Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/EU08.20250159
Published: July 2, 2025

Method for Developing a Digital Transformation Maturity Model for the Manufacturing Industry in Latin America

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Abstract

This research focused on designing and validating a Digital Transformation Maturity Model tailored to the manufacturing sector in Latin America. The study utilized a mixed-methods approach, incorporating qualitative tools such as focus groups and interviews, along with quantitative data from audits and key performance indicators. A multiple-case study methodology was implemented, applying the model iteratively to four manufacturing companies in Nuevo León, Mexico. Key phases included problem identification, theoretical foundation through a literature review, iterative model redesign based on empirical feedback, and validation of its applicability. The result was a consolidated maturity model, supported by a strategic roadmap to guide organizations toward higher levels of digital transformation maturity. This work contributes a structured, evidence-based framework to address the challenges and opportunities of Industry 4.0 in the region.

Keywords
Digital transformation, maturity model, validation, industry 4.0, manufacture.

1. Introduction
Industry 4.0 represents the conceptual framework of the Fourth Industrial Revolution. It encompasses a new model for organizing and controlling value chains by integrating information technologies across the product life cycle and associated manufacturing systems. Commonly referred to as the *Smart Factory* or *Industrial Internet*, this framework is driven by the Internet of Things (IoT), which serves as a critical enabler of industrial transformation. A defining characteristic of Industry 4.0 is the ongoing digital transformation of manufacturing and production processes, which is fueled by the rapid evolution of information technologies, software, and computing systems (Del Val Román, 2016). Despite these developments, a significant number of firms in Latin America remain unaware of their current stage of digital transformation. A recent study by EY (2023), revealed that only 30% of Latin American companies have implemented policies aimed at mitigating digital risks. In parallel, the Economic Commission for Latin America and the Caribbean (CEPAL, 2023) has emphasized the region's technological lag, pointing out that many firms have fallen behind in multiple waves of technological advancement. This scenario limits organizational capacity to design and execute effective improvement and growth plans in the digital domain.

In response to the dynamics of the digital era, organizations have begun adopting comprehensive digitalization strategies across both productive and administrative processes. The emergence of *Digital Transformation Models* offers a reference framework to guide firms in adapting to the digital context by incorporating technologies into strategic and operational areas. The structure and dimensions of these models vary depending on industry sector and specific organizational goals (Fernández, 2021). According to CEPAL (2023), the Latin American region has the opportunity to overcome the challenges of technological lag through the effective adoption of digital technologies. In this context, a digital maturity model serves as a strategic tool for assessing the current state of digital transformation, enabling organizations to define future pathways toward the desired level of digital advancement

This study employs a mixed-methods approach to develop a robust Digital Transformation Maturity Model tailored to the manufacturing sector. The research design integrates a comprehensive literature review—through which 45 existing maturity models were identified globally—with an empirical component grounded in a multi-case study methodology. Specifically, the empirical phase involved the design and application of a structured audit instrument within four automotive sector companies, enabling a contextualized assessment of digital transformation practices.

The proposed model contributes to the academic and practical understanding of digital transformation by offering a structured framework for evaluating adoption levels in manufacturing organizations. It is supported by a self-assessment tool and a formal evaluation process that includes an audit phase to ensure objectivity and rigor. This article outlines the full methodological process used to develop the model, from theoretical foundations to instrument design, validation, and practical application in real-world organizational settings.

1.1 Objectives

General Objective

Develop, validate, and consolidate a maturity assessment model for Industry 4.0 in the manufacturing sector, through its application in an iterated case study in four companies in Nuevo León, in order to generate strategic roadmaps that facilitate their transition toward Digital Transformation.

Specific Objectives

1. Develop a maturity assessment model for Industry 4.0 based on a thorough literature review, aligning it with the specific characteristics and needs of the manufacturing sector.

2. Apply and validate the model through iterative audits in Cummins Meritor and other manufacturing companies, identifying their current level of Industry 4.0 maturity.

