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. 33, ART. 10, 2021

https://doi.org/10.33679/rfn.v1i1.2093

Knowledge-intensive SMEs in Ciudad Juárez: Diversity of trajectories, practices and understandings on I4.0
Las pymes intensivas en conocimiento de Ciudad Juárez: Diversidad de trayectorias, prácticas y entendimientos sobre la I4.0

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ABSTRACT

The objective is to analyze the trajectory of knowledge-intensive SMEs in Ciudad Juarez, with the determination to understand how the concept I4.0 has been defined. The methodology applied in-depth interviews with managers and visits to companies. The results show that the particular trajectory of the maquiladora industry in this city, as well as the experience in automation of local SMEs facilitate the appropriation of the new industrial model. The originality of the study relies on the fact that it is one of the few qualitative studies that explore the incursion of SMEs to I4.0 on the northern border of Mexico. The conclusions show that the conditions in a context of vulnerability have meant that some SMEs fail in their evolution towards I4.0, while others have opted for hybrid models, and the most successful have managed to scale towards the new industrial model thanks to their relation with other institutions of the innovation ecosystem. The main limitation of the study is that the sample is composed of 4 SMEs and the results cannot be generalized.

Keywords: 1. Industry 4.0, 2. spin-off, 3. knowledge-intensive SMEs, 4. Ciudad Juarez, 5. Mexico-U.S. Border.

RESUMEN

El objetivo del artículo es analizar la trayectoria de cuatro pymes intensivas en conocimiento localizadas en Ciudad Juárez, Chihuahua, con la finalidad de comprender cómo se han apropiado del concepto I4.0. La metodología implicó realizar entrevistas a profundidad con gerentes y visitas a empresas. Los resultados arrojaron que la particular trayectoria de la industria maquiladora en esta ciudad, así como la experiencia en automatización de las pymes, facilitan la transición al nuevo modelo industrial. La originalidad del estudio reside en que es uno de los pocos trabajos de corte cualitativo que exploran la incursión de pymes a la I4.0 en la frontera norte de México. Las conclusiones sugieren que las condiciones adversas del entorno han implicado que algunas pymes fracasen en su transición hacia la I4.0, en tanto que otras opten por modelos híbridos, y las más exitosas logren escalar hacia el nuevo modelo industrial gracias a su relación con diversas entidades del ecosistema de innovación. La limitación principal es que la muestra está compuesta por cuatro pymes y los resultados no se pueden generalizar.

Palabras clave: 1. Industria 4.0, 2. spin-off, 3. pymes intensivas en conocimiento, 4. Ciudad Juárez, 5. Frontera México-EE.UU.

Received: March 6, 2020
Approved: September 25, 2020
Online publication: May 31, 2021

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INTRODUCTION

Five decades ago, the state of Chihuahua integrated manufacture-related activities, which enabled it to develop major specialization in exporting maquila. Some of the prevailing industries are automotive, aerospace, electronics and information technologies. As of the eighties, in the state a spatial strategy has been carried out in order to further industrial development by means of promoting 37 industrial clusters considered key for the economy (FCCyT, 2014). As a result of the strategy, the municipality of Ciudad Juarez exhibits a noticeable concentration of maquiladoras and industrial parks, as well as other clusters and entrepreneurial organizations. Only in the first half of the previous decade, the state had 32 industrial parks, 19 business incubators and several entrepreneurial organizations (FCCyT, 2014).

In the present analysis we consider it relevant to enquire on the impact of the local innovation ecosystem on the advance of Industry 4.0 (I4.0) in the state, particularly in Ciudad Juarez and knowledge-intensive SMEs in this locality. The empirical evidence presented along the document suggests that some knowledge-intensive SMEs have managed to successfully transit toward the new industrial model owing to the collaboration between firms –facilitated by a number of institutions–.

Multinational enterprises (MNE) seated in the locality are actors with a polyvalent role in fostering I4.0 and its adoption by knowledge-intensive SMEs in Ciudad Juarez; they have served as allies, promoting the scale-up of SMEs by demanding development of I4.0 technology for their production lines. However their administrative conditions –lead time and payment terms– have made the transition difficult. In any case, it is of utmost relevance to point out that the firms we selected for the present study were in way or the other spin-offs of MNE already established in Ciudad Juarez.

I4.0 and knowledge-intensive spin-offs

The concept of I4.0, Industry 4.0, was publicly presented for the first time in 2011 Hannover Messe. I4.0 refers to the "real time digital integration of suppliers, producers and customers along the value chain and business models" (Lichtblau *et al.*, 2015, p. 10). For such integration to be possible, it is necessary to set up a series of technologies in the various phases of operation of the firms such as design, production, logistics, sales and customer service. In this regard, another definition identifies I4.0 as:

> […] the next organizational stage and total control over the value chain along the life cycle of a product. This cycle is based on the increasingly individualized desires of the customers, and goes from the idea, development, production and final delivery to the consumer through related and recycled services (Wolfgang, 2016, p.8).

https://doi.org/10.33679/rfn.v1i1.2093

I4.0 implies evolving toward a new industrial stage that encompasses:

> [the] integration of manufacturing operative systems and information and communications technologies (ICT) –particularly the Internet of Things (IoT)– […] from an operational standpoint, digital technologies such as CPS have the purpose of reducing set-up times, labor and material costs and processing times, which turns into a high-productivity process (Dalenogare, Guilherme, Ayala and Frank, 2018, p. 384).

In the case of Germany, Hirsch-Kreinsen, Weyer and Wilkesmann (2019) have proposed the following firm typology in connection with their transition to I4.0: 1) technologically intensive firms, which systematically apply new digital technologies and follow a planned strategy for long-term digitalization; 2) Selective firms, which use basic applications of digital technologies, e.g., new programming, Internet and cloud computing systems; and, 3) uninterested firms, which do not consider digital applications and seem unconcerned about the current debate on I4.0 (Hirsch-Kreinsen, Weyer and Wilkesmann, 2019).

