Opportunities and challenges

for the adoption of

Industry 4.0 in Mexico

Adriana Martínez Martínez
María Josefa Santos Corral
Rebeca de Gortari Rabiela

(Coordinators)

UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

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Alfonso Herrera 130, Interior 11,
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Ciudad de México C.P. 06470.
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Contenido

Industry 4.0 in Mexico. Regional Analysis on Knowledge and Implementation of 19 Technologies

Eduardo Arriola
Jorge Carrillo

Abstract

This study analyzes and compares the current situation of knowledge and implementation of Industry 4.0 (I4.0) technologies of skilled workers in the automotive industry in Baja California and Chihuahua. Based on the results of the I4.0 surveys applied in Baja California and Chihuahua, we analyze and compare the opinion of the workers surveyed on their knowledge of 19 technologies related to I4.0 and their level of implementation in the companies where they work. In general terms, companies in both states have low levels of knowledge and implementation of I4.0. Companies in Chihuahua have a higher level of implementation and are better prepared for I4.0 technologies than companies in Baja California. The main findings are that although Chihuahua and Baja California are at the forefront in the process of implementing Industry 4.0 technologies, both regions are still far from a widespread I4.0 adoption and from having a complete level of knowledge by their engineers. The study's limitations stem from the fact that these are perception surveys, and that two studies from different time periods are being compared.

Keywords: *Industry 4.0, engineers, automotive industry, Baja California, Chihuahua, Mexico.*

Introduction

We can say with some certainty that there is a consensus about what are the current technological trends in the automotive sector: Connectivity, Autonomy, Diverse Mobility and Electrification (CAME). These trends are part of something bigger that, in conceptual terms, is conceived as Industry 4.0 We therefore believe that it is appropriate to understand I4.0 as an umbrella concept that encompasses a set of technologies that are used in practically all industries, which we will describe below.

The automotive sector is not only a major consumer of the technologies associated with I4.0, but also a producer of them. While industries, as we know them today, have their own technological developments, we know that they are not entirely independent, as companies collect them in a vast market of technologies. But what stands out is that, with the consolidation of I4.0, different sciences, sectors and specific industries are increasingly converging in a conglomerate of innovation never seen before, characterized by enormous dynamism, high growth expectations and, most particularly, by broad and diverse experimentation.

The objective of this chapter is to determine engineers' knowledge and firms' adaptation of the technologies associated with I4.0 in two regions of northern Mexico, Baja California and Chihuahua, both characterized by a long tradition in the export manufacturing industry.

The study focuses on the comparison of the situation in Baja California and Chihuahua on the level of implementation of technologies inherent to I4.0 in the maquiladoras of the automotive sector and the level of knowledge of I4.0 that their workers have.

The chapter is structured as follows: the introductory section highlights the importance of I4.0 and the automotive sector in Baja California and Chihuahua. To do so, we will first describe conceptually what I4.0 is, the level of knowledge and the level of adaptation. In the methodological section, the methods used for the comparison of the estimation results with respect to the knowledge and implementation of 19 I4.0 technologies in the automotive industry in Baja California and Chihuahua are pointed out and described. The results section first presents the results regarding the comparison of the knowledge -in general- of I4.0 technologies, then the results of the comparison of the adoption levels - in general - of I4.0 technologies are shown, including the results of the comparison by type of technology, by level of complexity for the user and by level of technological novelty. Finally, the conclusion section highlights the importance of I4.0 in the automotive industry in border regions, discussing the main results obtained and possible future research.

About Industry 4.0

The term Industry 4.0 (I4.0) was coined by the German Government in 2011 during the Hannover Messe Fair in promotion of its strategic plan called *High-Tech Strategy 2020 Action Plan* (Flores-Saldivar *et al.,* 2015), and consists of robotization, autonomy and integration of the value chain. I4.0 implements digitalization technologies, robotization, internet tools and information and communication technologies; it integrates cyber-physical systems, products and people to create an internet of things and apply it in the industrial environment, thus enabling the formation of manufacturing networks (Pikas *et al*., 2016).

