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# Industry 4.0 Maturity Models in SMEs, Mexico Context

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## Abstract

This study shows the result of the review of the maturity models for the implementation of Industry 4.0 in SMEs. The aim is to establish a methodological framework that analyzes the validity of said models in Mexican SMEs. This background review has shown that in Mexico, there is a gap in applied and validated research in local SMEs considering their context, so future research should focus on taking advantage of the contributions that have been developed in other contexts such as Europe, United States, and Asia. To develop and improve the validity and reliability of the results presented in these studies, through specific surveys and a statistical generalization to a broader sample, in the context of Mexican SMEs. These results can then be contrasted with the results obtained in other latitudes.

## Keywords
Industry 4.0, Smart Manufacturing, SME 4.0, maturity models

## 1. Introduction
The fourth industrial revolution, commonly known as Industry 4.0, is a developing reality with global impact (Thoben et al. 2017). It is a cybernetic revolution (Demirbağ and Yıldırım 2021) that has brought with it a rise of intelligent technologies for manufacturing, such as Cyber-Physical Systems (CPS), Internet of Things (IoT), and Cloud Computing, aiming at the creation of intelligent, self-regulated industrial value and interconnected (Xu et al. 2018) (Liebrecht et al. 2021), (Müller et al. 2018).

Depending on the place, different terms may be used; for example, in the USA, the expression "Smart Manufacturing" is predominantly used; "Industry 4.0" is commonly used in Germany and Europe; "Smart Factory" in Korea, Asia, and Europe (Mittal and Khan et al. 2018). In this study, these terms are used interchangeably despite minor differences in their definitions. The important thing to note is that these terms are primarily intended to denote the use of new technologies in industries and their global manufacturing ecosystems. These terms can be described as “the marriage of information, technology, and human ingenuity to bring a rapid revolution in the development and application of manufacturing intelligence to every aspect of a business” (Romero and Stahre 2021). Those new technologies refer to new ways of connecting and embracing new information and operations technologies, as well as new business and operating models, to enable innovative revenue streams, decrease costs and increase efficiency. Aligning Industry 4.0 initiatives with organizational strategy is a generic success factor in the implementation of Industry 4.0 (Sony and Naik 2020).

The findings of the literature review carried out by show that the current models and methodologies related to the implementation and maturity of Industry 4.0 have been designed and therefore are more suitable, helpful, and easily available for large companies than SMEs.

The importance of SMEs in global economic development is well known. They represent approximately 99% of companies globally and employ 67% of the workforce. However, the impact on GDP is low, especially in Latin

American countries (CEPAL 2022), (SBA 2022), (Instituto Nacional de Estadística y Geografía 2021) and (European Commission 2021), so they continue to have many areas of opportunity and now more than before due to changes significant that Industry 4.0 is bringing with it.

As the backbone of the manufacturing industry, the impact of SMEs on the Fourth Industrial Revolution is significant. SMEs often face different challenges and barriers than larger companies (Wuest and Thoben 2012), (Wadhwa 2012). Few studies have explicitly focused on supporting SMEs' evolutionary path and the paradigm shift towards "Smart Manufacturing" or "Industry 4.0". Some authors refer to the SMEs that successfully managed this transition as "SME 4.0" (SME 4.0 2022), (Oasys 2022).

### 1.1 Objective

In this context, this study presents the most outstanding maturity models concerning the implementation of Industry 4.0 proposed in recent years for SMEs and thereby establishes a methodology to analyze the validity of said models in Mexican SMEs.

## 2. SMES Caracterization

SMEs are a vital segment of the economy of a country. They are generally companies with a staff that does not exceed 250 workers. In addition, they have less access to tools and resources than large companies (Instituto Nacional de Estadística y Geografía 2021). SMEs act as suppliers to many large companies and thus play a vital role in many value-creation processes along the supply chain (Müller et al. 2018), (Mittal et al. 2019). However, they often lag when it comes to innovation and competitiveness and can therefore impede the overall growth of their national economies (Lukacs 2005), (Kongolo 2010).

### 2.1 SMEs in Mexico

In Mexico, the classification of these companies is provided by the National Commission for the Protection and Defense of Financial Services Users (CONDUSEF by its Spanish name Comisión Nacional para la Protección y Defensa de los Usuarios de Servicios Financiero) (CONDUSEF, 2009) based on differentiation according to the sector in which they are located, the number of annual sales they receive, and the number of workers they have, these characteristics are shown in Table 1.