The consulting firm Mckinsey Global Institute (2017) puts forward five factors that define the digital transformation of firms, and thereby, their migration toward I4.0, namely: 1) technical viability; 2) cost of developing and implementing the solutions; 3) labor market dynamic; 4) economic benefits; and, 5) regulation and social acceptance (Mckinsey Global Institute, 2017). Furthermore, Yang (2017) carried out a vast review of the literature on technology related to I4.0 and its adoption by firms and pinpointed at technological interoperability as the main challenge for its implementation and massive adoption. Consequently, the author proposes eight principles to attain interoperability: "accessibility, multilingualism, security, privacy, subsidiarity, use of open standards, open-source software and multilateral solutions" (Yang, 2017, p. 6).

By performing an analysis of 15 digital transformation models or route maps for I4.0 at global level, Mittal, Muztoba, Romero and Wuest (2018) identified that most of the times, these models did not take the specific needs of SMEs into account. An instance of this is that often the level 1 proposed in such route maps was disconnected from the actual digital transformation processes SMEs have to undergo; such gap widens as higher levels are reached. Owing to this, the authors suggest developing digitalization models and route maps toward I4.0, specifically aimed at SMEs.

For Mittal *et al*. (2018), SMEs that intend to attain intelligent manufacturing, in the first place, have to address their basic needs as regards computerization of the firms' core processes and connectivity with production areas, besides developing the following aspects: use of advanced manufacturing technologies, comprehensive use of software (including data analysis), research and development, consideration of standards, organizational culture and leadership flexibility, firm strategy, alliances with universities and research centers, dependence on a collaboration network (Mittal *et al*., 2018).

In the works above, it is distinguishable that not enough attention is paid to the size, sector and territory where firms operate in order to consider them factors with an impact on their transition toward I4.0. As explored in this article, such factors are defining for the case of knowledge-intensive SMEs, which are basically suppliers for the automotive sector in Ciudad Juárez.

In the specific case of Mexican firms, studies such as the one carried out by International Data Corporation (IDC) have underscored noticeable advance in the adoption of technologies associated with I4.0 by SMEs, even above German SMEs in some dimensions. IDC carried out a study in 10 countries and the sample was composed of about 4000 SMEs.

The survey asked about their self-perception in relation to digital transformation in their administration, operation, and business model. According to its results, five percent of the Mexican SMEs assured they were capable of producing insights in real time owing to automation, as compared with 4 percent of German firms. It is also distinguishable that only 13 percent of Mexican SMEs considered they had done very little to apply technologies for their digital transformation and participation in digital economy, whereas 16 percent of German SMEs recognize they are in this situation (IDC, 2017).

Conversely, other studies have identified noticeable ignorance and backwardness in Mexican engineers –and specialized workers or managers– as regards technologies associated to I4.0 and the transition to this industrial model. Such is the case of Riquelme (2019), or Axis' survey (2019), applied to 164 firm collaborators from a number of sectors with a seat in Baja California. Analyzing the data from Axis' survey, the following is concluded about I4.0: "when comparing the results of the survey in the seven economic sectors, it is noticed that most has a poor knowledge level" (Carrillo, Gomis, Santos, Covarruvias and Matus, 2020, p. 11). Moreover, it is distinguishable that the sector that concentrates the most knowledge in this respect is aerospace and technical and technological services (Carrillo, *et al*. 2020).

From our standpoint, this apparent contradiction is partly due to the huge difference in capacities between conventional and knowledge-intensive SMEs; while the former are delayed in their transition, the latter are pioneers in adopting the new industrial model and also in the existence of hybrid processes. Though, it is common that studies focused on the analysis of knowledge level or transition state of the processes toward I4.0 do not make a distinction between SMEs and knowledge-intensive SMEs.

Knowledge-intensive SMEs' are "firms and organizations that depend to a large extent on professional knowledge; that is to say, knowledge or expertise related to a specific (technical) discipline or functional (technical) domain in order to supply intermediate knowledge-based products and services" (Hertog, 2001, p. 505). This is the case of the SMEs analyzed in this article, firms that are intensive in knowledge largely composed of highly specialized staff, which came to being as spin-offs of multinational enterprises (MNE).

https://doi.org/10.33679/rfn.v1i1.2093

These spin-offs have been conceptualized as firms that come from knowledge developed and absorbed in the parent firm –most of times an MNE– and which is retaken by the new firm as a core part of its business model. For their part, these firms may be identified as knowledge-intensive SMEs, since the highly specialized knowledge becomes a central element in their business strategy, in addition to using technologies and highly specialized processes and having highly skilled labor force as well (Gomis, Hualde and Matus, 2019). Several spin-offs have been identified in the literature though, by and large, two types are distinguished: 1) "Corporate" or "appropriated" firms, in the way that they were sanctioned by the parent company and from which somehow, it receives some sort of benefit; and, 2) "hostile", "competitive" or "entrepreneurial" spin-offs, which were not promoted by the parent company whatsoever and neither are beneficial for such firm (Parhankangas and Arenius, 2003; Lindholm, 1994; Matus, Carrillo and Gomis, 2018). Over the article, we will analyze if the knowledge-intensive SMEs we worked with fit into one of these categories, and whether any spin-off has promoted or restricted the transition of the knowledge-intensive SME toward I4.0. For practical purposes, in the present text we decided to use a spin-off classification as corporative vs entrepreneurial; understanding the former as those promoted and beneficial in some way for the parent company, while the latter are competitive and adverse against the parent company.

From the specificity of knowledge-intensive SMEs that came to being via any of the spin-off processes described above, we propose that, unlike conventional SMEs, this sort of firms is distinguished by particularities that make their transformation and scale-up to I4.0. easy. In the following table we list some differences between MNE, SMEs and knowledge-intensive SMEs.

Table1. MNE, SMEs and knowledge-intensive SMEs

	Characteristics	MNE	SMEs	Knowledge-intensive SMEs
1	Financial resources	High	Low	Medium
2	Use of advanced manufacturing techniques (AMTs)	Very high	Low	High
3	Comprehensive software (including data analysis)	High (with more standardized solutions)	Low (usually customized solutions)	Medium
4	Research and development	High	Low	Medium
5	Sort of product specialization	Low	High	High
6	Observance of standards	High	Low	High
7	Organizational culture and leadership flexibility	High	High	Low

8	Firm strategy	Market oriented and accurate analyses	Directed by the leader's (owner) instinct	Directed by the leader's (owner) instinct
9	Decision making	Board of (internal and external) advisers and consultants	Restricted to the leader / few people hold knowledge	Restricted to the leader / few people hold knowledge
10	Organizational structure	Complex and formal	Informal and less complex	Informal and less complex
11	Use of human resources	Specialized domains	Multiple domains	Specialized domains
12	Exposure to development of human resources	Low inside the industry / high outside the industry	High inside the industry / low outside the industry	High inside the industry / low outside the industry
13	Knowledge developed with universities and research institutions	Developed around a number of areas	Focused on a specific area	Focused on a specific area
14	Alliances with universities and research centers	High	Low	Medium
15	Important activities of the firm	Inside the organization	Via outsourcing	Inside the organization
16	Dependence on a collaboration network	Low	High	High
17	Relation with consumers and distributors	Low (not so close)	High (close)	High (close)

Source: adapted from Mittal *et al.* (2018, p. 4).