The continuous technological change promotes the implementation of new technologies in the productive chains of all industrial sectors, this brings changes that lead to a new way of producing and consuming, (Bensusán, Eichhorst and Rodríguez, 2017; AXIS Centro de Inteligencia Estratégica, 2019). In this tenor, the productive paradigm proposed by I4.0 promotes the benefits of technological adoption positively impacting the productivity of companies and the quality of products, in addition it enables production flexibility and reduces its costs (Cardoso *et al*., 2021); this has highlighted the importance of Industry 4.0 in the current industrial context.

About the level of knowledge about I4.0

It should be noted that the multidimensional nature of I4.0 causes it to be implemented differently in each case. In this sense, Carrillo *et al.* (2020) express that I4.0 is built in practice, "it is performative, and for it to exist, a continuous investment of actors committed to this new industrial reality is needed" (p. 6). Although the available literature on the term I4.0 and its implementation is abundant, the authors find that the literature on the knowledge required by workers to implement I4.0 is scarce.

In this sense, the knowledge of the I4.0 and the technologies that comprise it is considered valuable because it is closer to action (Ynzunza-Cortés *et al*., 2017), and its usefulness is evaluated by virtue of the decisions it leads to, such that better knowledge helps to make better decisions and this is necessary in the context of an increasingly competitive global economy (Albarrán-Trujillo *et al.* , 2020). In turn, the transformation of the classical industry towards the smart factory highlights the importance of technological knowledge, since it underlies the operation of the company, is part of its products and helps to differentiate products and services (Albarrán-Trujillo *et al*., 2020).

For their part, Sony and Naik (2019) in a study conducted in the European Union, found that some of the top management of organizations have little or no knowledge of the term I4.0. On the other hand, other industry leaders did have familiarity with I4.0, however, they were unaware of how to implement it in their organizations.

In relation to the above, Carrillo *et al.* (2020) highlight that the lack of preparation of organizations and the workforce with low levels of training represent a challenge for companies to successfully implement I4.0 technologies. In addition, the authors state that social or individual competencies, as well as the techniques used in I4.0 adoption and development processes are of vital importance for modern organizations.

About Industry 4.0 implementation

It is considered that the implementation of I4.0 should be designed in each case according to the specific organizational and production scenario, as well as the current resources and strategic objectives of the organizations (Martínez-Martínez, 2020). According to Müller, Kiel and Voigt, (2018), company size and production structure are also aspects that must be considered in the design of I4.0 implementation. This can represent major challenges, especially for companies that do not possess the financial means to implement all aspects of I4.0. The authors state that

> Thus, retrofitting of established production and logistics systems is required […]. In this context, industrial manufacturers should avoid implementing Industry 4.0 in the form of isolated applications […]. Otherwise, synchronization and coordination with existing production equipment and processes may result in high complexity levels and costs, which can become especially challenging for SMEs […] (Müller *et al.* , 2018, p. 7).

In relation to the requirements for the implementation of I4.0 technologies, Martínez-Martínez (2020) highlights that it is necessary for the organization to have a specific technological infrastructure, as well as workers with multidisciplinary profiles and varied skills. In addition, Ynzunza-Cortés *et al*. (2017) state that the success of I4.0 implementation depends largely on the network integration capacity that organizations can generate with the purpose of enabling connectivity and the generation of flexible production systems, as well as the complete integration of the value chain, allowing the operation of the new generation of manufacturing.

Among the challenges faced by organizations for the implementation of I4.0 Gökalp, Sener and Eren (2017) express that during the development stage it is of utmost importance to clearly define the structure and methodology to be used in the guidelines to be followed for the implementation of I4.0. For their part, Ynzunza-Cortés *et al.* (2017) highlight a series of challenges that must be considered among which are security issues, the high technological investment required for the transformation to I4.0, and the acquisition of skills related to data management and analysis, simulation, programming, predictive maintenance, among others (Ynzunza-Cortés *et al*., 2017).