Table 1. Stratification of micro, small and medium enterprises in Mexico
(Instituto Nacional de Estadística y Geografía, 2021)

| Sized | Sector | Staff headcount | Annual sales amount (Millions of pesos) |
|---|---|---|---|
| **Micro** | All | Until 10 | Until $ 4 Mdp |
| **Small** | Trade | Since 11 | Since $ 4.01 Mdp |
| | | Until 30 | Until $ 100 Mdp |
| | I\|ndustry and Services | Since 11 | Since $ 4.01 Mdp |
| | | Until 50 | Until $ 100 Mdp |
| **Medium** | Trade | Since 31 | Since $ 100.01 Mdp |
| | | Until 100 | Until $ 250Mdp |
| | Services | Since 51 | Since $ 10 Mdp |
| | | Until 100 | Until $ 100 Mdp |
| | Industry | Since 51 | Since $ 100.01 Mdp |
| | | Until 250 | Until $ 250Mdp |

According to the Study on the Demography of Businesses 2021 (Instituto Nacional de Estadística y Geografía, 2021), presented by the National Institute of Statistics and Geography (INEGI by its Spanish name Instituto Nacional de Estadística y Geografía), in Mexico, there are 4.9 million establishments in the private sector and the parastatal sector registered since the 2019 Economic Census.

According to (Instituto Nacional de Estadística y Geografía 2021), 95.4% of private companies in Mexico are microenterprises, 3.6% are small companies, 0.8% are medium-sized, and only 0.2% are large companies. According to (CEPAL 2022), these numbers are similar to Latin America. Around 99% of all companies are SMEs and employ around 67% of all workers. On the other hand, their contribution to GDP is relatively low, which reveals deficiencies in their productivity levels. For example, large companies in the region have productivity levels up to 33 times the productivity of micro-enterprises and up to six for small ones. While in the countries of the Organization for Economic Cooperation and Development (OECD), these numbers range between 1.3 and 2.4 times.
By applying coherent and coordinated policies, SMEs could be agents of structural change by contributing to increased productivity. This would make it possible to complement the economies of scale of large companies, favoring the creation of productive agglomerations and contributing to social inclusion, increasing the income of micro-enterprises and reducing their vulnerability (CEPAL 2022).

### 2.2 SMEs in the European Union and USA

According to the European Commission (European Commission 2021), SMEs can be defined as companies that employ less than 250 workers and have an annual turnover not exceeding EUR 50 million and/or an annual balance sheet not exceeding EUR 43 million (See Table 2).

Table 2. Classification of SMEs according to the European Commission
(European Commission 2021)

| Company category | Staff headcount | Turover | or | Balance shett total |
|---|---|---|---|---|
| Medium-sized | < 250 | ≤ € 50 m | | ≤ € 43 m |
| Small | < 50 | ≤ € 10 m | | ≤ € 10 m |
| Micro | < 10 | ≤ € 2 m | | ≤ € 2 m |

This definition is similar to the classification of Mexico according to the number of workers. However, it does not distinguish by economic sector.

In the case of the USA, the Office of Defense defines a small business as an independent company with fewer than 500 employees. The definition of the type of company for government programs and contracting of SMEs depends on the "size norms", which vary with the type of industry, the number of employees, and the amount of annual income the company has (SBA 2022).

In general, the classification of SMEs worldwide is very similar, although, as seen from the above data, there may be some differences, especially in the case of the USA.

## 3. Methodology

The maturity models described in this study are proposals that are in an incipient stage of validation since the publications show that they have been applied to a very small number of SMEs in the contexts in which they were developed, which is why it is interesting to analyze these proposals in the context of Mexican SMEs and in a larger number of companies so that more reliable and generalizable quantitative analyzes can be developed.

The objective of this study is to describe the most outstanding maturity models related to the implementation of Industry 4.0 in SMEs and thereby establish a methodology to analyze the validity of these models in Mexican SMEs. For this, it was necessary to follow the following phases:

1. Review of the state-of-the-art on "Smart Manufacturing" and "Industry 4.0" and maturity models associated with these concepts, all specifically applied to SMEs. For this, specialized databases such as SCOPUS were consulted.
2. Describe the most significant maturity models found in the previous review, for this, their structure, description and case study analysis will be taken into account, where their applicability is demonstrated.
3. Contrast of the maturity models found with the Mexican SMEs and methodological proposal for future research.