The table above makes it evident the need to distinguish between SMEs and knowledge-intensive SMEs to analyze their transition to I4.0. This may solve the apparent paradox, previously pinpointed and identified by Carrillo *et al*., (2020) when contrasting some studies that consider that Mexican SMEs are noticeably delayed in such transition (Riquelme, 2019; AXIS, 2019) with others that have identified major advances (IDC, 2017). However, even among knowledge-intensive SMEs there are important differences as regards their transition toward I4.0 and their scale-up trajectories, including their downgrading as a way to adapt to a hostile context; this will be discussed later in the text.

CONTEXT VULNERABILITY AND DIVERSITY OF TRAJECTORIES

Another factor worth distinguishing in the analysis of the transition of the analyzed SMEs toward I4.0 is the vulnerability of the ecosystem in which they have developed; in most of the cases, it has negatively impacted them. Though in a counterintuitive manner, the analysis also suggests that the adversity of the context might have also facilitated the migration of knowledge-intensive SMEs to the new industrial model, at least in their discourses, and as a

https://doi.org/10.33679/rfn.v1i1.2093

marketing strategy that allowed them to overcome the economic and social crisis in a context of vulnerability. The main factors that have affected the scale-up of the analyzed SMEs are two: 1) the intensification of violence by organized crime as of 2006; and, 2) the global financial crisis (2008).

Such factors impacted in a differenced manner the analyzed SMEs, both temporarily and on the operation of the firm. Some SMEs were affected from the beginning of the crisis, while some others at the end. Firms with little institutional robustness recovered fast, while more mature SMEs took longer to do so; when they did it, however, they managed to move toward I4.0. The above is related to the following factors: 1) the effects of the global financial crisis and the local violence both decreased when the concept of I4.0 started to popularize, which enabled them to "ride the wave"; and, 2) owing to their experience in automation processes, they had already developed some of the capabilities necessary to move toward the new industrial model.

Our analysis is framed within the "catching-up" theory (Pred and Tomsqvist, 1981), which considers that innovations and technological knowledge expand and are absorbed in other territories and by actors other than the creators, according to their characteristics and particular capabilities. On the basis of the foregoing, our initial hypothesis suggests that, for the specific case of Ciudad Juárez, a border city where important subsidiaries of MNE have established over the last fifty years and the emergence of a myriad of local service-providing firms have both facilitated the dissemination and absorption of such technological innovations; as it is the case of technologies and processes associated to I4.0. Nevertheless, these trajectories have taken place amidst contexts of local crisis and uncertainty, domestically and internationally: for example, economic and even political crises as well as the context of insecurity are factors scantly taken into account by studies on the transition of knowledge-intensive SMEs toward I4.0.

Knowledge-intensive SMEs in Ciudad Juárez have reacted to the uncertain context in a differenced manner. This means that even if the sector and value chain of the product niche are important, the vulnerability of the context affects in a particular way all the actors in their processes of dissemination and absorption of technology. Owing to this, it is of the utmost importance to analyze the individual trajectories of knowledge-intensive SMEs over their transition to I4.0.

METHODOLOGY

The sample was composed of four firms self-identified as SMEs and offered marketing and integration services of technologies related to the so called I4.0. Field visits were carried out in October 2018 by this paper's authors. In all of the cases, a guided tour of the facilities of the firms and institutions took place. In-depth interviews were held with their managers and CEOs; the conversations were transcribed, systematized and analyzed. Moreover, the

webpages of the analyzed SMEs and institutions, as well as secondary sources were consulted.

The work is structured in four sections, which deal with the analyzed cases. These sections, for their part, comprise four subsections each: 1) the background and career of the members who started the enterprise; 2) the profile and trajectory of the firm; 3) main challenges they have faced; and, 4) concept, practices and vision regarding I4.0. In Conclusions, the cases are contrasted and the existence of various practices, trajectories, and understandings of I4.0 is put forward.

CASE 1: DOWNGRADING AS A STRATEGY IN THE FACE OF EXTREME VIOLENCE AND THE GLOBAL ECONOMIC CRISIS

Background and career of the members who started the enterprise

Firm 1 is a society created in 2006 by three engineer friends who met at Instituto Tecnológico de Ciudad Juárez. At first, their business idea was to offer 100-percent advanced automation services, which from the standpoint of one the creators means I4.0 services. It is worth mentioning that by the turn of the century, the concept I4.0 was inexistent, it was introduced for the first time in Hannover Messe, 2011, this way the interpretation of the initial business model by this entrepreneur is *a posteriori*.

According to its website, Firm 1 specializes in solutions aimed at promoting business. Were it not for its full name, which refers to automation, integration and manufacture, it would be impossible to find out what sort of services it offers. As it will be explained later in the text, we deem this lack of clarity in their business model comes, to a good extent, from experiencing a downgrading process (Brito and Carrillo, 2019), which took it from being a firm specialized in automation to specializing in manufacturing rework.[3]

The three engineers who created the firm had worked in a number of local SMEs and MNE for various periods –from three to eight years– before beginning the firm. One of them had been a manager for a local SME specialized in automation and he states that it was the inspiration for the idea of venturing in this sector; another had worked for an important MNE in the automotive sector; while the third partner was the owner of a small metal-mechanical company. The fact that the three partners had different backgrounds –MNE, SME and an own business– makes it difficult to classify this enterprise into the traditional notion of spin-off. However, for practical purposes and since the idea for the firm came from the last experience one of the partners had in a SME specialized in automation, we will place the enterprise into this category.

