and automation of work environments, laying the essential foundations for the successful adoption of the I4.0 production model. There is a consensus that companies, driven by the pressures of the global competitive landscape, adopt new technologies to improve their market position and maintain competitiveness. This phenomenon has been widely documented in several studies (Dasgupta et al., 1999; Gouvêa & Cunha, 2005; Singh et al., 2008; Anaçoğlu, 2018; Nabukhotna & Zhygalkevych, 2022; Mohylna & Makarova, 2023).

In this regard, Anaçoğlu (2018) conducted a study in Turkey to estimate the impact of IT on business performance. The results indicate that the intensification of global competition and the urgent need for innovation are key factors driving companies to adopt new technologies. Anaçoğlu argues that adopting IT is crucial for maintaining competitiveness and productivity in modern markets. Similarly, Singh et al. (2008) found that SMEs in India face pressure to adopt IT in order to stay competitive in global markets. They also highlighted that these technologies are not only vital for improving efficiency and productivity but also for enhancing the quality and consistency of manufacturing processes.

Stoyanov (2013), in his study conducted in Bulgaria, analyzes the influence of IT on organizational change management and the optimization of business processes. The study concludes that IT is a critical tool for facilitating changes in business processes by promoting the adoption of more efficient, high-tech practices. In this context, Mohylna and Makarova (2023) found that, in the case of Ukrainian companies, IT improves working conditions and quality of life, while significantly increasing business productivity. The authors also emphasize that technological adoption enhances competitiveness and profitability in the market.

In a relevant study in Ukraine, Nabukhotna and Zhygalkevych (2022) examine the impact and importance of IT in business activities, focusing on how these technologies can improve management and operational efficiency. The authors highlight that IT not only accelerates the availability of crucial economic information for decision-making but also streamlines its processing, thus promoting economic development and strengthening competitiveness in the global market. They also note that companies implement IT to improve their economic indicators and update outdated systems.

Determinants of Technological Adoption in Companies

Regarding the determinants of technological adoption, studies by authors such as Dasgupta et al. (1999), Gouvêa and Cunha (2005), and Mohylna and Makarova (2023) have highlighted that a company's ability to successfully adopt new technologies is closely related to its size. This finding is supported by Müller et al. (2018) in their study on the adoption of I4.0 technologies. The rationale behind this is that larger companies typically have more resources and a stronger organizational structure, which enables them to more effectively integrate and leverage new technologies.

Furthermore, organizational culture plays a crucial role in the technological adoption process. This culture is closely tied to the willingness of top management to take risks and foster an environment that supports innovation and continuous learning—key factors that facilitate the integration of new technologies. On the other hand, research by Gouvêa and Cunha (2005) and Mohylna and Makarova (2023) has shown that government regulations that promote industrial development serve as enablers, encouraging companies to adopt specific technologies.

Gouvêa and Cunha (2005) note that a company's innovation capacity is a critical factor in technological adoption. Organizations with greater innovation capabilities are more likely to successfully adopt new technologies. Similarly, Dasgupta et al. (1999), in their study conducted in India, found that market structure significantly influences a company's ability to adopt technology. They observed that fluctuations in exchange rates and computer prices directly affect business decisions regarding technology investments.

On the other hand, Lee and Kim (2007) identify and synthesize the key factors that contribute to the successful adoption of Internet-based information systems. Among the most significant factors are compatibility with existing systems and the information systems infrastructure. According to the authors, these elements are crucial for enabling the effective and efficient integration of new technologies into the organizational environment.

Exploring the Challenges of I4.0 Adoption

Several authors have identified a range of challenges that arise during the early stages of transitioning to I4.0, particularly with regard to the knowledge required for a successful technological transformation. According to Gabriel and Pessl (2016), one key challenge in Germany is attracting and retaining skilled workers in medium-sized enterprises. In this context, Hecklau et al. (2016) emphasize that providing workers with opportunities for relevant training and ensuring their employability are fundamental challenges to address.

On the other hand, both Carrillo et al. (2020) and Arredondo-Hidalgo and Caldera-González (2023) highlight that delays in training companies and underqualified workers pose a significant challenge to the successful adoption of I4.0. In addition, Ynzunza Cortés et al. (2017) caution that a lack of expertise in areas such as programming, simulation, and maintenance could negatively impact implementation plans. Furthermore, Safar et al. (2020) argue that the lack of knowledge about I4.0-related concepts among the potential workforce is one of the main obstacles to a successful transition to the Fourth Industrial Revolution.

In relation to the above, Benešová and Tupa (2017) emphasize that the transition to the I4.0 production model cannot be rapid, as the shortage of qualified workers and the high implementation costs make it difficult for companies to undergo this transformation smoothly. As a result, it is expected that the adoption of I4.0 will occur gradually in most companies. Computerworld España (2018) offers a similar view, noting that SMEs face greater risks when adopting I4.0 technologies. While SMEs are typically more agile and flexible than larger companies, they also face significant economic risks when innovating, which can result in substantial losses if not managed properly. In this context, Singh et al. (2008) observe that SMEs often lack a structured approach to technology management. These companies typically do not have well-defined strategic plans for technology adoption, meaning their investments are often driven more by the owners' decisions than by formal cost-benefit analyses.

Regarding technological adoption in developing regions, Chin (2004), based on a study conducted with three Caribbean companies, highlights significant obstacles such as unstable economic conditions and a shortage of technological, financial, and skilled labor resources. These factors present critical challenges that hinder the technological transition of companies in these regions.

Similarly, Mohylna and Makarova (2023) note that although the initial adoption of technologies can be costly, the subsequent operational expenses are primarily limited to specialist salaries and software updates. This considerable reduction in operational costs makes the initial investment more attractive, particularly in terms of the time required to reach profitability. In many cases, this efficiency in cost management accelerates the financial break-even point, further increasing the appeal of adopting new technologies.

Kinzel (2017) cautions that the planning of new production systems often neglects the human factor in their design. These systems are typically centered on processes, algorithms, and analysis, driven primarily by technological motivations, while the human element is frequently absent from I4.0 system specifications. Kinzel points out that a significant number of workers are either excluded from production processes or, at the very least, perceive themselves as being excluded. The author underscores the critical need for active worker participation in all stages of production. Neglecting the human element in a system as intricate as I4.0 risks undermining the paradigm's success and could ultimately lead to its failure.

The Importance of Knowledge in a Successful Transition to I4.0

This section highlights the importance of evaluating how extensively companies adopt I4.0 practices and train their workforce to align with this transformative industrial paradigm. Albarrán Trujillo et al. (2020) argue that the value and mastery of technological knowledge should be measured by the quality of decisions it enables, which improve with a deeper understanding. In a globally competitive economy, acquiring I4.0-related skills and competencies is increasingly essential. Moreover, the transition to smart factories underscores the pivotal role of knowledge and expertise in emerging technologies, as these elements are fundamental to achieving business success in the era of I4.0.

Ynzunza Cortés et al. (2017) underscore the critical role of knowledge in I4.0, highlighting that workers primarily acquire it through hands-on experience. Similarly, Sony and Naik (2019) found that in the European Union, some senior executives lacked awareness of I4.0, while others, despite some familiarity with the concept, were often unacquainted with the methods required for its implementation. In their analysis of Turkish companies, Sarı et al. (2020) observed that, although workers were generally aware of I4.0, they lacked a clear understanding of its associated technologies. The authors argue that comprehensive knowledge is essential for companies to identify and adopt the most suitable technologies. Furthermore, they emphasize that investing solely in capital is insufficient. Companies must also dedicate resources to training and recruiting qualified personnel and to strategic management to maximize the benefits of I4.0.