3. Redesign the model using techniques such as expert feedback, benchmarking, and cross-case analysis to improve its applicability and robustness in real industrial contexts.

4. Design tailored strategic roadmaps with methodologies, tools, and improvement actions aimed at achieving the desired level of Industry 4.0 maturity in each company.

2. Literature Review

2.1 Digital Transformation in Latin America

We started our research with important findings that highlight the gap in the literature, regarding the fact that there is a limiting amount of research on this topic in Latin American countries. Manufacturing companies in Latin America have already started their journey of Digital Transformation, 24% have process automation, 68% have already a digital expansion and 51% of the companies have businesses that are assisted by artificial intelligence (Rodriguez, 2024). Meaning there's obviously an interest for the digital transformation. Additionally in Mexico 85% of the companies have started this transition of digital transformation, however, 70% of the initiatives will fail due to the reason there is no experience in the processes, and companies desire rapid changes (Rodriguez, 2024). Therefore, we found an opportunity in the manufacturing industry. We listened to the necessities of the market and decided to develop a digital transformation maturity model in order to provide a basis to the manufacturing companies.

2.2 Digital Transformation Maturity Models

Regarding the literature review, an exhaustive investigation of existing models on the level of maturity and evaluation in Industry 4.0 was carried out. It was carried out with the objective of identifying previous research and experiences regarding this topic.

To obtain highly relevant articles, digital databases of high academic level and global reach that were available in the UDEM library were first selected before beginning the search. The selected databases were: Scopus, Science Direct, Web of Science, Springerlink, Google Scholar, EBSCO and Emerald Insights. With this decision more than 10,000 articles were found available, so it was necessary to reduce them by exclusion criteria. Below is the process carried out for each stage with the updates made. Figure 1 shows the filter for selecting papers.

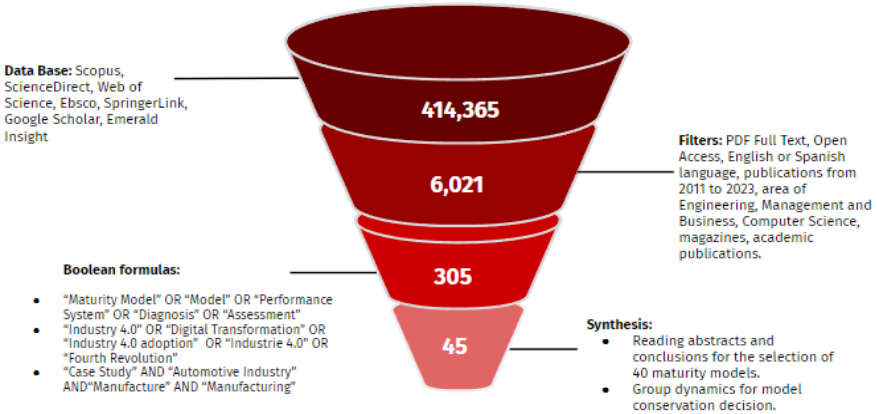

Figure 1. Updated literature review exclusion process
Source: Own elaboration

As it shows in Figure 1, of the 8 databases, 45 articles were selected as the research to be considered for the development of the maturity model. The criteria used in these was the reading of abstracts and conclusions for the analysis and selection decision.

However, a group process of model selection and conservation was carried out where each member shared their final decision regarding whether the selected model is relevant. Finally, the models with 3 and 4 members with a positive decision were preserved.

Based on the above, a comparative Table 1 was developed by extracting key information from the 45 identified models, considering the author, model name, year, country, and sector. Below is an excerpt presenting 10 of the 45 models identified through the literature review.