The results found after following the described methodology are shown below.

# 4. Results

## 4.1 Main maturity models associated with Industry 4.0 in SMEs

This section deals with the previous research that makes up the background framework of Industry 4.0. It focused mainly on proposals for maturity models or implementation of Industry 4.0 in SMEs. It is essential to highlight that as of 2019, a change was observed in the terminology in the investigations, and a new term is beginning to be used: SME 4.0 (Rauch et al. 2018), (Mittal and Romero et al. 2018a), (Chonsawat and Sopadang 2021), (Chonsawat and Sopadang 2020), which denotes the cases of successful SMEs that have managed to implement Industry 4.0 solutions. In this study, a detailed analysis is made of the contributions of research that already uses this term.

The background search was based directly on the terms related to Industry 4.0 in SMEs, using keywords such as Industry 4.0 and SME, Smart Manufacturing and SME, Smart Factory and SME, Industry 4.0 maturity models in SMEs, implementation of Industry 4.0 in SMEs, SME 4.0, SMEs 4.0, Smart SMEs. The search was carried out in indexed databases, such as Scopus and Web of Science, and only documents in English were considered.

A concept to work on during the proposed investigation is that of "Maturity". In general, "maturity" refers to a state of being complete, perfect, or ready and implies some progress in developing a system. Consequently, maturing systems (e.g., biological, organizational, or technological) increase their capabilities over time relative to the achievement of some desirable future state. Maturity can be captured qualitatively or quantitatively, in a discretely or continuously way (Schumacher et al. 2016).

Maturity models are crucial for the organizational level and can be used to create a roadmap for improvements (Tonelli et al. 2016), (Gökalp and Martinez 2021). Maturity models have been developed to assist companies in identifying ways to reduce costs, improve quality, and reduce time to market to gain and retain a competitive advantage (Tonelli et al. 2016), (Goncalves Filho and Waterson 2018).

Research agrees that there are few studies focused on the development of Industry 4.0 in SMEs (Mittal and Khan et al. 2018), (Mittal et al. 2019), (Mittal and Romero et al. 2018a). However, in 2018 a study was published that proposes an Industry 4.0 introduction model for SMEs: SME Maturity Model (SM$^3$E) (Mittal and Romero et al. 2018a), which aims to support SMEs on their way to digital transformation and the paradigm shift toward smart manufacturing and Industry 4.0 in three axes: "organizational dimensions", "toolboxes" and "maturity levels". The methodology allows companies to determine the real degree of maturity and a toolbox method to reach higher maturity levels. Figure 1 shows the SME Maturity Model (SM$^3$E) (Mittal and Romero et al. 2018a).

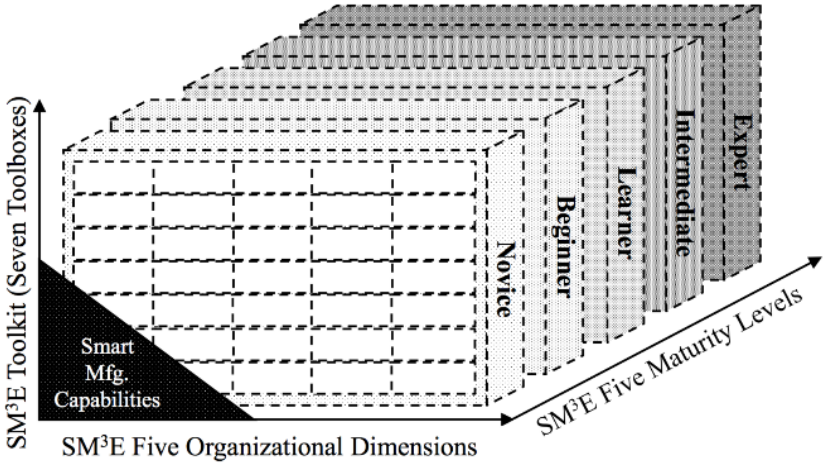


Figure 1. Smart Manufacturing Maturity Model for SMEs (SM$^3$E) (Mittal, Romero, et al., 2018a)

Table 3, shows the organizational dimensions and subdimensions of the SM$^3$E Maturity Model, which represent the y-axis of Figure 1.