It is by virtue of the vital importance that knowledge of I4.0 technologies has in the successful implementation of this, and taking into account that studies in this area are scarce, that the results obtained in this research acquire importance and shed light on the current situation about the knowledge and implementation of Industry 4.0 in the automotive and manufacturing sector in Baja California and Chihuahua.

Methodology

The present research focuses on the analysis and comparison of the levels of knowledge and implementation of technologies associated with I4.0 in Baja California and Chihuahua and uses the results of the I4.0 survey developed by AXIS Centro de Inteligencia Estratégica (2019).

The variables used for the analysis of the questionnaire applied were two: the level of knowledge about technologies associated with I4.0 of qualified employees in companies of different economic sectors, and the level of implementation of I4.0 technologies in the companies where the workers surveyed work.

The analysis considers 19 I4.0 technologies included in the questionnaire:

- Additive manufacturing (3D).
- Machine learning.
- Augmented reality.
- Virtual reality.
- Autonomous robotics.
- Collaborative robotics.
- Massive data analysis.
- Self-guided vehicles.
- Cloud computing.
- Blockchain.
- Cybersecurity schemes.
- Internet of things.
- Computational vision.
- Census and digital data collection.
- Advanced simulation/digital modeling.
- Vertical and horizontal software integration.
- Digital twin.
- Real-time process monitoring.
- Intelligent energy management.

For the case of Baja California, the questionnaire was sent to around 4,500 qualified employees of manufacturing companies during the month of June 2019. Responses were obtained from 164 people, yielding a confidence level of 90% with a margin of error of 6.3%. The questionnaire was administered online via email and through social networks.

The sample obtained includes employees from production, engineering, quality and supply chain departments. Respondents' organizational positions include technicians, engineers, department heads, managers and directors.

Respondents belong to seven manufacturing sectors: automotive, aerospace, electronics, medical devices, plastics, metalworking, and technical and technological services. The general results of the survey can be found on the AXIS website, under the report Baja I4.0/Industria 4.0 in Baja. Specific results with analytical treatment can be found in two previous publications: Carrillo, Vallejo and Gomis (2022) and Carrillo, Gomis, De los Santos, Covarrubias and Matus (2020).

For the case of Chihuahua, the I4.0 survey developed by AXIS is also used, but the survey measurement scale was modified to use a Likert scale with a 5-point response assignment. The questionnaire was administered online via email and through social networks during the period August 11, 2020 to February 3, 2021.

A total of 208 responses were received, of which 16 were eliminated because they showed statistical inconsistencies. The final sample contains the responses of 192 employees, representing 92.3% of the total number of questionnaires administered, yielding a confidence level of 90% with a margin of error of 5.95%.

The sample obtained includes workers from research and development, product/process engineering, supply chain, production, quality control, logistics and human resources planning and training departments. Respondents' positions include technicians, engineers, managers, directors and department heads.

The workers surveyed belong to eight manufacturing sectors: automotive, electrical/electronic/computer, medical devices, plastics, metalworking, paint application, and technical and technological services.

For the analysis of this chapter, we used exclusively the automotive manufacturing companies located in Chihuahua (representing 42.6% of the total respondents) and their indirect suppliers from the metal-mechanic industry (4.2%), plastics (5.3%) and technological services (7.9%).

Results

Next, the results are presented comparing the cases of Chihuahua and Baja California. The level of knowledge of skilled workers, in this case engineers, about I4.0 technologies is presented, followed by the level of adoption of these technologies by companies. Next, the type of technology, the level of complexity and the level of novelty of the technologies are analyzed.

Knowledge of I4.0 technologies.

Table 1 shows that, in general, the majority of workers in both states reported low levels of knowledge of I4.0 technologies. In addition, Baja California has a higher proportion of workers who reported having a high level of knowledge (36.9% BCN and 19.8% CHIH) and a lower proportion of workers who reported having a low level of knowledge, compared to workers in Chihuahua (63.1% BCN and 80.21% CHIH).