Table 1. Literature Review and Comparative Analysis of Models

Model	Author	Year	Model´s Name	Country	Sector
MM1	Schumacher et. al	2019	Maturity model to assess the readiness and maturity of manufacturing companies for Industry 4.0	Austria	Manufacturing
MM2	Ávila,et al	2022	Proposal and Validation of an Industry 4.0 Maturity Model for SMEs	Colombia	Manufacturing
MM3	Zoubek, et al	2021	A framework for Industry 4.0 readiness and smart manufacturing enterprise maturity: a case study	Turkey	Automotive
MM4	Lichtblau et al	2015	IMPULS	Germany	Manufacturing
MM5	Amaral et. al	2021	A framework for assessing the Industry 4.0 maturity of manufacturing SMEs	Portugal	Manufacturing
MM6	Wolniak et.al	2021	Diagnosis of the maturity level of the implementation of Industry 4.0 solutions in selected functional areas of automotive company management in Poland	Poland	Automotive
MM7	Sütőová et. al	2020	Determining Learning Needs for Industry 4.0 Maturity Development in Automotive Organizations in Slovakia	Eslovakia	Automotive
MM8	Rigato et. al	2021	An Industry 4.0 maturity model applied to the automotive supply chain	Brazil	Automotive
MM9	Kırmızı et. al	2022	Design Science Digital Transformation Maturity Model: Case Studies in Manufacturing	Turkey	Manufacturing
MM10	Semeraro, et. al	2023	Maturity model for assessing the impact of Industry 4.0 technologies and principles on SMEs	United Arab Emirates	Manufacturing

Source: Own elaboration

With the information obtained, important findings were obtained that highlight the gap in the literature, regarding the fact that there is a limiting amount of research on this topic in Latin American countries.
The geographical information of the selected investigations is presented in Figure 2.

Figure 2. Country distribution of selected research
Source: Own elaboration

In Figure 2 it can be seen how a large part of the research belongs to European countries and that only countries such as Brazil, Colombia and Mexico have contributed little research in the automotive sector, allowing us to detect a need to promote greater collaboration and participation of Latin America in the subject research of Digital Transformation in the automotive sector.

2.3 Digital Transformation Models in Latin America

In conclusion, the literature review reveals that although numerous digital transformation maturity models have been developed globally, there is still a limited body of knowledge in Latin America regarding tools and frameworks to effectively assess digital maturity levels. Most of the existing models are designed within European or Asian contexts, and often do not reflect the specific challenges, resource constraints, or industrial structures found in Latin American countries.

This gap represents a valuable opportunity to develop regionally adapted models that align with local realities. In this sense, the model proposed in this project aims to contribute to bridging the gap by offering a practical and context-specific approach to measuring digital maturity in manufacturing companies across Latin America.

Such an initiative not only supports regional companies in their digital transformation journeys but also encourages greater academic and industrial collaboration in the field of Digital Transformation within Latin America, especially in underrepresented sectors such as the automotive industry.

3. Methodology

This study adopted a mixed-methods, phased approach to design, validate, and refine a Digital Transformation Maturity Model tailored to the manufacturing sector in Latin America. The methodology was structured in five sequential phases, combining qualitative and quantitative techniques, and integrating recognized frameworks to ensure both theoretical grounding and practical applicability.

Phase 1: Model Construction through Case Study

The initial development of the maturity model was guided by Robert K. Yin's case study methodology (2013), enabling an in-depth understanding of digital transformation challenges in real organizational contexts. Through literature review, semi-structured interviews, and expert focus groups, key maturity dimensions were identified and structured into a preliminary model.

Selection of Dimensions
For the development of the model, the dimensions proposed by 45 selected authors were considered. From these 40 models, a list was compiled detailing the dimensions and the frequency with which each was referenced in the respective studies. Based on this information, a Pareto diagram was constructed to eliminate the least frequently cited dimensions across the 45 reviewed studies, thus focusing on the most recurrent and relevant elements.

As a result of applying the Pareto analysis, eight dimensions were selected from the initial 22 identified. Subsequently, a three-criterion analysis was conducted on the dimensions that emerged from the Pareto diagram: (1) relevance in Latin American countries, (2) applicability to the automotive sector, and (3) authors' conclusions regarding significance and impact. The objective of this analytical process was to confirm the relevance of the selected dimensions. Accordingly, the dimensions selected for the maturity model development were: Operations, Technology, Strategy, Organization, Products and Services, Culture, Logistics, and Quality.