Table 3. Organizational Dimensions and Sub-dimensions of SM$^3$E Maturity Model (Mittal, Romero, et al., 2018a)

| Dim. | Finance | People | Strategy | Process | Product |
|---|---|---|---|---|---|
| Sub-dim | - Cost-Benefit Analysis<br>- Budgeting and Costs Control<br>- Investments Risk and Returns Management | - Leadership<br>- Customer Feedback<br>- Safety and Ergonomics<br>- Training and Education | - Knowledge Management<br>- Decision Support/ Decision Making<br>- Standards<br>- Legal/ Tax Policies<br>- Sustainability Guidelines<br>- Government Regulations | - Quality Control<br>- Job Scheduling<br>- Rapair and maintenance<br>- Machines Operation<br>- Flexibility | - Logistics<br>- New Product Development<br>- Packaging<br>- Modularity<br>- Time to Market |

The SM$^3$E model recognizes the common number of levels in maturity models from five categories:

- Novice: represents organizations largely unaware of the Industry 4.0 paradigm.
- Beginner: means a recent awareness and fundamental notion of the Industry 4.0 paradigm.
- Apprentice: represents an SME that has started experimenting with Industry 4.0 technologies.
- Intermediate: involves successful pilot projects with Industry 4.0 technologies in different organizational domains.
- Expert: Represents an SME that strategically implements Industry 4.0 technologies and could therefore be referred to as "SME 4.0".

On the other hand, a toolkit is a set of methods, tools, and practices that can lead to an end goal. The SM$^3$E Maturity Model Toolkit is made up of seven toolboxes (Mittal and Romero et al. 2018b):

1. Manufacturing toolbox
2. Design and simulation toolbox,
3. Robotics and automation toolbox,
4. Sensor and connectivity toolbox,
5. Cloud/storage toolbox,
6. Data analysis toolbox, and
7. Business management toolbox

The rationale behind these seven toolboxes is to include technologies, skills, and business practices that can serve both the technical and managerial aspects needed in an SME and thus adopt the Industry 4.0 paradigm (Mittal and Romero et al. 2018b).

Another model to highlight is the one proposed by (Chonsawat and Sopadang 2020), who, through a bibliometric analysis, showed that scientific studies about the evaluation and aspects of Industry 4.0 are a popular topic. However, there is a lack of quantitative analysis and the development of useful indicators. Through Bibliometric techniques, 23 SMEs 4.0 readiness indicators were defined and grouped into five dimensions (see Figure 2).