The automotive sector follows the same behavior, Baja California has a higher proportion of workers with high knowledge (29.4% BCN and 24.7% CHIH) and a lower proportion of workers who reported having a low level of knowledge (70.6% BCN and 75.3% CHIH), however, the gap is smaller for this sector.

The same dynamic occurs for the rest of the sectors, once again Baja California shows a higher proportion of workers with a high level of knowledge (39.6% BCN and 16.22% CHIH) compared to Chihuahua, and a lower proportion of workers with a low level of knowledge when comparing both states (60.4% BCN and 83.78% CHIH).

An important difference

When reviewing the automotive sector, we find that Chihuahua has a higher proportion of workers with a high level of I4.0 knowledge compared to the rest of the sectors (24.7% Automotive and 16.22% Rest), while, in Baja California, the automotive sector has a lower proportion of workers with a high level of I4.0 knowledge compared to the rest of the sectors (29.4% Automotive and 39.6% Rest).

Adoption of I4.0 technologies

In general, most companies in both states reported low levels of adoption of I4.0 technologies. In addition, Baja California has a higher proportion of firms with high levels of I4.0 adoption (46.7% BCN and 26.04% CHIH) and a lower proportion of firms with low levels of I4.0 adoption (53.3% BCN and 73.96% CHIH).

Regarding automotive sector companies, most companies in Baja California reported having a high level of adoption of I4.0 technologies [56.3% BCN and 30.86% CHIH]. While in Chihuahua the majority of automotive sector companies reported having a low level of I4.0 adoption (69.1% CHIH and 43.70% BCN).

For the rest of the sectors, most companies in both states reported having a low level of adoption of I4.0 technologies (77.48% CHIH and 56.8% BCN). However, proportionally speaking, there are more Baja California companies with a high level of I.40 adoption (43.2% BCN and 22.52% CHIH).

In both states, a higher proportion of companies in the automotive sector reported having a high level of adoption of I4.0 technologies compared to companies in the rest of the sectors. In Chihuahua, 30.9% of automotive sector companies reported a high level of I4.0 adoption, versus 22.5% of companies in the rest of the sectors. In Baja California, 56.3% of companies in the automotive sector reported a high level of I4.0 adoption, versus 43.2% of companies in the rest of the sectors.

Table 1 Level of knowledge and adoption of I4.0 technologies in automotive companies and the rest in Chihuahua and Baja California

		Level of knowledge of I4.0 technologies		Level of adoption of 4.0 technologies		Level in the sector (average)*	
Entity	Sector	Under	High	Under	High	Knowledge	Adoption
Chihuahua N=192	Automotive	75.31%	24.69%	69.14%	30.86%	0.470	0.463
	Rest	83.78%	16.22%	77.48%	22.52%	0.424	0.436
	Total	**80.21%**	**19.79%**	**73.96%**	**26.04%**	**0.443**	**0.447**
Baja California** N=66	Automotive	70.60%	29.40%	43.70%	56.30%	0.404	0.391
	Rest	60.40%	39.60%	56.80%	43.20%	0.323	0.410
	Total	**63.10%**	**36.90%**	**53.30%**	**46.70%**	**0.345**	**0.405**

Source: Own elaboration with information from the I4.0 Survey of Baja California and the I4.0 Survey of Chihuahua.

Notes: *Level represents an indicator ranging from 0 to 1, where 0 indicates the absence of the indicator and 1 is its maximum level.

**Data for Baja California were taken from Carrillo, *et al.*, 2022, Table 3.

Adoption by type of technology

The results in Table 2 indicate that Chihuahua companies have a higher level (0.48) of implementation of *tangible* I4.0 technologies compared to Baja California companies (0.37). In addition, Chihuahua firms have a higher level (0.43) of implementation of *intangible* I4.0 technologies compared to Baja California firms (0.33).

On the other hand, both states have a higher level of implementation of tangible technologies (0.48 CHIH and 0.37 BCN) and a lower level of implementation of intangible technologies (0.43 CHIH and 0.33 BCN).