[3] Rework implies dispersing an order among various firms with a view to timely and duly meeting the demands of the enterprise that asked for the service.

https://doi.org/10.33679/rfn.v1i1.2093

In any case, it is relevant to underscore that the enterprise came from the convergence of engineers with different career backgrounds, which implies that the knowledge absorbed and developed, and the capabilities generated, were administrative, in some of the cases, while in others, technical. Being able to work in managerial posts for local SMEs, or that one was the owner of a metal-mechanical firm, allowed the partners to develop the administrative and commercial capabilities necessary for the new enterprise. While the experience of being with a MNE specialized in automation fostered the absorption of tacit and configured knowledge required to begin the new enterprise that would specialize in marketing and developing this sort of solutions.

In this sense, according to the spin-off classification presented in the introduction –corporative vs entrepreneurial– produced following Parhankangas and Arenius (2003), and Lindholm (1994), we consider this enterprise may be catalogued as one entrepreneurial, that is to say, it was not promoted by the parent companies the two partners had worked for before, neither did it benefit them directly. Though, it is relevant as well to emphasize that an extra characteristic that distinguishes this enterprise is its multi-stakeholder nature, in the way that it was promoted by three engineers with diverse backgrounds, which points at a situation not always addressed in the literature that discusses spin-off variations, in which it is common to consider these are promoted by individual agents dismissed from only one parent company. Owing to this, we consider it appropriate to identify this enterprise as "entrepreneurial and with multiple actors".

Firm's profile and history

The firm did not receive support from any governmental, academic or private agency to be created. With a limited budget, Firm 1 started operations in the garage of one of the founders. From the start, its customer base concentrated in MNE in the automotive sector, which accounts for 80-90 percent of the firm's projects.

The success of the enterprise encouraged the partners to move their offices to an industrial zone. Though, extreme violence propitiated by the war on drugs in Ciudad Juárez and the global financial crisis started to negatively affect the firm's operations: "for about two years we were in subsistence mode, adding to the extreme violence that had started, the global crisis came and hit everyone –2008-2010–" (face-to-face communication with the manager of Firm 1; October 7, 2018).

After the 2008 crisis and when local violence lessened, the firm managed to recover. The respondent (the manager) considers that this was possible partly because it was a small enterprise with a short existence: "we who started were more flexible with the employees because we had a narrow market share. This flexibility helped us rebound when there was an upturn" (face-to-face communication with the manager of Firm 1, October 7, 2018).

In point of fact, the respondent considered that the adverse economic and social context in the city back then even helped them rebound after the crises and began competing in areas neglected by enterprises with longer careers, which did not manage to recover from the crisis in spite of their institutional robustness. However, owing to the difficulties of having steady costumers in automation and the high cost implied in maintain a widely trained labor force, in recent years the firm moved their business model to advanced automation for manufacture "rework".

In 2018, the firm had 20 employees, though in previous years its workforce had reached up to 70, comprising engineers and operatives. Notwithstanding, the manager told us it was very difficult to keep a workforce of such characteristics, since the demand may change suddenly and unexpectedly:

> […] if the four clients we had were involved in a GM launching at once, we'd reach 70 people […] it is a graph difficult to control for, sometimes there were many projects, some others, none […] so we changed to manufacturing […] obviously business is not the same, but from my standpoint, it is more profitable than automation (face-to-face communication with the manager of Firm 1, October 7, 2018).

The challenges of running a knowledge-intensive SME: downgrading as a form of entrepreneurial resilience

From our point of view, the phenomenon of changing business model from advanced automation to manufacturing rework may be labeled as downgrading; it is the case when a firm decides to "involute" in order to adapt to a complex context of economic crisis and extreme violence (Brito and Carrillo, 2019). This does not mean the firm did not have the knowledge or capacities needed to offer advanced automation services in the ecosystems it operates and even transit toward I4.0.

In the respondent's words, what prevented them to carry out working in this area was that the MNE they worked with increased their administrative demands and extended the time for payments, which required large amounts of capital to continue operating:

> […] MNE have had to reinvent themselves, we are a mirror of them because they're competing with each other […] it was 16 or 18 weeks in the past, now you have to deliver in 12. "What are you going to do? I don't know, I lend you the robot, but I need you to dully abide by our terms" (face-to-face communication with the manager of Firm 1, October 7, 2018).

On the contrary, payments take a different path: "there are many enterprises that do not make any upfront payment and boldly tell you, I pay after 90 or 120 days, as a Delta, and you end up not accepting (face-to-face communication with the manager of Firm 1, October 7, 2018).

https://doi.org/10.33679/rfn.v1i1.2093

Concept, practices and vision on I4.0

As mentioned earlier, for the interviewed manager I4.0 is virtually synonym to advanced automation and because of that he considers that the initial business model of their company may be inscribed in I4.0. One of the automation projects developed around this time was a bending station capable to adapt to various car models:

> […] the initial prototype, the machine was in Germany, over a video they asked us what we were able to do locally with this project. We watched and agreed to do it on a rush, as the typical Mexican, we did it, delivered it, that was one of the most complex challenges […] it started as a one-tonne machine and end up as a three-tonne, it changed much from beginning to end (face-to-face communication with the manager of Firm 1, October 7, 2018).

From this anecdote, it is possible to infer that in some sense, the flexibility of Mexican knowledge-intensive SMEs to adapt to their clients' demands has been an added value to their busines model.

From the respondent's standpoint, in Mexico there is much to do in order to attain a full transition to I4.0, and to a good extent this is because the country assembles or integrates technology, rather than developing it: "we, in this automation sector in I4.0 only promote the side of machinery and staff, not the part of the product, which in my opinion, we would have to command in Mexico" (face-to-face communication with the manager of Firm 1, October 7th, 2018).

CASE 2: FROM SOLUTIONS IN ELECTRICITY TO DIVERSIFICATION TO ADAPT TO TECHNOLOGICAL AND GENERATIONAL CHANGES

Firm 2 is a family firm established in 1982 in the City of Chihuahua. It was founded by the father of the current CEO, who was an accountant who worked for a French company specialized in marketing electrical material. Over time, the accountant became the firm representative and when the owner died, he decided to become self-employed and started his own business in the same sector, in any case the original company continued its operations.