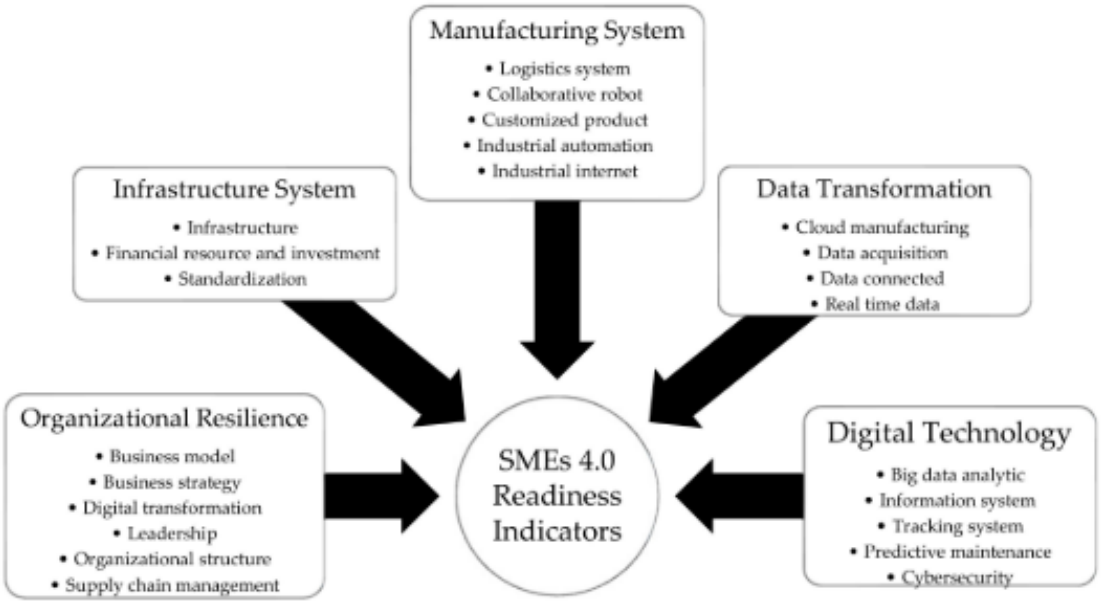


Figure 2. The aspect of SMEs 4.0 readiness indicators (Chonsawat and Sopadang 2020)

The SMEs 4.0 Readiness Indicators Model (Chonsawat and Sopadang 2020) establishes levels for the measurement of each of the indicators on a percentage scale that is easy to interpret (the higher the %, the greater the achievement of the indicator), which finally allows calculating the score of SMEs' 4.0 Readiness, through a simple average of the measurements obtained in the indicators. The designers propose a final scale for assessing the degree of preparation of SMEs, which is shown in Table 4.

Table 4. Readiness level SME 4.0
(Chonsawat and Sopadang 2020)

| **SMEs 4.0 readiness average indicators score (%)** | **Readiness level SME 4.0** |
|---|---|
| 0 - 15 | Not Achieved |
| 16 - 50 | Partially Achieved |
| 51 - 80 | Achieved |
| 81 - 100 | Fully Achieved |

This model is based on an extensive and objective background check. Another advantage is its easy interpretation and application. However, weights that establish the relative importance between dimensions and even between indicators are not defined. It is an opportunity to improve and deepen what these researchers propose with future studies.

Another essential reference is the studies that have been developed through the research project "SME 4.0 - Industry 4.0 for SMEs", an initiative financed by the European Union's Horizon 2020 research and innovation program within the framework of the Marie Skłodowska-Curie grant agreement (Rauch et al. 2018), (Rauch et al. 2019), (Rauch and Woschank 2020). This project has created an international research network under the leadership of the Free University of Bolzano (Italy). It includes European academic and industrial partners (Montanuniversität Leoben Austria, Technical University of Kosice Slovakia, Elcom s.r.o. Slovakia), USA. (Massachusetts Institute of Technology and Worcester Polytechnic Institute) and Asia (University of Chiang Mai in Thailand and SACS Engineering College India).

The methodology used to define the research fields of this project consisted of an exploratory field study using workshops with SME managers, key collaborators, and other experts. These workshops allowed the exchange of

experiences and stimulated discussion among the participants, thus creating a deeper experiential environment. Four workshops were held in Europe (Italy and Austria), the US (Massachusetts), and Asia (Thailand) to investigate the specific requirements of SMEs.

The proposed research of this team (Rauch et al. 2018) is organized into three fields (see Figure 3):

1. Smart Manufacturing in SMEs, specific solutions for
2. Smart Logistics in SMEs and
3. Adapted Organization and Management Models for the introduction of Industry 4.0 and the management of smart SMEs.

These fields are further decomposed into nine topics that investigate specific concepts.