In relation to the adoption of I4.0, Carrillo et al. (2020) highlight that, due to its multifaceted complexity, companies adopt its technologies in various ways. It is crucial to note that the implementation process requires ongoing investment from all participants. As a result, planning must consider the unique characteristics of each case, including the organizational environment, available resources, and strategic objectives (Martínez Martínez, 2020). In this context, Johny and Bhasi (2015) emphasize that technological adoption can face challenges due to its inherent complexity. They describe technological implementation as a multifaceted process involving several stages, where any oversight can lead to inefficiencies and uncertainty. This underscores the importance of careful planning and execution, ensuring that each phase is carried out with precision to avoid setbacks that could undermine the overall effectiveness of the process.

In this context, although the transition to I4.0 can present complications and significant expenses for SMEs, it is crucial for them to adapt their existing production systems. These challenges are particularly pronounced for small businesses due to their scale and limited resources (Buenrostro Mercado, 2022). Beyond financial constraints, the adoption of I4.0 may be further hindered by other factors. For instance, Martínez Martínez (2020) points out that the limited capacity of companies to acquire specific technological infrastructure and employ workers with multidisciplinary skills can serve as major barriers. Additionally, Ynzunza Cortés et al. (2017) argue that progress in the adoption of I4.0 is closely tied to a company's ability to foster interconnection through networks, enabling the establishment of adaptable production systems, the integration of value chains, and the optimization of internal processes. These authors also stress the importance of addressing security concerns, making significant technological investments, and acquiring the necessary skills to manage and analyze information. Gökalp et al. (2017) further complement these perspectives by emphasizing the need to clearly define the guidelines, methods, and structures to follow during the development phase of I4.0.

Given the critical role that technological expertise plays in advancing toward full adoption of I4.0, and considering the limited research in this area, conducting studies to gain a deeper understanding of its adoption is essential.

METHODOLOGY

The proposed methodological strategy for this research employs a quantitative approach. From a comparative approach, it aims to estimate and analyze the level of adoption and mastery of I4.0 technologies in manufacturing companies and their suppliers in Tijuana and Ciudad Juárez. To achieve this, the study utilizes the results of the I4.0 survey developed by the AXIS Institute (AXIS Centro de Inteligencia Estratégica, 2019), which was initially applied in Tijuana and later in Ciudad Juárez, using the measurement instrument developed by Arriola Ruiz (2024).

The analysis focused on three variables: 1) the level of knowledge among workers in manufacturing companies about I4.0-related technologies; 2) the level of implementation of I4.0 technologies in the companies where the surveyed workers are employed; and 3) the intention to implement these technologies. The company served as the unit of analysis, with skilled workers providing the data, focusing on their knowledge of the technologies and their employer's implementation efforts. Table 1 outlines the variables for which data was collected, specifying the number of items for each variable and the type of measurement scale used. Table 2 lists the technologies considered, categorizing them by type, user complexity level, and degree of industrial novelty.

Table 1. Variables, Number of Items and Scales

Variable	Items	Measurement scale
Level of knowledge of I4.0 technologies	19	From 1 = completely unaware to 5 = expert on the topic
Level of implementation of I4.0 technologies	19	From 1 = not implemented to 5 = fully implemented
Intention to implement I4.0 technologies by company area	9	1 = yes, I consider it convenient 0 = no, I don't consider it convenient

Source: Own elaboration based on AXIS Centro de Inteligencia Estratégica (2019) and Arriola Ruiz (2024).

For the variables related to the domain and adoption of I4.0 technologies, a five-point Likert scale was used. To assess the variable measuring the willingness to adopt these technologies in various areas of the company, a dichotomous scale was applied to identify the specific areas where employees believe their incorporation would be appropriate.

Table 2. Categorization of Technologies by Type, User Complexity and Industrial Novelty

Technology	Type of technology	User complexity level	Industrial novelty level
Additive manufacturing (3D printing)	Tangible	Low	Low
Machine learning	Intangible	High	High
Augmented reality	Intangible	Medium	Medium
Virtual reality	Intangible	Medium	Low
Autonomous robots	Tangible	Medium	Medium
Collaborative robots (cobots)	Tangible	Medium	Medium
Big data analytics	Intangible	High	Medium
Automated guided vehicles	Tangible	Low	Low
Cloud computing	Intangible	Low	Medium
Blockchain	Intangible	High	High
Cybersecurity	Intangible	Medium	Medium
Internet of Things (IoT)	Intangible	Low	Medium
Computer vision	Tangible	High	Medium
Sensing and digital data collection	Tangible	Low	Low
Advanced simulation/digital modeling	Intangible	Low	Low
Horizontal and vertical systems integration	Intangible	Medium	Medium
Digital twin	Intangible	High	High
Real-time process monitoring	Tangible	Medium	Low
Intelligent energy management	Intangible	Medium	Medium

Source: Own elaboration based on AXIS Centro de Inteligencia Estratégica (2019, p. 55), and Arriola Ruiz (2024).

Data Collection

In Tijuana, the questionnaire was distributed to 4 500 skilled workers from manufacturing companies, yielding 164 responses. After validation, 124 responses were deemed valid.[4] This survey was conducted online during June 2019. In Ciudad Juárez, the survey took place during the COVID-19 pandemic, between August 2020 and February 2021, resulting in 192 responses, of which 92 were considered valid. Table 3 presents the respondents' profiles, categorized by job position and the industrial sector of their respective companies.

The sample comprises responses from workers in specific organizational roles, including engineers, managers, directors, department heads, and technicians, employed in production, engineering, quality, and supply chain departments. This distinction is critical, as the responses represent skilled employees directly involved with I4.0 technologies, rather than the entire

[4] Only responses without statistical inconsistencies were deemed valid. These included questionnaires that did not exhibit uniform selection of the same option across all items, duplicate submissions, or incomplete information.

workforce. In the case of Tijuana, general survey results are accessible on the AXIS Institute website (AXIS Centro de Inteligencia Estratégica, 2019), while detailed findings are reported in Carrillo et al. (2020, 2022). For Ciudad Juárez, the results are documented in Arriola Ruiz (2022).

Table 3 reveals notable differences between the regions studied. For example, in Tijuana, one-third of respondents held managerial positions, whereas in Ciudad Juárez, only 7% occupied such roles. Conversely, technicians represented 32% of respondents in Ciudad Juárez, compared to just 2% in Tijuana. Significant disparities were also observed in sectoral composition: in Ciudad Juárez, one-third of respondents worked in the automotive industry, while a similar proportion in Tijuana were employed in the medical device sector. While it is difficult to determine the precise impact of these differences, they likely influenced the results.