Selection of Criteria
Subsequently, specific criteria were developed for each dimension. Heat maps were generated to evaluate the frequency of use across 45 research studies. These were categorized according to three specific criteria: manufacturing models, automotive sector models, and models focused on Latin American contexts.

For each dimension, the most frequently cited criteria were selected based on the three analytical categories: manufacturing models, automotive sector models, and models from Latin American context. As a result, the final structure of the Industry 4.0 maturity model consisted of 8 dimensions, 61 criteria, and 166 assessment elements.

Weighting of Criteria and Dimensions
After selecting the evaluation criteria for each dimension, a weighting process was conducted using the scale proposed by Schumacher et al. (2016), which ranges from 1 to 4, where 1 represents "Very low importance" and 4 denotes "Very high importance."In addition, each dimension was weighted according to the number of evaluation criteria it contains. This approach was adopted to reflect the fact that not all dimensions and criteria carry the same weight. These weightings will be integrated into the formula used to calculate the overall maturity level of the organization.

Formulas
Subsequently, formulas were defined to calculate both the overall maturity level and the maturity level per dimension, based on the methodology proposed by Schumacher, Erol, and Sihn (2016). Additionally, parameters were established to categorize the calculated maturity level for both the dimensions and the overall assessment, going from 0 to 5.

Evaluation Scale at a General Level
Regarding the evaluation scale, it was decided to consider the scales proposed by three authors: Lichtblau (2015), Amaral (2021), and Viharos (2017). The evaluation scale consists of six levels, where 0 represents the lowest level and corresponds to an organization that is unaware of Industry 4.0, while 5 represents the highest level, in which the company is recognized as a benchmark and a leader in Industry 4.0 within its competitive landscape.

Audit format
Once the essential elements of the model were established, the audit form was developed as a tool intended to evaluate the organization. The audit structure consists of usage instructions, audit forms by dimension, an evaluation scale for each dimension, a section for calculating the overall maturity level accompanied by its respective level analysis table, and finally, the references of the main authors involved in the development of the audit.

Phase 2: Pilot Testing
A pilot test was conducted with a single automotive company in Nuevo León, applying the model in practice through participatory workshops and interviews. This phase served as a validation loop to test the model's clarity, relevance, and usability, leading to early refinements. Overall, we followed five steps to gain a thorough understanding of the company's processes. Step one was a trial run focused on measuring the duration of the audits and establishing the evaluation procedures, including the evaluation questions and compliance review. Step two involved defining the audit time per participant, the evaluation setting, the number of participants, and the number of internal auditors. Step three consisted of generating and sending the electronic invitation with all the audit details. Step four was dedicated to training two internal auditors on the use of the tool, calculation management, and result analysis. Lastly, step fiv**e**

was the execution of the audit, which began with a warm welcome to the participants, followed by the administration of the questionnaire.

Phase 3: Multi-Case Validation and Model Redesign
Following the pilot, the model was applied to four additional manufacturing firms using a multiple-case study design. This phase was informed by the Becker et al. (2009) methodology for maturity model development, which emphasizes iterative validation and refinement. Comparative analysis across cases led to structural adjustments to better fit sector-specific realities.

First Application and Initial Results
The first version of the model was applied in 3 to 4 manufacturing companies in Nuevo León. This pilot application allowed researchers to gather preliminary results by dimension and company, identifying initial maturity levels and common gaps. The data collected also served as the foundation for feedback collection.

Model Feedback and Evaluation
Feedback was collected from participating companies regarding the content, clarity, and practical application of the model. Participants suggested improvements in the contextual examples, dimensional relevance, and differentiation between operational and administrative areas. This feedback was documented by dimension and used to classify elements for revision.