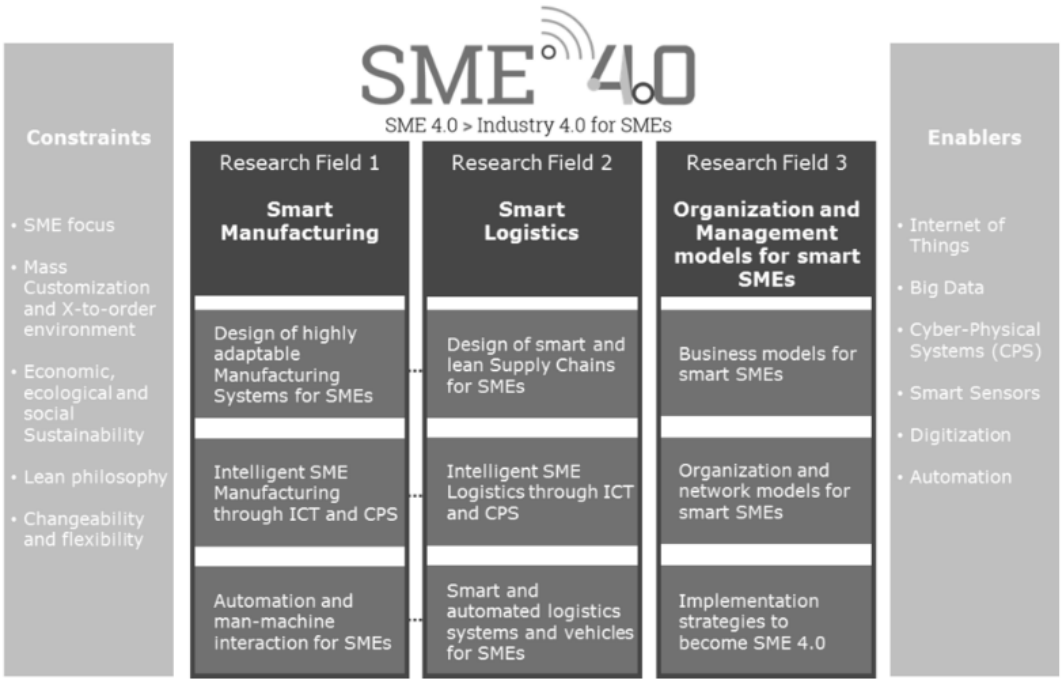


Figure 3. Research fields and topics in the project SME 4.0 (Rauch et al. 2018)

The structure shown in Figure 3 represents for the SME 4.0 project a guide to classify the research that can be developed to analyze and facilitate the implementation of intelligent manufacturing in SMEs. This guide is useful for the network members and any researcher who wants to contribute to this context.

A later publication, but from this same team of the SME 4.0 Project (Rauch et al. 2019), presents the requirements and barriers for introducing intelligent manufacturing in SMEs. These elements were identified using the same strategy of SME expert workshops (in the United States, Central Europe, and northern Thailand).

Regarding the requirements that were determined through the workshops, 65 requirements grouped into 27 groups or dimensions were defined (Rauch et al. 2019). Of these 65 requirements, the following four were of most significant interest to the workshop participants: 1) Agility in manufacturing and Mass Customization, 2) Real-time data, digitization, and connectivity, 3) Advanced Manufacturing Technologies and Automation, 4) Ease of Use and low Investment, and Machine Learning and Smart Data Analytics. The latter is of great interest to SMEs, stating that they are not yet prepared for these concepts.

Regarding the barriers or difficulties, 14 were defined and grouped into 6 groups (Rauch et al. 2019). The main barriers are the following: 1) Cultural barriers in terms of lack of acceptance by owners, managers, and employees, 2) difficulties within the implementation, 3) shortage of qualified people, and 4) the problematic guarantee of an adequate level of data security. Based on these results, recommendations were made for managerial action to support an adequate adaptation of Industry 4.0 technologies and concepts in SMEs.

### 4.2 Maturity models and Mexican SMEs and methodological proposal for future research

The largest companies have advanced in the process of implementing efficient Industry 4.0 solutions, and SMEs risk not fully exploiting this potential to improve efficiency and develop their competitiveness. Even if SMEs have the potential to transform their manufacturing digitally, the implementation of Industry 4.0 remains a major challenge (Rauch et al. 2019).

This study has shown the review of the most outstanding maturity models for the implementation of the principles of Industry 4.0 in SMEs. This importance lies in their significant contributions to supporting the adoption of Industry 4.0 solutions in SMEs. In addition to the methodological rigor to arrive at a specific proposal, they have made applications to case studies that have allowed their proposals to be validated and even improved.

This background review has shown that in Mexico, there is a gap in applied and validated research in local SMEs considering their context, so future research should focus on taking advantage of the contributions that have been developed in other contexts such as Europe, United States, and Asia, to develop and improve the validity and reliability of the results presented in these studies, through specific surveys and a statistical generalization to a broader population, but in the Mexican reality. These results can then be contrasted with the results obtained in other latitudes.

## 5. Conclusion

In order to achieve this objective, it is necessary to continue researching and delving into these issues in order to propose a maturity model that adapts and truly understands the reality of Mexican SMEs. In this sense, a methodological route is proposed which will determine the direction of future research:

1. Apply the maturity models found in Mexican SMEs in order to analyze their relevance and applicability in the Mexican context.
2. Define a theoretical model for the evaluation and implementation of Mexican SME 4.0, considering the previous results.
3. Validate the proposed model in a representative sample that allows quantitative analyzes that can be comparable to longitudinal studies.