In the case of the automotive sector, companies in Chihuahua have a higher level of implementation of tangible (0.50) and intangible (0.45) technologies than companies in the automotive sector in Baja California (0.46 and 0.37, respectively).

Similarly, companies in the rest of the sectors in Chihuahua have a higher level of implementation of tangible (0.47) and intangible (0.42) technologies than companies in the rest of the sectors in Baja California (0.33 and 0.32, respectively).

Adoption by level of user complexity

The results obtained regarding the adoption of technologies according to their level of complexity for the user show that companies in Chihuahua have a higher level of implementation of I4.0 technologies at all levels of complexity for the user, with low complexity technologies being the most used in both states (0.48 CHIH and 0.39 BCN), followed by medium complexity technologies (0.46 CHIH and 0.35 BCN), and high complexity technologies showing the lowest levels of adoption (0.41 CHIH and 0.29 BCN).

This same dynamic occurs for companies in the automotive sector, where low complexity technologies for the user are the most used in both states (0.49 CHIH and 0.45 BCN), followed by medium complexity technologies (0.47 CHIH and 0.42 BCN) and high complexity technologies show the lowest levels of implementation (0.43 CHIH and 0.33 BCN). The state of Chihuahua has the highest levels of implementation of I4.0 technologies for all levels of complexity for the user.

A similar behavior occurs with the companies in the rest of the sectors, such that low complexity technologies for the user are the most used in both states (0.46 CHIH and 0.37 BCN), followed by medium complexity technologies (0.44 CHIH and 0.32 BCN) and high complexity technologies show the lowest levels of implementation (0.40 CHIH and 0.27 BCN). Once again, the state of Chihuahua shows the highest levels of implementation of I4.0 technologies for all levels of complexity for the user.

It is noteworthy that, in both states, it is companies in the automotive sector that tend to show higher levels of implementation of I4.0 technologies regardless of the level of complexity of these.

Table 2 Average level of implementation of I4.0 technologies by type, level of complexity and level of novelty of the manufacturing sectors in Chihuahua and Baja California

Group of 19 I4.0 technologies										
		Type		User complexity			New at		
Entity	Sector	Tangible	Intangible	Download	Media	High	Download	Media	High
Chihuahua N=192	Automotive	0.50	0.45	0.49	0.47	0.43	0.49	0.47	0.43
	Rest	0.47	0.42	0.46	0.44	0.40	0.45	0.45	0.38
	Average	0.48	0.43	0.48	0.46	0.41	0.47	0.46	0.41
Baja California** N=66	Automotive	0.46	0.37	0.45	0.42	0.33	0.43	0.43	0.27
	Rest	0.33	0.32	0.37	0.32	0.27	0.36	0.33	0.23
	Average	0.37	0.33	0.39	0.35	0.29	0.38	0.35	0.24

Source: Prepared by the authors with information from the I4.0 survey in Baja California and the I4.0 survey in Chihuahua.
Note: *Level represents an indicator ranging from 0 to 1, where 0 indicates the absence of the indicator and 1 is its maximum level.
**Data for Baja California were taken from Carrillo, *et al*., 2022. Table 4.

Adoption by novelty level

The results obtained for the level of implementation of I4.0 technologies according to the level of novelty follow the same behavior as the results obtained for the level of implementation of I4.0 technologies according to their level of complexity for the user (Table 2).

And show that companies in Chihuahua have a higher level of implementation of I4.0 technologies at all levels of novelty, with technologies with a low level of novelty being the most used in both states (0.47 CHIH and 0.38 BCN), followed by technologies with a medium level of novelty (0.46 CHIH and 0.35 BCN), and technologies with a high level of novelty showing the lowest levels of adoption (0.41 CHIH and 0.24 BCN).

Similarly, in both states, automotive companies show a higher level of implementation of technologies with low level of novelty (0.49 CHIH and 0.43 BCN), followed by technologies with medium level of novelty (0.47 CHIH and 0.43 BCN) and technologies with high level of novelty show the lowest levels of implementation (0.43 CHIH and 0.27 BCN).