Content Redesign Using Wan & Weber Technique
The feedback was combined with findings from the literature to carry out a structured redesign of the model using the Wan & Weber (2020) classification framework. Evaluation elements were reviewed and categorized as non-applicable, redundant, unclear, incomplete, or overloaded. Updates included the addition of new criteria related to sustainability, digital ethics, and financial digitalization topics previously underrepresented in existing maturity models.

Process Redesign: Integration of a Self-Assessment Tool
In parallel with the content redesign, a self-assessment tool was developed and integrated into the methodology. Inspired by the Malcolm Baldrige Performance Excellence Framework (2019), the tool enabled companies to conduct an internal pre-audit reflection and evaluate their digital maturity level independently. This tool helped increase preparedness, reduced audit resistance, and encouraged early internal alignment.

The redesigned process incorporated new steps: tool delivery, company self-assessment, analysis of responses, and use of results to guide the subsequent external audit. This dual approach (internal + external) enhanced the model's robustness and usability in different organizational contexts.

Second Application and Analysis
The improved version of the model, including the new process and content, was reapplied in the same companies. The comparison between first and second applications validated the model's ability to deliver more consistent, actionable, and context-sensitive results. It also confirmed the value of incorporating both external and internal assessment mechanisms.

Phase 4: Self-Assessment Tool Development
In parallel with the conceptual framework, a comprehensive self-assessment tool was designed and developed to support organizations in evaluating their current level of digital transformation maturity. The tool was based on the principles of the Malcolm Baldrige Performance Excellence Framework (2019), which served as a foundational reference for structuring the assessment criteria and performance dimensions.

This digital instrument was carefully tailored to be intuitive, accessible, and self-explanatory, ensuring that companies of varying sizes could use it without the need for external facilitation. By operationalizing the theoretical model into concrete indicators and guided questions, the tool enabled users to carry out a structured diagnosis of their organization's strengths and improvement areas across key dimensions such as technology, operations, culture, etc. This was a core feature of the tool, as it has the ability to give preliminary results of the organization for their own knowledge, it was designed with general questions that will complement with the implementation of the tool.

Phase 5: Roadmap Creation Using the PDCA Cycle
Based on the self-assessment, strategic roadmaps were developed using the PDCA cycle (Deming, 1986), offering tailored actions for each company to reach higher digital maturity levels. The methodology includes the following steps:.The steps of the methodology are as follows:

Plan: The desired level to which the company seeks to reach the literature review of Industry 4.0 roadmaps is established.
Do: The roadmap is created and the times and resources necessary for its implementation are defined.
Verify: Validation interviews are carried out with the organization's managers and the respective modifications are made.
Act: The final roadmap is delivered to the organization.

The selected methodology supports project management focused on continuous improvement through structured steps such as diagnosis and strategy design (Moyano & Villamil, 2021).

Additionally, the PDCA cycle offers a flexible and iterative framework ideal for Industry 4.0 transitions, enabling repeated phases to ensure a solid and adaptable action plan (Castillo, 2019).

4. Results

The final product is a consolidated Digital Transformation Maturity Model for the manufacturing industry within the Latin American context with 8 dimensions, 65 criteria and 173 evaluation elements. Figure 3 illustrates the developed model.

Figure 3. Digital Transformation Maturity Model

Source: Own elaboration

The adoption of a gradual and strategic approach based on the maturity model can significantly enhance competitiveness, resource optimization, and the ability of companies to adapt to global challenges. Beyond technological implementation, cultural change and employee training are key elements for progressing through the maturity levels.

It is recommended that companies implement a continuous evaluation system using the maturity model to regularly measure their Digital Transformation by identifying strengths and weaknesses. Likewise, ongoing training is advised to promote development programs for personnel at all organizational levels, with a focus on digital skills, change management, and leadership in the digital era.