The statistical analysis tools that will be used are Factor Analysis, Correlational Analysis, and Structural Equations, through which relationships and weights between variables of different natures can be determined. This is one of the weaknesses found in the models, where no importance is established between factors or dimensions.

Findings of an exploratory nature will help SMEs and their stakeholders plan for technology that can provide them with a long-term competitive advantage.

## References

CEPAL. *Acerca de Microempresas y Pymes*. Naciones Unidas - CEPAL. Available: https://www.cepal.org/es/temas/pymes/acerca-microempresas-pymes, Sep 21, 2022.

Chonsawat, N., & Sopadang, A. Defining SMEs' 4.0 Readiness Indicators. *Applied Sciences*, vol. 10, no. 8998, pp. 1–30, 2020. (https://doi.org/10.3390/app10248998).

Chonsawat, N., & Sopadang, A. Smart SMEs 4.0 Maturity Model to Evaluate the Readiness of SMEs Implementing Industry 4.0. *Chiang Mai University Journal of Natural Sciences*, vol. 20, no. 2, pp.1–13, 2021. (https://doi.org/10.12982/CMUJNS.2021.027).

CONDUSEF. *ACUERDO por el que se establece la estratificación de las micro, pequeñas y medianas empresas.* Publicado En El Diario Oficial de La Federación El 30 de Junio de 2009. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.gob.mx/cms/uploads/attachment/file/50882/A539.pdf

Demirbağ, K. Ş., & Yıldırım, N. Revisiting the theoretical evolution of Industry 4.0: A thematic analysis of research focus. *International Journal of Technology, Policy and Management*, vol. 21, no. 1, pp. 20–46, 2021. (https://doi.org/10.1504/IJTPM.2021.114307)

European Commission. COMMISSION STAFF WORKING DOCUMENT EVALUATION of Recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises (2003/361/EC). *European Union*, *May 2003*. consulted Oct 27, 2021.

Gökalp, E., & Martinez, V. Digital transformation capability maturity model enabling the assessment of industrial

manufacturers. *Computers in Industry*, *132*. https://doi.org/10.1016/j.compind.2021.103522, 2021.

Goncalves Filho, A. P., & Waterson, P. Maturity models and safety culture: A critical review. *Safety Science*, vol. 105, pp. 192–211, 2018. (https://doi.org/10.1016/j.ssci.2018.02.017).

Instituto Nacional de Estadística y Geografía. *Comunicado de Prensa Núm. 790/21, comunicación social el INEGI presenta los resultados del estudio sobre la demografía de los negocios 2021*. Avalaive: https://www.inegi.org.mx/contenidos/saladeprensa/boletines/2021/EDN/EDN_2021.pdf, Sep 15, 2021.

Kongolo, M. *Job creation versus job shedding and the role of SMEs in economic development*. vol. 4, no. 11, pp. 2288–2295, 2010.

Liebrecht, C., Kandler, M., Lang, M., Schaumann, S., Stricker, N., Wuest, T., & Lanza, G. Decision support for the implementation of Industry 4.0 methods: Toolbox, Assessment and Implementation Sequences for Industry 4.0. *Journal of Manufacturing Systems*, vol. 58(PA), pp. 412–430, 2021. (https://doi.org/10.1016/j.jmsy.2020.12.008)

Lukacs, N.. The economic role of SMEs in the world economy. *European Integration Studies*, vol. 1, no. 1, pp. 1–7, 2005. (http://real.mtak.hu/91214/1/ISSN_1588-6735_vol_4_no_1_2005_eng_003-012.pdf).

Mittal, S., Khan, M. A., Purohit, J. K., Menon, K., Romero, D., & Wuest, T. A smart manufacturing adoption framework for SMEs. *International Journal of Production Research*, vol. 58, no. 5, pp. 1555–1573, 2019. (https://doi.org/10.1080/00207543.2019.1661540).

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). In *Journal of Manufacturing Systems,* vol. 49, pp. 194–214, 2018.( https://doi.org/10.1016/j.jmsy.2018.10.005).