As in the previous case, we consider that it is difficult to catalogue this enterprise as a corporate or entrepreneurial spin-off in the categories commonly resorted to (Parhankangas and Arenius, 2003; Lindholm, 1994) because the creation of the firm was triggered by an unexpected circumstance, not rationally planned in advance. However, for practical purposes, this spin-off will be considered "entrepreneurial-circumstantial", for its inception was not promoted by the parent company, neither was it benefitted in any way; on the contrary, they soon became competitors. Owing to this, we consider that the particularity of this spin-off suggests that the rational action commonly associated to a spin-off is not always relevant for a firm to appear; the contingency, the casual and unexpected may be drivers as well.

In our visit in 2018, the three daughters of the founder of Firm 2 worked for it, and so did two of their respective husbands. Back then, the enterprise had moved their headquarters to Ciudad Juárez years ago. One of the daughters studied chemical engineering and marketing; she was a CEO around that time. Other daughter, a nurse specialized in hospital management, was in charge of managing the firm. For her part, the youngest daughter, who studied electronic engineering and held a master in automation, was the manager of the Engineering area.

The husband of the interviewed CEO was also a chemical engineer and was in charge of providing technical support to sellers; while his brother-in-law was an electronic engineer and provided support in a number of areas of the firm. Out of the profiles and capabilities of the sisters and husbands who are part of the family firm, it is distinguishable that only one of the sisters is specialized in automation, whereas the rest of them has skills in electronic engineering, chemistry and even administration, in the health care sector, though. Due to the above, they had to learn and develop the capabilities needed to run a firm which at present focuses a sizeable part of their business model on marketing technology associated to I4.0.

At the time of our research in 2018, the total workforce of the firm reached 40 people; around 90 percent was specialized in any engineering. That is to say, it is a firm with highly specialized human capital.

Profile, history and running of the firm

In its first year of operation (1982), the firm in electric material commercialization stood out because it offered a prompt and personalized delivery of products that were not easy to find in Mexico; the owner made constant express round trips from Chihuahua to El Paso, Texas, in order to secure their clients' requirements.

In 1995, the firm moved their offices from Chihuahua to Ciudad Juárez with a view to being closer to the maquiladoras' headquarters for decision making and gaining easier access to the novelties of the trans-border business ecosystem. As the current CEO of the firm told us, such change was out of the need to be always at the forefront and in a business ecosystem with clients open to innovations. Over time, the firm started to diversify its products and services, changing from marketing electric products to installing them: "then we evolved, selling the products delivers a solution that is automation, it's been evolving, right now what we do is to deliver fully assembled machinery" (face-to-face communication with the CEO of Firm 2, October 8, 2018).

Similar to Firm 1, as a consequence of the high rate of violence in the city, by 2009 Firm 2 closed its central office and moved its operations to a private house: "[…] four years ago we returned here, we were five years hiding in a private home. It was devastating, around here fires were set because no racket was collected" (face-to-face communication with the CEO of Firm 2, October 8, 2018). Besides, the manager pointed out that this decision was

https://doi.org/10.33679/rfn.v1i1.2093

made after two employees were shot while driving a truck of the firm, apparently mistaken for staff of another firm that was being extorted.

The firm's recovery in the face of the crisis caused by violence in Ciudad Juárez was relatively fast, partly as a consequence of its capacity to diversify its business model and explore other market segments, beyond selling and installing electric material; the firm started to enter into areas such as manufacturing and integration. Such strategy, contrary to the downgrading of Firm 1, may be identified as "business diversification", which helped the firm's resilience over the crisis. In 2018, the firm started to market software and technology associated to automation and I4.0 from alliances with international companies.

At present, the customer base is diverse. The CEO considers they have a record of more than 200 clients, who at some moment they have served and provided services to; though out of them, the returning customers who do business often are 60. Moreover, she thinks they serve 30 percent of the 370 maquiladoras in Ciudad Juárez, most of which belongs to the automotive sector. Distinguishable clients are Continental, Johnson Controls, Delphi, among others.

The CEO also expressed that five of their customers alone account for 80 percent of the revenue, begin Continental and Johnson Controls the most prominent. Nevertheless, she was very cautious stating that such figures are approximations because they do not have a clear measure for clients and recurrent purchases, which pinpoints a technological lack in administration. On the contrary, the sales area has noticeably advanced in the automation of its processes. As expressed by the CEO:

> When sellers or sales forces go out to the street, we developed an application [which] automatically by pressing enter directs to sales department or customer support […] All of our products are loaded in the system, a quote can be automatically generated, the idea is that the customer receives the quote within half an hour (face-to-face communication with the CEO of Firm 2, October 8, 2018).

The above indicates that the firm's sales area has become involved in the automation of the orders, which suggests that within knowledge-intensive SMEs, there is diversity between the automation levels of its internal processes.

From electrical solutions to diversification in order to adapt to technological and generational changes

The engineering department – led by one of the sisters– designs and selects the products necessary for solutions in automation from its suppliers' stocks. In case the required products are unavailable, the firm looks for a new supplier, and even manages to develop it if it is within their capabilities. Owing to this, the machining area is one of the new activities of the firm as of 2015. If they are not able to develop the solution, they hire a company specialized in machining. Once the solution is ready, a team of technicians, supervised by the CEO's husband, carries out the installation.

As regards the marketing of energy and production efficiency software, the enterprise formed an alliance with a Spanish developer company. As stated by the respondent (CEO), the advantage of such software is its adaptability to their clients' needs. However, they have to develop capabilities in such area, this is the reason why a nephew studies computer engineering, for the purpose of taking charge of the area of software development in the future. This suggests that some knowledge-intensive SMEs, organized from a family firm model, train and specialize their younger generations in order to integrate them into the SME and adapt it to technological changes and associated capabilities.

Another area which this firm has recently explored is education. In this regard, they offer robotics courses for children and adults, workshops to certificate digital skills:

> […] we integrated lessons and workshops for people in need of increasing their schooling level because they have the expertise, but lack the certification or even the theoretical background, we are working to make a junior technical team in mechatronics (face-to-face communication with the CEO of Firm 2, October 8, 2018).

As for this firm's trajectory, its wide diversification of activities in recent years is noticeable. It is considered this strategy has served the firm well, not only to adapt to the vulnerability of the ecosystem where it operates, but also to technologic and generational changes. Being a family firm, its members have found it necessary to integrate younger generations and explore activities that are complemented by their professionalization, and all signs indicate it has been a successful strategy.