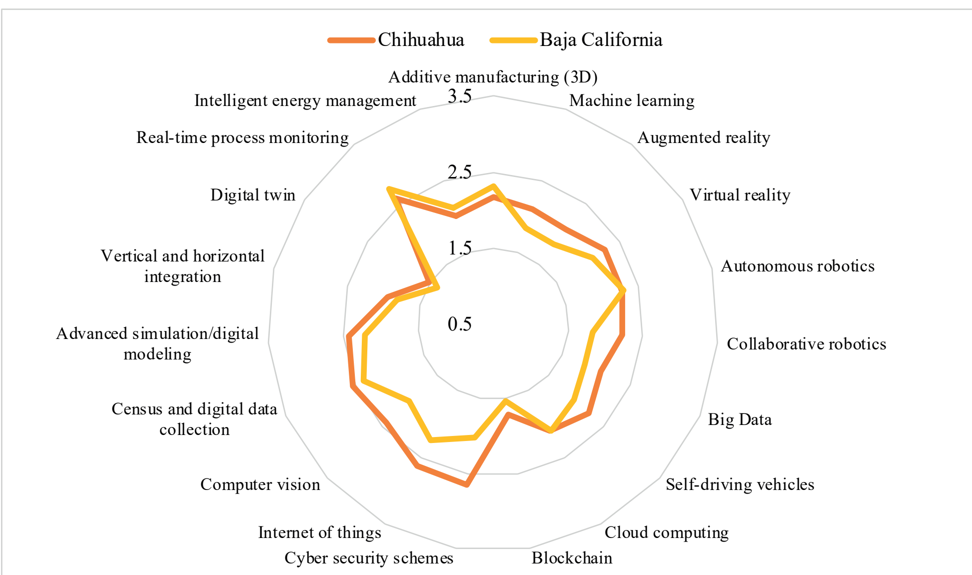
The state of Chihuahua is the one with the highest levels of implementation of I4.0 technologies for all levels of novelty.

In relation to companies in the rest of the sectors, once again, the behavior is similar, that is, technologies with a low level of novelty are the most used for the case of Baja California (0.45 CHIH and 0.36 BCN), while for Chihuahua, the same level of implementation is shown as technologies with a medium level of implementation (0.45 CHIH and 0.33 BCN) and technologies with a high level of novelty show the lowest levels of implementation for both states (0.38 CHIH and 0.23 BCN). Once again, the state of Chihuahua has the highest levels of implementation of I4.0 technologies for all levels of user complexity.

It is noteworthy that, in both states, it is companies in the automotive sector that tend to show higher levels of I4.0 technology implementation regardless of the level of complexity of these technologies.

Figure 1 shows the average knowledge levels reported for 19 I4.0 technologies in the states of Baja California and Chihuahua. The level has a range from 1 to 5 where a value equal to 1 means no knowledge and a value equal to 5 implies the highest level of knowledge.

Figure 1. Level of knowledge of I4.0 technologies in Chihuahua and Baja California



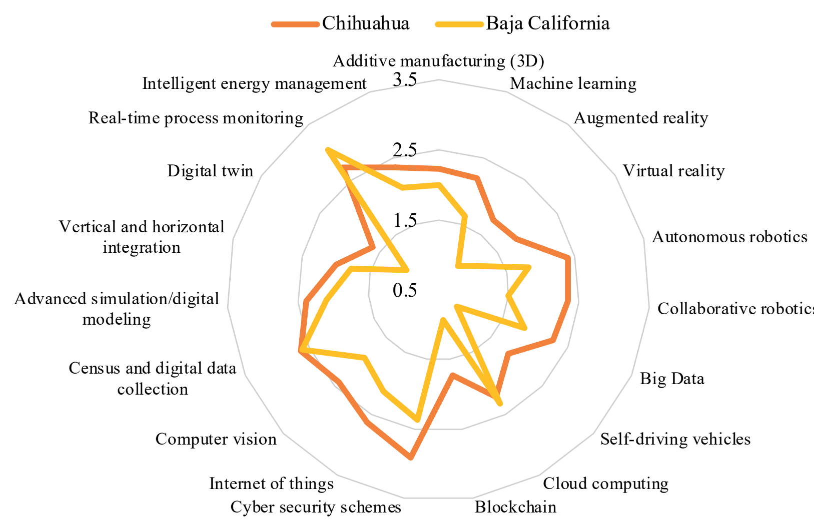
Source: Prepared by the authors with data from the I4.0 surveys of Baja California and Chihuahua.