Table 3. Sample of Workers by Position and Industrial Sector

Profiles		City		Total
		Tijuana (frequency)	Ciudad Juárez (frequency)	
Organizational position	Technician	3	29	32
	Engineer	44	25	69
	Department Head	24	8	32
	Manager	38	6	44
	Director	9	4	13
	Other	6	18	24
	No Response	0	2	2
	Total	124	92	216
Industrial Sector	Electrical/Electronic	21	17	38
	Automotive	12	30	42
	Aerospace	6	0	6
	Medical Devices	38	15	53
	Plastics	17	7	24
	Metalworking	12	4	16
	Technical and Technological Services	9	9	18
	Other	9	9	18
	No Response	0	1	1
	Total	124	92	216

Source: Own elaboration based on survey results conducted in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

Limitations of the Research

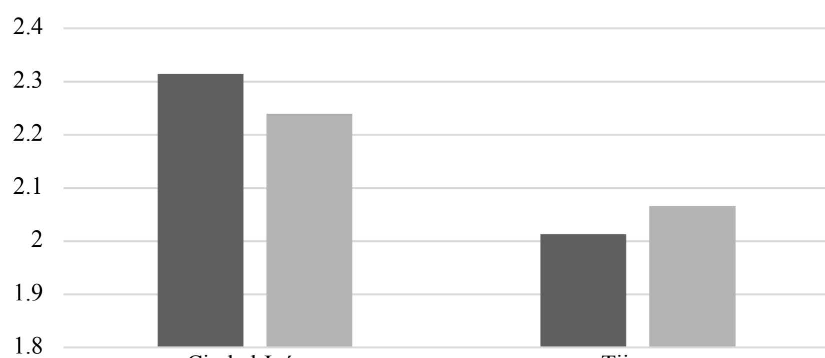
Although this research focuses on Tijuana and Ciudad Juárez, two significant industrial hubs, these cities represent only a portion of Mexico's manufacturing sector, so the findings may not be fully generalizable. Additionally, since the measurement instrument primarily aims to assess workers' perceptions of the adoption and mastery of I4.0 technologies, it is important to recognize that the responses reflect the participants' opinions, which introduces a subjective element into the study.

RESULTS

The general results indicate that both workers and companies in both locations exhibit limited levels of mastery and adoption of I4.0 technologies. However, workers in Ciudad Juárez demonstrate a higher level of technological expertise, and their companies show slightly higher levels of adoption of these technologies.

Graph 1 illustrates modest scores for the degree of adoption of I4.0 technologies in companies in both Ciudad Juárez (average of 2.01) and Tijuana (average of 2.06), as well as low ratings for employee training (2.31 in Ciudad Juárez and 2.24 in Tijuana). These scores are classified as follows: an average below 2.33 is considered low, between 2.33 and 3.66 as medium, and above 3.66 as high.

Graph 1. Knowledge and Implementation Levels of I4.0 Technologies



	Ciudad Juárez	Tijuana
Knowledge	2.3146	2.0122
Implementation	2.2391	2.0654

Note: This data reflects the average of the respondents' answers regarding their level of expertise, as well as the degree of adoption of I4.0 technologies in the companies. Here, one indicates the lowest level of both expertise and adoption, while five represents the highest level in both categories.

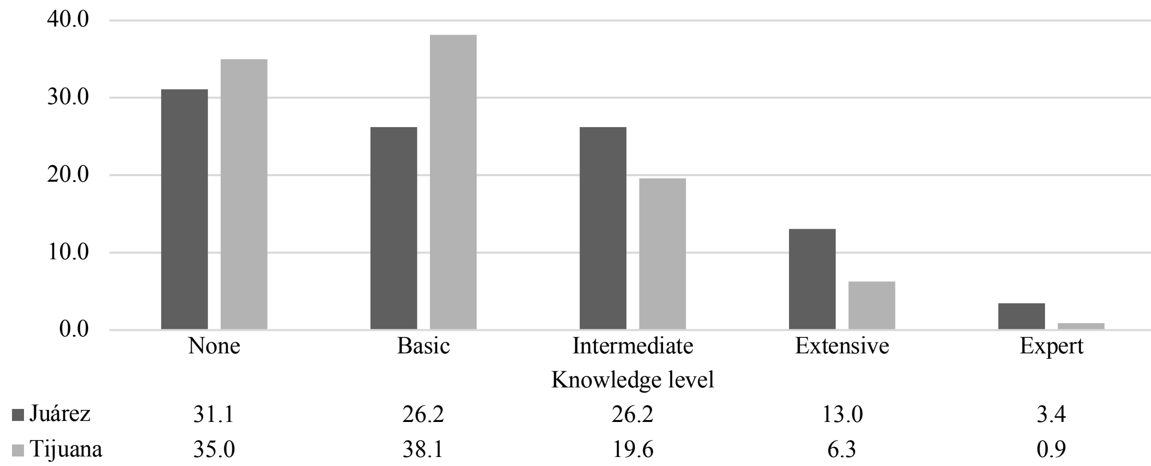
Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

Level of Knowledge About I4.0 Technologies

Although knowledge of I4.0 is limited in both cities, workers in Ciudad Juárez's companies showed better preparedness to handle these technologies compared to their counterparts in Tijuana. Ciudad Juárez has a lower proportion of workers with basic or no knowledge of I4.0, and a higher proportion with intermediate or advanced knowledge. Moreover, Ciudad Juárez has more than three times the number of workers who reported the highest level of expertise in I4.0 technologies.

As shown in Graph 2, most employees report having basic or no knowledge of I4.0 technologies, with 57.3% in Ciudad Juárez and 73.1% in Tijuana falling into this category. Approximately one in four workers in Juárez consider themselves to have intermediate knowledge of I4.0, while in Tijuana, this proportion is one in five. Conversely, only a small percentage of workers in both cities—16.4% in Juárez and 10.2% in Tijuana—consider themselves to have extensive knowledge or to be experts in I4.0.

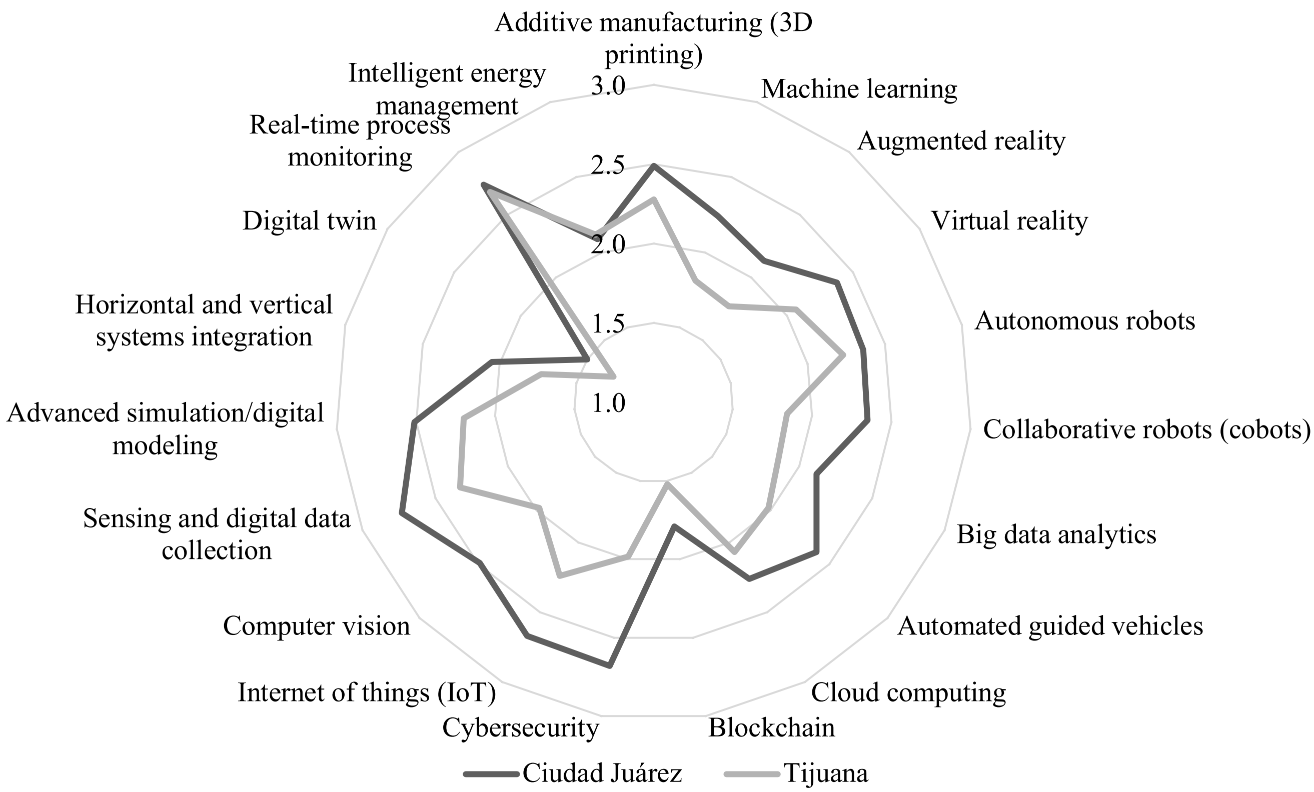
Graph 2. Level of Knowledge of I4.0 Technologies (Percentages)



Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

If the analysis focused on the specific knowledge of each I4.0 technology, rather than general and aggregated knowledge, distinct trends would emerge. Graph 3 displays the distribution of knowledge across the 19 evaluated technologies. While the overall pattern is similar in both regions, Ciudad Juárez shows higher knowledge scores for all technologies, except for intelligent energy management, where Tijuana slightly outpaces Juárez.

Graph 3. Average Knowledge of I4.0 by Technology, Ciudad Juárez vs. Tijuana



Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

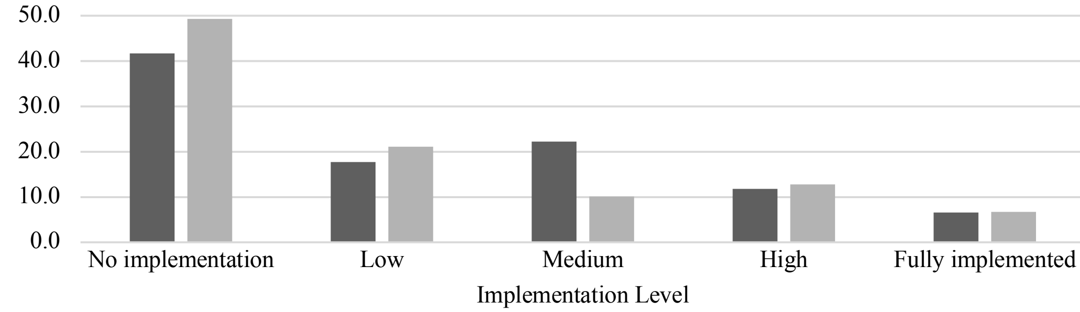
In this context, the surveyed workers in Ciudad Juárez demonstrated greater proficiency in real-time process monitoring technologies, sensing and digital data collection, cybersecurity schemes, the Internet of Things, advanced simulation/digital modeling, and additive manufacturing (3D printing). On the other hand, the technologies with the lowest knowledge scores were digital twin, blockchain, horizontal and vertical software integration, and intelligent energy management.

As for the workers in Tijuana, they demonstrated greater proficiency in technologies such as real-time process monitoring, sensing and digital data collection, additive manufacturing (3D printing), the Internet of Things, and autonomous robots. On the other hand, the technologies with the lowest knowledge scores were digital twin, blockchain, horizontal and vertical software integration, and augmented reality.

Level of Implementation of I4.0 Technologies

Consistent with the low scores in the mastery of I4.0 technologies, companies also show low levels of adoption of these technologies. Graph 4 reveals that nearly half of the I4.0 technologies (41.7% in Juárez and 49.3% in Tijuana) are not being implemented in either region. Only a small proportion of these technologies (6.6% in Juárez and 6.7% in Tijuana) are fully implemented. A significant proportion (51.7% in Juárez and 43.9% in Tijuana) are at an early stage of adoption or in the process of being fully implemented.

Graph 4. Level of Implementation of I4.0 Technologies (Percentages)

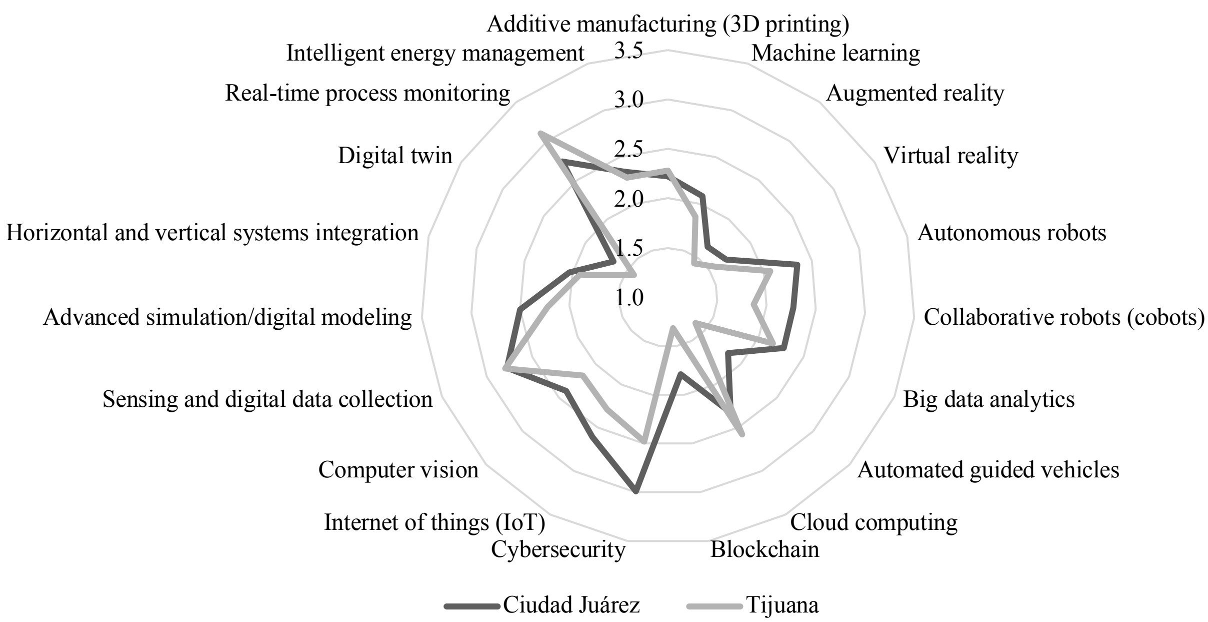


	No implementation	Low	Medium	High	Fully implemented
Ciudad Juárez	41.7	17.7	22.3	11.7	6.6
Tijuana	49.3	21.0	10.1	12.8	6.7

Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

Graph 5 shows that companies in Juárez and Tijuana exhibit similar patterns of I4.0 technology adoption. Ciudad Juárez leads in the adoption of most technologies, except for real-time process monitoring, additive manufacturing (3D printing), sensing and digital data collection, and cloud computing.