Concept, practices and vision on I4.0

As previously mentioned, in 2018, the firm started to introduce itself as specialist in I4.0 industry solutions. This was partly because of its recent association with a cluster specialized in automation and I4.0. Though additionally, this change was driven by the youngest sister, for in 2018, she was granted support from the now defunct *Instituto Nacional del Emprendedor*, Inadem [National Institute for Entrepreneurship] to stay for a month in Germany and learn about I4.0 in a SME. The following anecdote was shared by the respondent:

> [The] place we were taken is a firm just like ours, where one process is carried out just by robots; another in which all they do is 3D printing, but not the entire enterprise, certain highly specialized areas: collaborative robot arm. Another is the application of 3D printing, the rest is machining (face-to-face communication with the CEO of Firm 2, October 8, 2018).

Even if in recent years the firm has explored the use and sale of various technologies associated to I4.0, the CEO of the firm considers that its added value is in the specialization they are developing in industrial big data and as she deems it, none of the companies in the cluster above was developing that at the moment:

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> We're using [Big Data] in a project we've won […] what we did was to look for an alliance with someone who had it already, now such alliance is with a Spanish firm because they already had it. We are pressed by time because the customer wants it already, tells us 'hey, I want it now', 'but I don't have it yet, it's under development' (face-to-face communication with the CEO of Firm 2, October 8, 2018).

The way the firm solved the client's need to develop software hints at the inoperability of the funds provided by *Consejo Nacional de Ciencia y Tecnología*, Conacyt [National Council of Science and Technology] for this sort of developments due to the usual delay in their allotment. It also suggests a different management of such funds to overcome the contingence, instead of developing a software of their own, they are forced to buy it and adapt it –to the extent possible– to the local needs.

The wide diversification of the firm's business model and its incapacity to produce a quick response, according to the times demanded by some of its clients, have made it forge international alliances in the best of cases. On other occasions, they have lost customers as the firm does not have fulltime personnel to develop innovative solutions: "our dream is to have a person, a guru, thinking of the solutions. The poor boys get desperate and say do I think or do or what because it is urgent and it's not working or stuck… because we have to fight against all this" (face-to-face communication with the CEO of Firm 2, October 8, 2018)

As regards their vision on I4.0, the CEO considered that the new industrial model is a tendency that everyone wants to follow, even though it also implies fear of cybersecurity issues, and this is one of the greatest barriers for full adoption:

> […] our solutions need Internet and these are on the machine, one goes to maintenance, production, quality and says 'I need this', but I need an Internet node to communicate it and that is a killer, because people in systems do not want anyone in their network, from corporate to internal policies because they are afraid (face-to-face communication with the CEO of Firm 2, October 8, 2018).

CASE 3: SPECIALIST IN ADVANCED MANUFACTURING INDUSTRIAL PROCESSES

Background and career of the members who started the enterprise

Firm 3 specializes in advanced manufacturing industrial processes. It has its central offices in Ciudad Juárez, but also has presence in El Paso, Texas, and in el Bajío. The CEO of the firm holds a degree in engineering. When he finished, he entered into the maquila industry in Ciudad Juárez. In the beginning of his work trajectory, early in the nineties, he was a process engineer with Johnson Controls, in 1995 he incorporated into the automotive systems area with Bosch, in the department of mechanical design and process improvement.

Over the three years the respondent work for this MNE, he specialized in 3D design. Once this expertise was gained, after the recommendation of a friend who worked for Bosch, he

decided to quit and start his own enterprise in 1999. At that time, the current CEO of Firm 3 was not even 30 years of age and was single, which he considers helped him boost his enterprise, as he was able to invest all his resources –i.e., time and money– on the new firm. In 2001, he formalized his company by creating a *Sociedad Anónima*, S.A. (a stock corporation or somewhat a Limited Liability firm).

In 2018, the workforce in Firm 3 comprised 110 collaborators, of which 50 percent were professionals specialized in various fields of engineering –control, mechanical–. Moreover, through Conacyt programs, the firm used to incorporate personnel from local institutions highly specialized in specific projects.

As regards the characterization of the firm as a spin-off, we consider it may be a sort of "internal-corporation"; that is to say, driven by internal stakeholders, since former managers with Bosch motivated its inception, they also benefitted from it purchasing its services over a number of years.

Background, career and operation of the enterprise

The first opportunity window the new firm found in the automotive sector was unforeseen events and emergencies. In an interview with Guerrero (2019), this very CEO pointed out:

> Automotive industry reacts in a rush when a defective product reaches the client. It may be in need of contention measures, as an additional machine to verify or run the process more safely. I was called in for cases like these (Guerrero, 2019, p. 1).

Having no machining workshop in the beginning, the current CEO opted for outsourcing the service, he did the same in operations for Programmable Logic Controllers (PLC). The first employee of the firm was a student in charge of delivering works and making adjustments. To make his firm grow, the CEO virtually invested all his revenues on equipment, hiring and renting the place. From his standpoint, it was this way that over the first 15 years, he managed to attain a 25-percent annual growth (face-to-face communication with the CEO of Firm 3, October 10, 2018)

At present, the firm's main business lines are the design and integration of automated production lines. Its principal clients are MNE in the automotive sector, which virtually account for 95 percent of the earnings. Notable clients are Continental and Bosch.

The CEO pointed out that the products and services offered by his company have evolved together with the needs and demands of the MNE it works with:

> They [MNEs] have commanded us, what we know we have learnt from the challenges, they ask us to assemble a robot, integrate it, we have to learn about robots, vision, and laser welding. They are indicating us the areas in which we need to be ready (face-to-face communication with the CEO of Firm 3, October 10, 2018).

The firm also has an office in El Paso, where it is registered under a different name. The decision of opening this office has to do with the fact that most of the purchases are made in

https://doi.org/10.33679/rfn.v1i1.2093

the United States, in addition to having direct access to producers. Another factor that motivated the binational expansion of the firm was that its Mexican clients prefer to shop via an American enterprise with a view to reducing taxation in Mexico.