Mittal, S., Romero, D., & Wuest, T. Towards a Smart Manufacturing Maturity Model for SMEs ($SM^3E$). *IFIP Advances in Information and Communication Technology*, *540*(August), pp. 476–487, 2018a. (https://doi.org/10.1007/978-3-030-01614-2_44).

Mittal, S., Romero, D., & Wuest, T. Towards a smart manufacturing toolkit for SMEs. *IFIP Advances in Information and Communication Technology*, vol. 540(May), pp. 476–487, 2018b. (https://doi.org/10.1007/978-3-030-01614-2_44).

Müller, J. M., Buliga, O., & Voigt, K. I. Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, vol. 132, pp. 2–17, 2018. (https://doi.org/10.1016/j.techfore.2017.12.019).

Oasys. *Beneficios de convertirse en una PYME 4.0*. Oasys, Outsourcing Automatic Systems, (2022). (https://oasys-sw.com/beneficios-convertirse-una-pyme-4-0/).

Rauch, E., Dallasega, P., & Unterhofer, M. Requirements and Barriers for Introducing Smart Manufacturing in Small and Medium-Sized Enterprises. *IEEE Engineering Management Review*, vol. 47, no. 3, pp. 87–94, 2019. (https://doi.org/10.1109/EMR.2019.2931564).

Rauch, E., Matt, D. T., Brown, C. A., Towner, W., Vickery, A., & Santiteerakul, S. Transfer of industry 4.0 to small and medium sized enterprises. *Advances in Transdisciplinary Engineering*, *7*(August), pp. 63–71, 2018. (https://doi.org/10.3233/978-1-61499-898-3-63)

Rauch, E., & Woschank, M. Industry 4.0 for SMEs - Smart Manufacturing and Logistics for SMEs. In *Industry 4.0 for SMEs - Smart Manufacturing and Logistics for SMEs,* 2020. (https://doi.org/10.3390/books978-3-03936-568-5).

Romero, D., & Stahre, J. Towards the Resilient Operator 5.0: The Future of Work in Smart Resilient Manufacturing Systems. *Procedia CIRP*, vol. 104(September), pp. 1089–1094, 2021. (https://doi.org/10.1016/j.procir.2021.11.183).

SBA. *Table of size standards*. U.S. Small Business Administration. https://www.sba.gov/document/support-table-size-standards, 2022.

Schumacher, A., Erol, S., & Sihn, W. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, vol. 52, pp. 161–166, 2016. (https://doi.org/10.1016/j.procir.2016.07.040).

SME 4.0. *Smart Manufacturing and Logistics for SMEs in an X-to-order and Mass Customization Environment*. SME 4.0 - Industry 4.0 for SMEs, 2022. (https://www.sme40.eu/).

Sony, M., & Naik, S. Critical factors for the successful implementation of Industry 4.0: a review and future research direction. *Production Planning and Control*, vol. 31, no. 10, pp. 799–815, 2020. (https://doi.org/10.1080/09537287.2019.1691278)

Thoben, K. D., Wiesner, S. A., & Wuest, T. "Industrie 4.0" and smart manufacturing-a review of research issues and application examples. *International Journal of Automation Technology*, vol. 11, no. 1, pp. 4–16, 2017. (https://doi.org/10.20965/ijat.2017.p0004).

Tonelli, F., Demartini, M., Loleo, A., & Testa, C. A Novel Methodology for Manufacturing Firms Value Modeling

and Mapping to Improve Operational Performance in the Industry 4.0 Era. *Procedia CIRP*, vol. 57, pp. 122–127, 2016. (https://doi.org/10.1016/j.procir.2016.11.022).

Wadhwa, R. S. Flexibility in manufacturing automation: A living lab case study of Norwegian metalcasting SMEs. *Journal of Manufacturing Systems*, vol. 31, no. 4, pp. 444–454, 2012. (https://doi.org/10.1016/j.jmsy.2012.07.008)

Wuest, T., & Thoben, K. D. Information management for manufacturing SMEs. *IFIP Advances in Information and Communication Technology*, *384 AICT*, pp. 488–495, 2012. (https://doi.org/10.1007/978-3-642-33980-6_53)

Xu, L. Da, Xu, E. L., & Li, L. Industry 4.0: State of the art and future trends. *International Journal of Production Research*, vol. 56, no. 8, pp. 2941–2962, 2018. (https://doi.org/10.1080/00207543.2018.1444806)

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