Graph 5. Average Implementation of I4.0 by Technology,
Ciudad Juárez vs. Tijuana



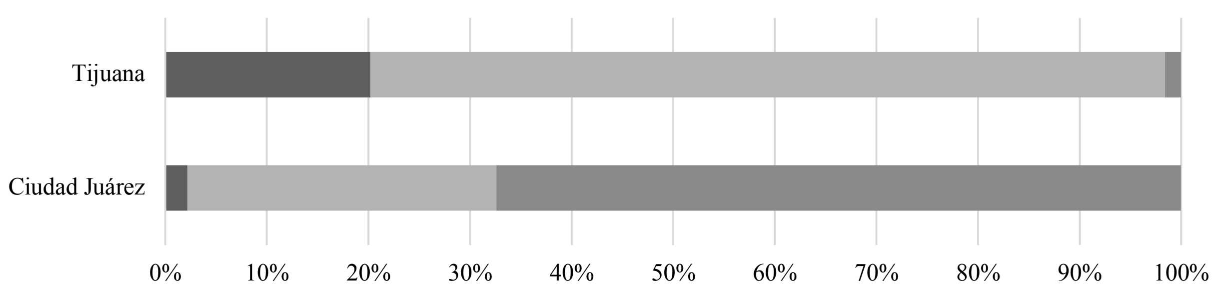
Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

Regarding adoption by individual technologies, the highest rates in both locations were observed for real-time process monitoring, sensing and digital data collection, cybersecurity schemes, and cloud computing. Conversely, the technologies with the lowest adoption rates were digital twin, augmented reality, blockchain, automated guided vehicles, and virtual reality. Unlike the significant differences in knowledge levels between Juárez and Tijuana, the variations in implementation levels between the two cities are less pronounced.

Level of Willingness for Technology Adoption by Company Area

Another key dimension for which data was collected is the level of workers' willingness to adopt I4.0-related technologies, not broadly but within specific business areas. Graph 6 illustrates differences in employee perceptions between companies in Ciudad Juárez and Tijuana. To assess a potential association between the two locations, Pearson's Chi-square test was applied. A p-value of less than 0.001 was considered statistically significant, indicating a meaningful association between the samples. These findings suggest that workers' willingness to implement I4.0 technologies in various areas is significantly influenced by their geographical location.

Graph 6. Percentage of Areas Where the Implementation of I4.0 Technologies is Considered Appropriate



	Ciudad Juárez	Tijuana
In none	2.17	20.16
In some	30.43	78.23
In all	67.39	1.61

Note: These differences are statistically significant at the 99.9 percent level (p-value=0.000 in the Chi-square test).

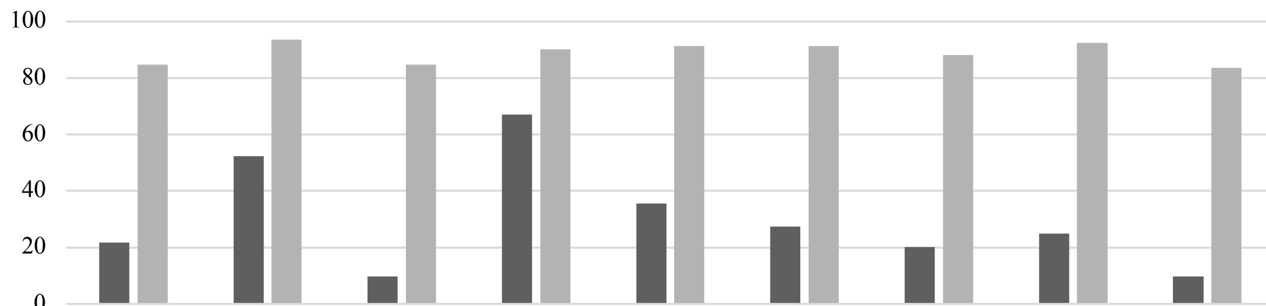
Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

In general, the majority of workers in Tijuana (78.23%) believe that I4.0 should only be adopted in certain areas of the company. A small proportion (1.61%) think it should be implemented across all areas, while about one in five workers believe I4.0 technologies should not be adopted in any area.

In contrast, most workers in Ciudad Juárez (67.39%) believe I4.0 technologies should be adopted company-wide. A significant proportion (30.43%) think these technologies should be implemented in specific areas, while a small minority (2.17%) oppose adoption in any area.

Graph 7 shows the proportion of employees who supported the implementation of I4.0 technologies across various areas of the company. To evaluate the potential association between the samples from Juárez and Tijuana, both Pearson's Chi-square test and Fisher's exact test were applied. According to Hae-Young (2017), Fisher's exact test is recommended when more than 20% of cells have expected frequencies below five, as the Chi-square approximation may be unreliable in such cases. Both tests were applied across all company areas, and in every case, a statistically significant association between the Juárez and Tijuana samples was found, with a confidence level of 99.9%. This suggests that the decision to adopt I4.0 technologies in specific areas is not independent of the workers' geographic location. In other words, the geographical differences between Juárez and Tijuana significantly influence how and where these technologies are adopted within companies.

Graph 7. Percentage of Areas Where the Implementation of I4.0 Technologies Is Deemed Appropriate



	Research and development	Product / process engineering	Supply chain	Manufacturing / production	Quality control	Maintenance	Distribution / logistics	Planning	Human resources training
Tijuana n=124	21.77	52.42	9.68	66.94	35.48	27.42	20.16	25.00	9.68
Ciudad Juárez n=92	84.78	93.48	84.78	90.22	91.30	91.30	88.04	92.39	83.70

Note: Statistically significant differences (associations) were found in all areas at the 99.9% confidence level (p-value = 0.000 for both the Chi-square test and Fisher's exact test).

Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

These results highlight notable differences in the opinions of workers from Juárez and Tijuana. In general, workers in Ciudad Juárez show strong support for the adoption of I4.0 technologies across various areas of the company, with agreement levels ranging from 83.7% to 93.5%. In contrast, workers in Tijuana tend to oppose adoption in most areas. Notably, the manufacturing and production (66.94%) and product engineering (52.48%) areas receive the most support from Tijuana workers for adopting I4.0 technologies. Conversely, workers in Tijuana are least supportive of the

e-ISSN 2594-0260 https://doi.org/10.33679/rfn.v1i1.2383

implementation of these technologies in the supply chain (9.68%) and human resources development (9.68%).

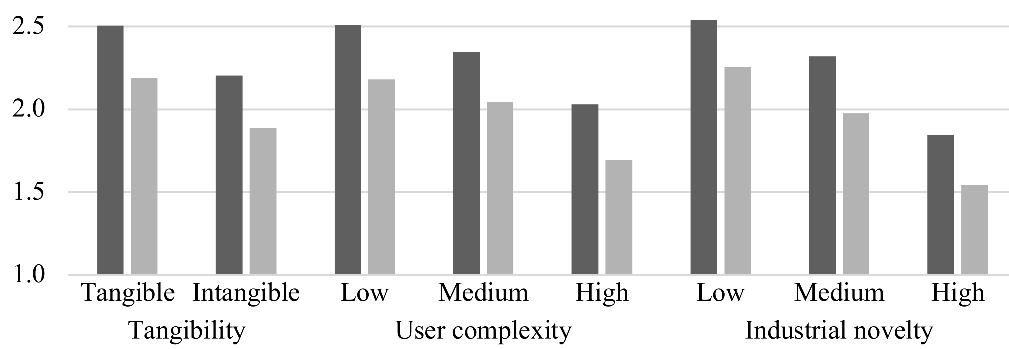
In summary, the perspectives of workers from both regions differ significantly. While workers in Juárez advocate for a broad industrial transformation, workers in Tijuana adopt a more cautious and selective approach to the I4.0 adoption process.

Levels of Knowledge and Implementation by Technology Type

Regarding the measurement of knowledge and implementation of I4.0 technologies by type, user complexity, and industrial novelty level (Table 2), it is evident that technologies with higher knowledge and adoption rates are generally tangible, with moderate to low user complexity and moderate to low industrial novelty. In contrast, technologies with the lowest levels of knowledge and adoption are typically intangible, with medium to high user complexity and medium to high industrial novelty.