From the loss of confidence due to social deterioration to the emergence of MACH cluster

The social context experienced in Ciudad Juárez by then end of the first decade of XXI century was not only violent and marked by economic crisis, but also of loss of confidence among local entrepreneurs. A fact that crushed social bonds was:

> There is an antecedent in Ciudad Juárez. It was intended to create a machining cluster, but it was a fraud. We all who do automation do machining as well, we all took part of the experience. Funds were transferred, fees paid, an industrial nave was built, where each of us will have our own areas sharing services such as forklifts, ramps. It was all done and in the end the project stopped because the money never arrived (face-to-face communication with the CEO of Firm 3, October 10, 2018).

Some years after this experience, in 2017, the CEO himself decided to promote *Clúster de Manufactura Avanzada del Estado de Chihuahua*, MACH [Advanced Manufacturing Cluster of the State of Chihuahua]. According to information from the website of the cluster, in 2019, it comprised 10 SMEs, which in total had 622 employees. Their sales amounted to 29.45 million USD a year and have an installed capacity worth 20.6 million USD. It is distinguishable that 50 percent of the firms is binational.

Concept, practices and vision on I4.0

Up to 2018, the CEO of Firm 3 considered that I4.0 was nothing but advanced manufacturing and that the term was just a fad:

> I was sort of skeptical, I said it was advanced automation, robots already exist, the same for distribution systems, the cloud, that is not industry 4.0; it is a topic in fashion, cliches, everyone wants to talk about current topics […] truth is it took me almost a year to assimilate what industry 4.0 is, in spite of being already immersed in such topics (face-to-face communication with the CEO of Firm 3, October 10, 2018).

Furthermore, the respondent pointed out that it was because of MACH cluster that they managed to access information on I4.0, his firm as well as the other SMEs that are part of such organization: “owing to the formation of the cluster we had a greater information scope, we attended congresses, participated in forums, we learnt about industry 4.0. We did have it, but we hadn’t conceptualized it” (face-to-face communication with the CEO of Firm 3, October 10, 2018).

From his point of view, in Mexico, I4.0 is still under “experimentation”; it is a sort of laboratory and there is a long way to reach 50 percent of the transition. Owing to this, he

considers it necessary the participation of various stakeholders: governments, education institutions and the firms themselves.

In relation to some of the problems the CEO of Firm 3 identifies as limits for knowledge-intensive SMEs in Ciudad Juárez manage to scale and fully transit toward I4.0; underscoring funding, product innovation and security. On the first, he pointed out that the corporations pay SMEs after 90, 120 or 180 days, which has taken some of them to bankruptcy. In relation to the impossibility of innovating, he stated that due to financial pressures and the shortness of delivery times as a CEO he spends his time "putting fires out, completing the payroll, trying to deliver on time, and trying to save money; we scantly look at the ecosystem or plan a future strategy" (face-to-face communication with the CEO of Firm 3, October 10, 2018). Regarding security, he considered "there is fear of an inadequate use of the information uploaded to the cloud […] uploading it to the cloud makes it vulnerable, many of the opportunities we have to implement I4.0 are not being taken" (face-to-face communication with the CEO of Firm 3, October 10, 2018).

CASE 4. A KNOWLEDGE-INTENSIVE SME FOCUSED ON INNOVATION OF I.40 PRODUCTS AND SERVICES

Background and career of the members who started the enterprise

Firm 4 started operations in 2001. Its CEO is an electromechanical engineer graduated from Instituto Tecnológico de Ciudad Juárez. Before he decided to become an entrepreneur, this firm's founder worked for four years in some MNEs in Ciudad Juárez engaged in maquila and manufacture. In these companies he learnt the technical skills that would enable him to start his enterprise. Moreover, the CEO remembers that he decided to do so to a good extent motivated by the people whom he provided the services with while working for the MNEs. That is to say, on occasion spin-offs are also motivated by external agents who encourage an individual to start a firm to offer freelance services, and in this way, personally dealing with the customers or making discounts, among other motivations.

Due to the above and according to the classification of spin-offs, i.e., corporative vs entrepreneurial, we deem this enterprise as the latter. That is to say, it was not promoted by the parent company, while the spin-off did not benefit it directly. Albeit, it is also relevant to emphasize that it was indirectly encouraged by agents alien to the parent company, who motivated the spin-off with a view to benefiting from the new firm; for example, accessing direct deals and lower costs. Owing to this, we consider it appropriate to call this enterprise as "entrepreneurial-external", for it was encouraged by agents external to the MNEs and for the purpose of becoming a competitor.

When we visited Firm 4 in 2018, it had 23 employees, out of which, 12 were engineers; that is to say, roughly 50 percent; plus, eight technicians and administrative staff. Adding to

https://doi.org/10.33679/rfn.v1i1.2093

that, there are external collaborators, doctors from local universities, who support on R&D or are called to help solve specific problems.

Profile, trajectory, and operation of the enterprise

The last company the CEO of Firm 4 worked for was *Integración de Sistemas Electrónicos* (ISEL), supplier for Delphi and Simens. In this enterprise he was given the chance to experiment with technology and over time he decided to become self-employed: "when I left, I made a catalogue of the services I was able to provide, I knocked at the maquilas' doors and left my brochures" (face-to-face communication with the CEO of Firm 4, October 9, 2018).

This CEO narrates he started offering services to develop machinery, processes, and technology. He recalls that at the beginning it was very difficult to secure a project because of his age, 25 at the time, while his experience in the field was limited, though not so the knowledge he had gained in ISEL. This came into conflict with the idea he had from clients and distributors with ISEL, who had encouraged him to start and enterprise with the promise of hiring his services. And since sales expectations agreed "in talks" were not realized, the CEO started a sort of creative improvisation to adapt to the adverse social and economic conditions:

> […] we found there were opportunities to develop stuff for maquilas which industrial services didn't provide, there was stuff that was inexistent, needs that hadn't been addressed, we started to develop technological products (face-to-face communication with the CEO of Firm 4, October 9, 2018).

Firm 4 started to operate with no facilities. Its initial business model implied a personal visit to the clients and develop the services inside the firm itself:

> […] I remember I had a 50-inch screen, I took that, my CPU and the route; then I arrived and they told me 'I want to change that machine programming'; I was there with my computer, a very large CPU, I started with illegal software (piracy), a computer I built myself, one of the cheapest (face-to-face communication with the CEO of Firm 4, October 9, 2018).