The model will enable a deeper exploration of the characteristics, needs, and improvement opportunities related to the digital maturity level of the sector. This will contribute to the generation of applied knowledge on how manufacturing companies in the region can adapt and evolve toward Industry 4.0. Additionally, it will facilitate the identification of

trends, best practices, and critical gaps, serving as a foundation for developing strategies that enhance competitiveness, foster innovation, and promote collaboration between academia and the industrial sector. The results may be applied in academic programs, public policy initiatives, and continuous improvement models, thereby strengthening the digital development of the manufacturing sector in Latin America.

Moreover, the incorporation of self-assessment tools within the model represents a significant advancement, as it empowers companies to conduct continuous evaluations and to be optimally prepared prior to external audits. Figure 4 presents the self-assessment developed based on the Malcolm Baldrige Performance Excellence framework.

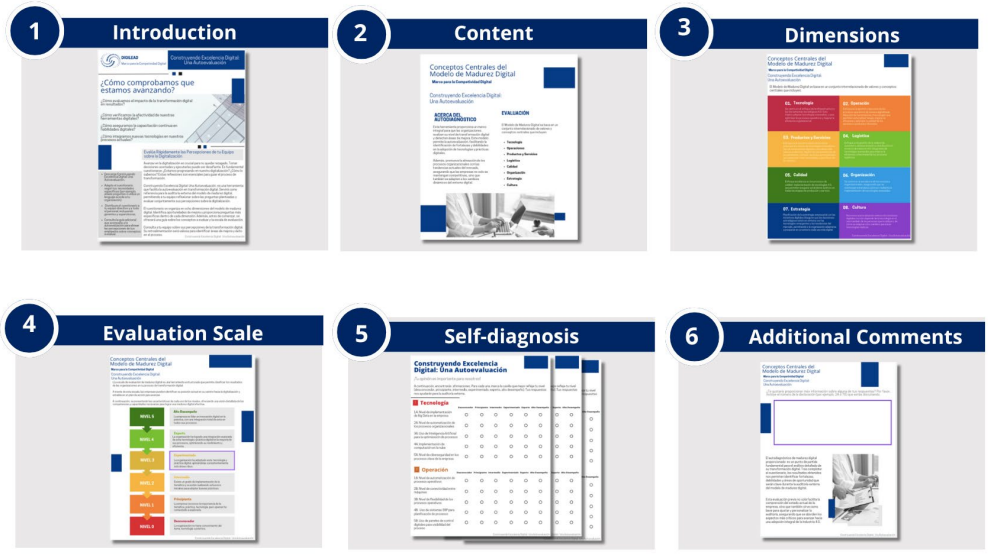

Figure 4. Digilead Self-Assessment Guide: Digital Transformation Model
Source: Own elaboration

Based on the figure, it can be observed that the self-assessment consists of six sections: usage instructions; explanation of the dimensions to be evaluated; the evaluation scale used to categorize responses; the self-assessment section with corresponding evaluation questions; a section for providing further details on the company's processes; and a final message emphasizing how this information serves as the foundation for the external audit within the digital maturity model.

Finally, Figure 5 presents an example of the roadmap developed for a manufacturing company assessed using the proposed model.