It is observed that both states, in general, show similar levels of knowledge of I4.0 technologies. Real-time process monitoring, census and digital data collection, internet of things, cybersecurity schemes and autonomous robotics technologies stand out as the most known by workers in both states. On the other hand, digital twin and blockchain are the technologies that presented the lowest levels of awareness in both states.

It is also noteworthy that the most notable differences in knowledge are in the technologies of cybersecurity schemes, computer vision, internet of things, collaborative robotics and machine learning, with workers in the state of Chihuahua having the highest levels.

Figure 2 shows the average implementation levels reported for 19 I4.0 technologies in the states of Baja California and Chihuahua. The level has a range from 1 to 5 where a value equal to 1 means no implementation and a value equal to 5 implies the highest level of implementation.

Figure 2 Level of implementation of I4.0 technologies in Chihuahua and Baja California



Source: Prepared by the authors with data from the I4.0 survey of Baja California and Chihuahua.

The graph shows that, in general, both states show similar levels of implementation of I4.0 technologies. Real-time process monitoring technologies, cybersecurity schemes, census and digital data collection and internet of things stand out as the most used in both states. On the other hand, virtual reality, augmented reality, self-driving vehicles, digital twin and blockchain technologies are the technologies that presented the lowest levels of implementation in both states.

In terms of the most notable implementation differences between states, the technologies of self-driving vehicles, collaborative robotics, augmented reality, blockchain and virtual reality had the largest implementation gaps between states, with companies in the state of Chihuahua having the highest levels.

While Chihuahua companies reported higher levels of implementation in most I4.0 technologies, Baja California companies reported higher levels of implementation in real-time process monitoring and cloud computing technologies.

Conclusions

As we have seen, Industry 4.0 is present in some regions of Mexico, such as the northern border of the country. Chihuahua and Baja California are two states with a long industrial tradition of more than 50 years, as well as a clear export vocation. The maquiladora companies established in these regions have given way to the incorporation of various I4.0 technologies. This has gone hand in hand with the level of knowledge required by qualified human resources. Given the importance of the automotive sector, particularly the auto parts sector in the case of Chihuahua, it is to be expected that this process has started earlier and with greater strength compared to Baja California. However, since there is no data on this matter, we had to compare two studies carried out in different periods. First in Baja California and a couple of years later in Chihuahua.

The results show diverse data and differences depending on the specific technology analyzed. But in general terms, and as the graphs presented clearly indicate, companies in Chihuahua are more advanced in this process of adopting I4.0 technologies than companies in Baja California. The same is true for qualified human resources, who are better prepared to work with these technologies in Chihuahua than in Baja California.

In any case, what is most relevant is that both regions are still far from a generalized adoption and a more complete knowledge on the part of their engineers. As is known, industrial regions, especially exporting ones, such as Queretaro, Guanajuato, Jalisco and of course the northern states of Mexico, particularly Nuevo Leon, Chihuahua and Baja California, are at the forefront in the process of implementing Industry 4.0 technologies. More quantitative studies are needed to know the diffusion of I4.0 in Mexico, as well as more qualitative studies to understand the significance of this technological trend.

It is evident that technological change will become more aggressive and intense as the years go by, particularly in the mobility industry. Let us hope that governments manage to understand the importance of this paradigm shift and the necessary intervention with public policies, in order to move towards a more sustainable development.

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