Graph 8 displays the technology proficiency scores reported by workers according to technology type in both cities. The results show that workers in Ciudad Juárez demonstrate higher levels of competence across all technology types, user complexity levels, and industrial novelty levels. To detect differences between the samples from Ciudad Juárez and Tijuana, the Kruskal-Wallis test was applied. As noted by Ostertagová et al. (2014), this test is a non-parametric method useful for comparing independent samples, determining whether the samples come from the same distribution. Statistically significant differences were found across all categories analyzed, indicating that workers in Juárez are better prepared to handle I4.0-related technologies compared to those in Tijuana.

Graph 8. Average Response Score Regarding Knowledge of I4.0 Technologies by Type, User Complexity Level, and Industrial Novelty Level



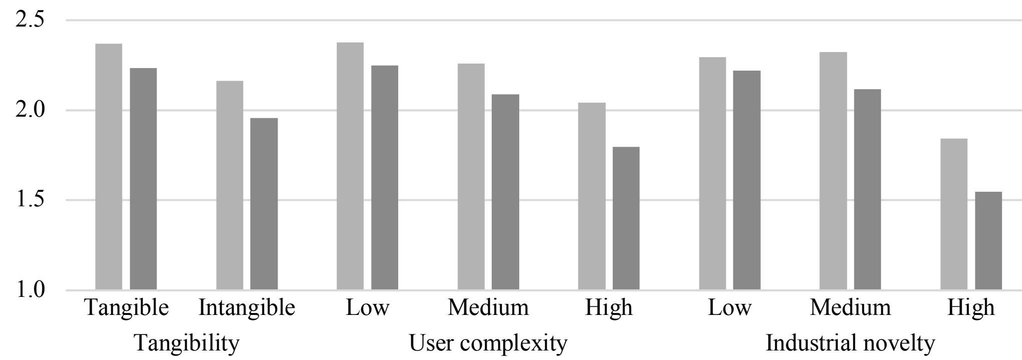
	Tangible	Intangible	Low	Medium	High	Low	Medium	High
Ciudad Juárez	2.506	2.203	2.509	2.348	2.028	2.540	2.321	1.844
Tijuana	2.187	1.889	2.181	2.047	1.694	2.254	1.977	1.543
Kruskal-Wallis (p-value)	0.015	0.003	0.006	0.021	0.002	0.006	0.001	0.001

Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

From a different perspective, the adoption of I4.0-related technologies in companies generally follows a pattern distinct from technological proficiency. Graph 9 illustrates the technological adoption index based on technology type, user complexity, and industrial novelty level. Although the data show that companies in Ciudad Juárez exhibit a higher technological adoption index across all aspects considered, the Kruskal-Wallis test identified statistically significant differences only in technologies with high user complexity[5] and high industrial novelty.[6]

Based on the results, it can be concluded that workers in Ciudad Juárez are better prepared to handle I4.0 technologies. However, when it comes to technological adoption, companies in both regions do not show significant differences. While Juárez stands out in the adoption of technologies with high user complexity and industrial novelty, this advantage appears to be marginal, as no substantial differences are observed in the adoption of other technologies.

Graph 9. Average Response Score on the Adoption of I4.0 technologies by Type, User Complexity Level, and Industrial Novelty Level



	Tangible	Intangible	Low	Medium	High	Low	Medium	High
Ciuda Juárez	2.370	2.163	2.377	2.258	2.043	2.293	2.325	1.844
Tijuana	2.235	1.957	2.248	2.089	1.796	2.221	2.118	1.548
Kruskal Walis (p-value)	0.288	0.156	0.296	0.204	0.088	0.528	0.132	0.018

Source: Own elaboration based on data from the I4.0 surveys in Tijuana and Ciudad Juárez (AXIS Centro de Inteligencia Estratégica, 2019; Carrillo et al., 2020, 2022; Arriola Ruiz, 2022, 2024).

DISCUSSION AND CONCLUSIONS

In Mexico, Ciudad Juárez and Tijuana are leading cities in the technological advancement of their production processes. However, there is still a long way to go before achieving a complete transition to the I4.0 production model. Additionally, workers still lack the necessary skills to fully master the technologies associated with the Fourth Industrial Revolution.

[5] The technologies identified with a high level of complexity for the user are: machine learning, big data analytics, blockchain, computer vision, and digital twin (Table 2).

[6] The technologies considered to have a high level of industrial novelty are: machine learning, blockchain, and digital twin (Table 2).

The disparities in the adoption of I4.0 technologies can be attributed to several critical factors: the specific industrial sector of each company, the unique characteristics of the products it manufactures, and its financial capacity to incorporate technological innovations (Müller et al., 2018; Carrillo et al., 2020; Martínez Martínez, 2020). It is uncommon for companies to adopt the full spectrum of available technologies in an integrated manner. Instead, the prevailing trend is for companies to selectively implement those technologies that best align with their goals of improving productivity, flexibility, and cost reduction.

From this perspective, it can be argued that the success of companies in adopting I4.0 lies in their ability to select technologies that enable autonomy in their production processes. In other words, the successful adoption of the I4.0 production model is not determined by the implementation of numerous technologies, but rather by the strategic adoption of a carefully chosen set that enhances autonomy in one or more manufacturing processes, whether to address specific challenges or improve efficiency.

The general findings of this research indicate that workers in both cities have a limited mastery of technologies related to I4.0, and manufacturing companies in both regions exhibit equally limited levels of adoption of these technologies. This mirrors other studies focused on Mexico (Riquelme, 2019; AXIS Vantage Point, 2019), which have shown that the country is lagging in adopting I4.0. According to Ynzunza Cortés et al. (2017), this delay is largely due to the significant technological and connectivity gaps that persist. A similar argument is presented in the Network Readiness Index report (Dutta and Lanvin, 2021), which states that the country's levels of technological inclusion and trust are inadequate. Furthermore, the 2023 report stresses that Mexico must increase the adoption and investment in emerging technologies, improve access to and affordability of Internet infrastructure, and enhance digital skills among both the general population and the business sector to better integrate and participate in the digital economy (Dutta and Lanvin, 2023).

Regarding the differences between Tijuana and Ciudad Juárez, it is noteworthy that workers in Ciudad Juárez demonstrate a higher level of technological mastery compared to their counterparts in Tijuana. While companies in both cities show low levels of adoption of I4.0 technologies, companies in Ciudad Juárez stand out in the adoption of technologies with high user complexity and industrial novelty. However, the advantage of Ciudad Juárez companies over those in Tijuana appears to be marginal.

In line with this finding, a study by Martínez Martínez et al. (2023) in manufacturing companies in Guanajuato revealed significant heterogeneity in the adoption of advanced technologies and human resources policies within the Mexican manufacturing sector. The authors note that while some companies are making substantial investments in technological talent, others continue to rely on more traditional business models.

Furthermore, it is worth highlighting that in Ciudad Juárez, there is considerable interest in adopting I4.0 technologies across all areas of the company. This suggests that companies in this region are well-positioned to accelerate their transition to I4.0 in the near future.

Finally, it can be concluded that knowledge of I4.0-related technologies is a key factor in their successful implementation within companies. This conclusion becomes evident when comparing the technological expertise of workers in Ciudad Juárez and Tijuana. Workers in Tijuana generally exhibit lower levels of knowledge across all evaluated technologies compared to their counterparts in Juárez. Additionally, workers in Tijuana are more inclined to believe that I4.0 technologies should not be implemented throughout the entire company. Instead, they advocate for a more selective approach, focusing primarily on production areas such as manufacturing and product engineering.