One of his first important clients was the company ALTEC Electrónica Chihuahua, engaged in assembling industrial vacuum cleaners. The respondent recalls that the payment was relatively low in comparison with the quality demanded. Moreover, at first, he had to hire the machining services, which made him spend on this and reduce his earnings. Over time, however, he learnt to make quotes and little by little his firm started to produce revenues up to establishing his own operation workshop in an industrial zone of Ciudad Juárez. That is to say, the respondent developed administrative skills "on the fly".

The firm evolved well over the first ten years; though, the 2008 crisis and the wave of violence in Ciudad Juárez forced a partial closure early in the 2010's decade. The firm reopened in 2015: "everything came down […] people you trust starts leaving you, they get

intimidated and quit, they are afraid" (face-to-face communication with the CEO of Firm 4, October 9th, 2018). When asking the CEO the reason to close after other firms started reopening after the severe wave of violence in the city, he pointed out that crises hit firms at various times, which suggests that each has a varying capacity to adapt that depends on their internal maturity and resilience capacity.

At present, Firm 4 has a binational presence as well. In its offices in El Paso, Texas, they manage the administration, in this way they deduce taxes of the company and clients. Moreover, this makes it easy for them to import the materials necessary for their developments.

From lack of confidence in institutions to alliances with emerging actors

From the respondent's standpoint, corruption is an evil that affects the advance of industry in the country. He has visited factories where he is asked to solve a specific problem with a machine or production line, and when he examined the problem, he realized that corruption is to blame, for the technology failed from the start because inadequate technology was acquired, or it was bought at overprice.

He even told us he had been offered projects as long as he charged at an overprice up to 50 percent, for the individual who would grant the project. Owing to this, the philosophy of Firm 4 does not promote nor allows partaking of this sort of corruption.

An extreme case faced by Firm 4 is related to one of the federal programs supposedly to support R&D. Over the interview, the CEO stated that on one occasion the national institute for the promotion of technologic and scientific developments in the country approved a project between a university and an enterprise, whose objective was to help develop a vision system for a production line.

However, in order to receive the resources, as a condition they were asked to hire a private marketing company, which would charge more than 50 percent of the money allotted to develop the project; he did not accept. From this disagreeable experience the firm decided not to work with such governmental institution again.

Concept, practices, and vision of I4.0

In 2015, when Firm 4 formally started operations once again, it focused on I4.0:

> […] we noticed the industry needs, we make our money from machines, we notice the need to connect them […] right now all the firms tell us 'we want manufacture 4.0, we want innovation and more productivity because those are the tendencies' (face-to-face communication with the CEO of Firm 4, October 9, 2018).

Unlike the previous SMEs, Firm 4 invest 10% of its monthly revenues on R&D. This is an essential part of its business model, as the CEO considers not only they are "solving

https://doi.org/10.33679/rfn.v1i1.2093

problems", pressured to deliver an automated production line as soon as possible, with delayed payments and with no funding:

> […] we're the creative part, we're not interested in manufacturing thousands of robots, the time will come to change from robot manufacturing to something else. Yes, we create the concept, make it a prototype and works, but what we envision is that if someone arrives, we're going to give them manufacturing (face-to-face communication with the CEO of Firm 4, October 9, 2018).

As regards the barriers this CEO identified for the success of knowledge-intensive SMEs, he mentioned lack of confidence in locally developed technology. He even confided that on occasion, when selling his technology 4.0, he tried to hide his Mexican nationality, and introduces himself as the individual who installs the technology, not the developer.

CONCLUSIONS

The four knowledge-intensive SMEs under analysis point at the existence of various trajectories in their respective transitions to I4.0, and suggest that there is no single path; thereby, it is neither possible to produce extensive typologies nor follow route maps so that SMEs evolve to the new industrial model (Mittal *et al.*, 2018). The analyzed case studies make it clear that various factors have boosted or delayed their transition to I4.0, underscoring the adversity of the context –violence and economic crisis– as one of the main, which is not usually taken into account by studies interested in the transition toward I4.0 (IDC, 2017; McKinsey Global Institute, 2017; Yang, 2017; Hirsch-Kreinsen, Weyer, & Wilkesmann, 2019).

In the first case, a downgrading was identified; the firm moved from advanced automation services to manufacturing reworks as a reaction to an adverse economic context and extreme violence. In the second case, we identified a service diversification process as a reaction to the same adverse context, which somehow allowed such SME to escalate to market products associated to I4.0.

Conversely, the third case shows an evolutionary transition from a SME that offered advanced manufacturing services to an enterprise that is currently recognized at global level as a pioneer in offering I4.0 services; however, their possibilities to grow are restricted by several problems associated to the conditions imposed by MNEs for them to work together.

Last case, Firm 4, is also a SME that has successfully transitioned to I4.0, though via a particular scale-up and business model. This firm invests an important amount of its revenues on generating autochthonous technology 4.0. and intends to commercialize it following a particular business model, which sometimes focuses on selling services to operate and manage the information generated by the technology it has designed. In this way, the existence of various possibilities and scale-up levels between the analyzed SMEs is demonstrated with empirical evidence; each firm contributes from their specialty to foster I4.0 in Mexico.

We noticed a similar dynamic when analyzing the way these knowledge-intensive SMEs were boosted. Following the proposals developed by Lindholm (1994) and Parhankangas and Arenius (2003), we consider that by and large most of them may be considered spin-offs from a corporative or entrepreneurial MNE. However, a comprehensive analysis of the processes identifies the following spin-offs: 1) entrepreneurial with multiple actors; 2) entrepreneurial-circumstantial; 3) corporative-internal; and, 4) entrepreneurial-external.

From the authors' standpoint, the particularity of the conditions in which the analyzed firms appeared invite to reflection on how this has affected their transition to I4.0. Even if the results we have from these experiences cannot be conclusive owing to the limited number, we consider that a larger sample may reveal more patterns of this sort.

In any case, the four trajectories and strategies presented serve to think of the opportunities and challenges faced by knowledge-intensive SMEs and allow us to enrich the theoretical typologies developed by other studies in contrast with the particularities of the presented cases. Here lies the main contribution of this study: emphasizing the particularities of the trajectories of the knowledge-intensive SMEs, not the similarities.

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