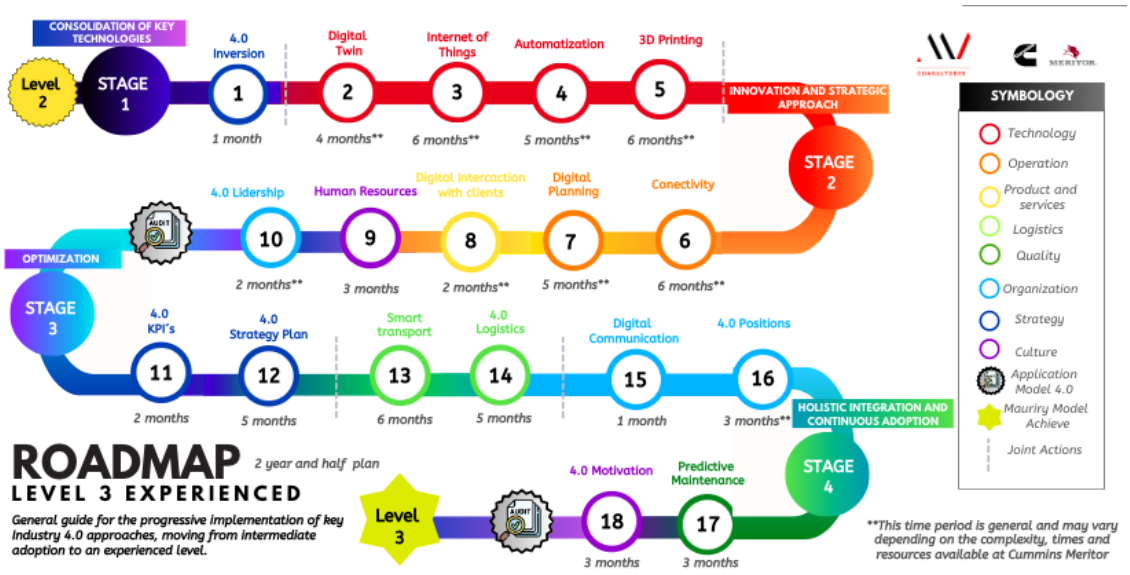

Figure 5. Roadmap Example Manufacturing Company Level 2
Source: Own elaboration

This roadmap includes its corresponding color-coded dimensional symbols, the defined stages, the estimated implementation timeline, the audit checkpoints, and the guiding document detailing the actions and objectives associated with each step.

5. Conclusions

This study contributes to the body of knowledge by consolidating a Digital Transformation Maturity Model tailored to the Latin American manufacturing sector. The model was built through a literature review of 45 existing models and validated through iterative application in four companies in Nuevo León. It establishes a theoretical framework connecting digitalization with key organizational areas such as technology, operations, culture, and strategy. The use of the PDCA methodology allowed for the design of strategic roadmaps based on each company's maturity level, offering practical and adaptive guidance toward digital advancement.

The project's outcomes include a robust model, self-assessment tools, detailed diagnostics, and tailored action plans. Although limited to the automotive manufacturing sector, its methodology is scalable and adaptable to other industries. Future research may involve comparative studies across regions and sectors, longitudinal evaluation of roadmap implementation, and final registration of the model as intellectual property. This initiative strengthens both academic understanding and industrial capabilities in the context of Digital Transformation in Latin America.

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Biographies

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Ana Fer has experience as an intern in platforms and processes at Cemex, at Cummins Meritor / John Deere / Sisamex / Evco Plastics, she contributed to a comprehensive Industry 4.0 project, which included developing a maturity assessment model, conducting internal audits, creating strategic roadmaps, and conducting literature reviews on digital transformation in the manufacturing sector. Previously, at ZF Group, she managed accounts receivable tasks, including invoice processing and client communications.

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Valeria has experience in Digital Supply chain consulting at Cemex, where she has developed with a team strategies for digital continuous improvement for Supply Chain in countries such as the United States, United Kingdom, Mexico and Colombia. She also has experience in processes and auditory in Cummins Meritor, John Deere, EVCO plastics and Sisamex, she contributed to a comprehensive Industry 4.0 project, which included developing a maturity assessment model, conducting internal audits, creating strategic roadmaps, and conducting literature reviews on digital transformation in the manufacturing sector.

Ayesha De Anda is a graduate of the Business Management Engineering program at Universidad de Monterrey. She is a Junior Consultant on the project *"Consolidation of a Maturity Model for Digital Transformation in the Manufacturing Industry within the Latin American Context."* Ayesha De Anda has experience as an intern of global sourcing Home Depot Mexico, where she focused on; negotiating with international suppliers, performing cost analysis, doing follow ups of Classification formats and RFQ's and lastly selling product proposals to the merchandising team. She also developed the Industry 4.0 project that was applied to companies such as John Deere, Sisamex, Evco Plastics and Cummins Meritor. This project included the performance of a literature review, the development of the maturity model, the audits and the elaboration of roadmaps.