In contrast, workers in Ciudad Juárez exhibit a higher relative mastery of all the analyzed technologies and support the adoption of I4.0 technologies across all areas of the company. This finding suggests that advanced knowledge of these technologies facilitates their adoption, as it helps workers understand how these tools can enhance productivity and streamline tasks. It also reinforces the idea that technological adoption complements and augments human labor, rather than replacing it. Similar results have been observed by authors like Rajnai and Kocsis (2017) and Raso Delgue (2018), challenging the perspective that technology simply replaces human labor through automation and computerization, as suggested by Frey and Osborne (2017).

In this context, Arredondo-Hidalgo and Caldera-González (2023), in their study on AI in Mexican SMEs, found that while this technology can enhance the efficiency and competitiveness of companies, it may also lead to a reduction in the workforce. The authors stress that any labor substitution dynamics should be handled ethically and responsibly, focusing on skill reassignment and upskilling rather than cost-cutting through employee layoffs.

Conversely, Arriola Ruiz (2022) notes that in companies in Ciudad Juárez, the close relationship between workers' mastery of I4.0 technologies and the level of adoption of these technologies could be attributed to these companies' intentional efforts to hire skilled personnel to manage them. Therefore, the link between mastery and adoption of I4.0 technologies in these companies can be seen as a result of their strategies for technological advancement and recruitment.

Several authors have explored the phenomenon of technological rejection by workers, and their findings help to better understand the variability in technological acceptance levels between employees in Tijuana and Ciudad Juárez. Azizah and Susanto (2016), through an extensive literature review, identified various factors influencing workers' acceptance of technology, including knowledge and mastery of the technologies. They also emphasized that the design of technology, particularly the visual aspects of website homepage layouts, can significantly affect users' perceptions and acceptance.

Dasgupta et al. (1999), in their research conducted in India, found that resistance to technological change is often linked to a lack of necessary skills to implement new technologies. Similarly, Nabukhotna and Zhygalkevych (2022), in their study in Ukraine, identified that both resistance to change and a reliance on outdated practices are significant barriers to a successful transition to I4.0.

In this context, it would be valuable to extend this research to other regions, thus encompassing a broader range of industrial contexts. Doing so would not only deepen the understanding of the challenges related to I4.0 adoption but also allow for comparisons between different environments.

Translation: Erika Morales.

REFERENCES

Albarrán Trujillo, S. E., Salgado Gallegos, M., & Pérez Merlos, J. C. (2020). Integración de la gestión del conocimiento y la Industria 4.0, una guía para su aplicación en una organización. *Revista de Desarrollo Sustentable, Negocios, Emprendimiento y Educación RILCO DS*, *6*(7), 1-13. https://bit.ly/3NVDIyk

Anaçoğlu, E. (2018). Effects of information technology usage on business performance. *Pamukkale Journal of Business and Information Management*, *5*(1), 22-29. https://dergipark.org.tr/en/download/article-file/621931

Arredondo-Hidalgo, M. G., & Caldera-González, D. del C. (2023). La Industria 4.0 como una alternativa de economía inclusiva. Un estudio en pymes guanajuatenses. In L. Porto Pedroza, & V. Sanagustín-Fons (Eds.), *Vulnerabilidades y nuevas demandas sociales: un enfoque interdisciplinar desde las organizaciones* (pp. 185-198). Editorial Dykinson. https://doi.org/10.2307/jj.5076210

Arriola Ruiz, E. (2022). *La adopción de la Industria 4.0 en Ciudad Juárez y su impacto sobre las empresas de manufactura y sus trabajadores* [Doctoral dissertation, Universidad Autónoma de Ciudad Juárez]. https://erecursos.uacj.mx/items/9f84c818-ac09-4595-a1ef-a234362a4548

Arriola, Ruiz, E. (2024). *Conocimiento e implementación de la Industria 4.0 en el sector de manufactura. Instrumento de medición* (10.13140/RG.2.2.33113.70242). AXIS Centro de Inteligencia Estratégica. http://dx.doi.org/10.13140/RG.2.2.33113.70242

Arriola Ruiz, E., & Carrillo, J. (2022). La Industria 4.0 en México: análisis regional sobre el conocimiento y la implementación de 19 tecnologías. In A. Martínez Martínez, & M. J. Santos Corral (Eds.), *Oportunidades y retos para la adopción de la Industria 4.0 en México* (pp. 191-206). Plaza y Valdés. https://www.researchgate.net/publication/364091856_Oportunidades_y_retos_para_la_adopcion_de_la_industria_40_en_Mexico

Arvind, A. (2016). *Architecture for Industry 4.0-based manufacturing systems* [Master's thesis, Carnegie Mellon University]. https://bit.ly/3tIEGXR

Asociación de Maquiladoras, A. C. (AMAC)-Index Juárez. (2023, September 1). Importaciones y exportaciones. *Información Estadística Mensual.* https://indexjuarez.com/wp-content/uploads/2023/09/1-de-Septiembre-2023.pdf

AXIS Centro de Inteligencia Estratégica. (2019). BAJA i4.0. Industria 4.0 en Baja California. *AXIS Vantage Point.* https://vp.inteliaxis.com/PDF/Bajai40.pdf

Azizah, A. F., & Susanto, T. D. (2016). Conceptual model cognitive, affective, physical, and external factor for individual information technology acceptance. *IPTEK Journal of Proceedings Series*, *2*(1), 171-172. https://iptek.its.ac.id/index.php/jps/article/view/1169/988

Benešová, A., & Tupa, J. (2017). Requirements for education and qualification of people in Industry 4.0. *Procedia Manufacturing*, *11*, 2195-2202. https://doi.org/10.1016/j.promfg.2017.07.366

Buenrostro Mercado, E. (2022). Propuesta de adopción de tecnologías asociadas a la Industria 4.0 en las pymes mexicanas. *Entreciencias*: *Diálogos en la Sociedad del Conocimiento*, *10*(24), 1-19. https://doi.org/10.22201/enesl.20078064e.2022.24.81347

Carrillo, J., Gomis, R., De los Santos, S., Covarrubias, L., & Matus, M. (2020). ¿Podrán transitar los ingenieros a la Industria 4.0? Análisis industrial en Baja California. *Entreciencias: Diálogos en la Sociedad del Conocimiento*, *8*(22). 1-22. https://doi.org/10.22201/enesl.20078064e.2020.22.76089

Carrillo, J., Vallejo, B., & Gomis, R. (2022). COVID-19 and industrial resilience in the Global South. A case study on the auto parts sector in Mexico. *International Journal of Automotive Technology and Management*, *22*(1), 82-105. http://doi.org/10.1504/IJATM.2022.122115

Chin, P. (2004). An examination of factors that affect the management of information technology in organizations. *AMCIS 2004 Proceedings*, *75*, 521-528. https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1651&context=amcis2004

Computerworld España. (2018, February 12). *El impacto de la Industria 4.0 en las pymes. Computerworld.* https://www.computerworld.es/article/2135297/el-impacto-de-la-industria-4-0-en-las-pymes.html

Dasgupta, S., Agarwal, D., Ioannidis, A., & Gopalakrishnan, S. (1999). Determinants of information technology adoption: An extension of existing models to firms in a developing country. *Journal of Global Information Management*, *7*(3), 30-40. https://d1wqtxts1xzle7.cloudfront.net/69520125/6c4379e184c055e93a0a4bbdf6861ea843e2-libre.pdf

Dutta, S., & Lanvin, B. (Eds.). (2021). *The network readiness index 2021. Shaping the global recovery.* Portulans Institute. https://networkreadinessindex.org

Dutta, S., & Lanvin, B. (Eds.). (2023). *Network readiness index 2023. Trust in a network society: A crisis of the digital age?* Portulans Institute. https://networkreadinessindex.org

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change*, *114*, 254-280. https://doi.org/10.1016/j.techfore.2016.08.019

Gabriel, M., & Pessl, E. (2016). Industry 4.0 and sustainability impacts: Critical discussion of sustainability aspects with a special focus on future of work and ecological consequences. *International Journal of Engineering*, *14*, 131-136. https://bit.ly/48NdTZi

Gökalp, E., Şener, U., & Eren, P. E. (2017). Development of an assessment model for Industry 4.0: Industry 4.0-MM. In A. Mas, A. Mesquida, R. V. O'Connor, T. Rout, & A. Dorling (Eds.), *Software process improvement and capability determination* (pp. 128-142). Springer. http://bit.ly/48NBMj8

Gouvêa, M. A., & Cunha, R. D. (2005). The implementation of technology and its association with organizational profiles. *Revista Eletrônica de Administração*, *11*(5). https://seer.ufrgs.br/read/article/download/40624/25836

Hae-Young, K. (2017). Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restorative Dentistry & Endodontics*, *42*(2), 152-155. https://doi.org/10.5395/rde.2017.42.2.152

Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2016). Holistic approach for human resource management in Industry 4.0. *Procedia CIRP*, *54*, 1-6. https://doi.org/10.1016/j.procir.2016.05.102

Index Zona Costa BC. (2023, 2nd fortnight of the month). *Boletín Analítico Quincenal*. https://bit.ly/3Yx8jXy

International Data Corporation (IDC). (2017, January). *The next steps in digital transformation. How small and midsize companies are applying technology to meet key business goals*. Insights for Professionals. https://bit.ly/48LJ5YL

Johny, A., & Bhasi, M. (2015). An integrated model of factors affecting information technology implementation success in organizations. *International Journal of Engineering and Management Research*, *5*(2), 81-89. https://www.indianjournals.com/ijor.aspx?target=ijor:ijemr&volume=5&issue=2&article=017

Kinzel, H. (2017). Industry 4.0: Where does this leave the human factor? *Journal of Urban Culture Research*, *15*, 70-83. https://doi.org/10.14456/jucr.2017.14

Lee, S., & Kim, K.-J. (2007). Factors affecting the implementation success of Internet-based information systems. *Computers in Human Behavior*, *23*(4), 1853-1880. https://bit.ly/485tCDE

Martínez Martínez, A. (2020). Retos en la implementación de Industria 4.0: el caso de GKN Driveline. In A. Martínez Martínez, M. de L. Álvarez Medina, & A. García Garnica (Coords.), *Industria 4.0. Elementos diagnósticos y puesta en práctica en sectores y empresas* (pp. 133-152). Universidad Nacional Autónoma de México; Plaza y Valdés. https://www.researchgate.net/publication/346006091_Capitulo_6_Retos_en_la_implementacion_de_Industria_40_el_caso_de_GKN_Driveline - fullTextFileContent

Martínez Martínez, A., Hernández Sangabriel, A., & Cervantes Fuentes, L. R. (2023). Transformación digital y desafíos laborales en la industria manufacturera de Guanajuato. Una primera aproximación sobre GPI. *Entretextos*, *15*(39), 1-20. https://doi.org/10.59057/iberoleon.20075316.202339683

Matus, M. (2022). Respuestas socio-tecnológicas frente a la COVID-19 en México: spin-offs, repositorios e impresión 3D. *Nóesis. Revista de Ciencias Sociales y Humanidades*, *31*(61), 68-88. https://doi.org/10.20983/noesis.2022.1.4

Mohylna, L., & Makarova, V. (2023). Впровадження інформаційних технологій на вітчизняних підприємствах [Implementation of information technologies in domestic enterprises]. *Приазовський економічний вісник* [*Pryazovskyi Economic Herald*], *1*(33), 65-69. http://pev.kpu.zp.ua/journals/2023/1_33_ukr/13.pdf

Müller, J. M., Kiel, D., & Voigt, K.-I. (2018). What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*, *10*(1), 1-24. https://doi.org/10.3390/su10010247

Nabukhotna, Y., & Zhygalkevych, Z. (2022). Вплив інформаційних технологій на діяльність підприємства [The impact of information technology on the activities of the enterprise]. *International Scientific Journal "Internauka"*. https://doi.org/10.25313/2520-2057-2022-14

Ostertagová, E., Ostertag, O., & Kováč, J. (2014). Methodology and application of the Kruskal-Wallis Test. *Applied Mechanics and Materials*, *611*, 115-120. https://doi.org/10.4028/www.scientific.net/amm.611.115

Rajnai, Z., & Kocsis, I. (2017). Labor market risks of Industry 4.0, digitization, robots and AI. En *2017 IEEE 15th international symposium on intelligent systems and informatics (SISY)* (pp. 343-346). Institute of Electrical and Electronics Engineers. https://ieeexplore.ieee.org/abstract/document/8080580

Raso Delgue, J. (2018). América latina: el impacto de las tecnologías en el empleo y las reformas laborales. *Revista Internacional y Comparada de Relaciones Laborales y Derecho del Empleo*, *6*(1). https://ejcls.adapt.it/index.php/rlde_adapt/article/view/549/750

Riquelme, R. (2019, October 9). México llega con retraso a la Cuarta Revolución Industrial. *El Economista*. https://bit.ly/3Y0Rynm

Safar, L., Sopko, J., Dancakova, D., & Woschank, M. (2020). Industry 4.0: Awareness in South India. *Sustainability*, *12*(8), 1-18. https://doi.org/10.3390/su12083207

Sampietro-Saquicela, J. L. (2020). Transformación digital de la Industria 4.0. *Polo del Conocimiento*, *5*(8), 1344-1356. https://dialnet.unirioja.es/descarga/articulo/7554338.pdf

Sarı, T., Güleş, H. K., & Yiğitol, B. (2020). Awareness and readiness of Industry 4.0: The case of Turkish manufacturing industry. *Advances in Production Engineering & Management*, *15*(1), 57-68. https://doi.org/10.14743/apem2020.1.349

Singh, R. K., Garg, S. K., & Deshmukh, S. G. (2008). Implementation of information technology: Evidence from Indian SMEs. *International Journal of Enterprise Network Management*, *2*(3), 248-267. https://www.inderscience.com/info/inarticle.php?artid=18780

Sony, M., & Naik, S. (2019). Key ingredients for evaluating Industry 4.0 readiness for organizations: A literature review. *Benchmarking: An International Journal*. *27*(7), 2213-2232. https://www.emerald.com/insight/content/doi/10.1108/BIJ-09-2018-0284/full/html

Stoyanov, I. (2013). Information technology and managing organizational change. *KSI Transactions on Knowledge Society*, *6*(1), 10-13.

https://web.archive.org/web/20180409222740id_/http://www.tksi.org/JOURNAL-KSI/PAPER-PDF-2013/KSI-2013-1.pdf#page=10

Wang, L., & Wang, G. (2016). Big data in cyber-physical systems, digital manufacturing and Industry 4.0. *International Journal of Engineering and Manufacturing*, *6*(4), 1-8. https://doi.org/10.5815/ijem.2016.04.01

Ynzunza Cortés, C. B., Izar Landeta, J. M., Bocarando Chacón, J. G., Aguilar Pereyra, F., & Larios Osorio, M. (2017). El entorno de la Industria 4.0: implicaciones y perspectivas futuras. *Conciencia Tecnológica*, (54), 33-45. https://www.redalyc.org/journal/944/94454631006/94454631006.pdf