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FACTORS INFLUENCING THE ADOPTION OF 4.0 TECHNOLOGIES IN MANUFACTURING SMES IN DUITAMA, BOYACÁ, COLOMBIA

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Abstract

The manufacturing sector in the municipality of Duitama, Boyacá, currently faces significant limitations stemming from increasing globalization. This global pressure is prompting various companies within the subsector to consider integrating Industry 4.0 tools. However, small and medium-sized enterprises (SMEs) often encounter difficulties in transitioning to the comprehensive suite of tools inherent to this new technological era. This challenge may also stem from entrepreneurs' limited vision of their own potential. Furthermore, several factors impede the successful adoption of these technologies, potentially leading to a passive waiting approach from managers, coupled with an inadequate appreciation of the risks associated with delayed adoption. Therefore, this study aims to define strategic guidelines to steer managers of manufacturing SMEs towards a successful adoption of Industry 4.0 technologies. The study employs a qualitative, descriptive approach with a case study design. Findings indicate that the primary constraints are a lack of financial and technical resources, compounded by insufficient knowledge of technological integration and resistance to change. Consequently, the strategic guidelines proposed in this study are expected to mitigate these limitations, thereby facilitating a successful transition to Industry 4.0 within the local manufacturing subsector.

Keywords: Industry 4.0; SMEs; manufacturing sector; digitalization; technology adoption.

Introduction

The transformation of manufacturing in Colombia has been very evident in recent years, causing profound changes and generating transformations in the sector that directly affect its development and growth. However, the sector's productivity still faces serious limitations that prevent it from incorporating economies of scale, as well as its participation in international trade (Vizcaíno et al., 2023).

Despite significant advances in Industry 4.0 and smart manufacturing (Ynzunza et al., 2017), there is a lack of understanding among entrepreneurs about the potential of these technologies, but this perception stems from the ignorance that still prevails in relation to them. Various circumstances also affect the adoption of these innovations, leading managers to adopt a wait-and-see attitude and not take on the risks that late adoption could have for their companies. Although technology adoption has grown in the industry in recent years, there remains a fear of change and of breaking with traditional methods, which could lead to a gradual replacement of traditional technologies with Industry 4.0 technologies in the near future (Ynzunza et al., 2017).

In the contemporary economic context, manufacturing companies face multidimensional problems caused by increasing globalization and the need for customized products, in addition to business competitiveness (Zheng et al., 2021). As a result, they have been driven to adopt Industry 4.0. This industrial revolution combines advanced automation, artificial intelligence, the Internet of Things, and data analytics to improve processes, increase the quality of real-time decision-making, and adapt to the ever-changing demands of the market (Zheng et al., 2021).

Small and medium-sized enterprises (SMEs) in Colombia are a fundamental part of the business structure, showing remarkable diversity in both their productivity and the characteristics of their founders. This business group ranges from small companies with low productivity, where the founders' efforts are mainly focused on the domestic market and there is little emphasis on innovation processes and an international vision, to medium-sized companies with high growth rates, which are dynamic, innovative, and strongly export-oriented (Franco & Urbano, 2019).

The importance of SMEs for Colombia is demonstrated by their high employment rate in the business sector. Indeed, data from DANE collected by former Minister of Labor Alicia Arango Olmos during the “1st Congress on Occupational Safety and Health in Small and Medium-sized Enterprises - MiPymes” (Ministry of Labor, 2019) show

that these companies constitute more than 90% of the national productive sector, produce 35% of GDP, and account for 80% of employment in the country.

In a particular environment, such as Duitama, Boyacá, small and medium-sized manufacturing companies face a number of significant barriers to the adoption of digital tools. These barriers include a lack of awareness of the benefits of incorporating innovation, a shortage of financial resources to understand the technology, and a shortage of human resources trained in the use of the technology.

Based on the above, this study not only sought to identify existing difficulties, but also to establish clear rules to guide managers of manufacturing SMEs in Duitama, Boyacá, in overcoming the obstacles that hinder the implementation of 4.0 tools in their processes. Similarly, it sought to generate new knowledge in this field of study to help improve the development, growth, and competitiveness of these companies in a changing business environment, given the scarcity of studies focusing on business issues in their immediate environment.

Industry 4.0 and its impact on manufacturing SMEs

Industry 4.0 is conceived as a transformation of production processes that harnesses the benefits of digitization, the IoT, artificial intelligence, and big data (Peres et al., 2020), using these technologies to improve process efficiency, facilitate real-time decision-making, and enable intelligent automation in any of the various production sectors, including manufacturing. However, for small and medium-sized enterprises (SMEs), the adoption of Industry 4.0 poses challenges related to financial resources, technical knowledge, and the organization's own resistance to change (Masood & Sonntag, 2020).

In the context of manufacturing SMEs, increasing business competitiveness through the application of Industry 4.0 technology has an impact on their sustainability and scalability. Recent studies have indicated that, by incorporating digital technology, companies can improve their productivity and access to international markets (Brozzi et al., 2020). However, the transition to digitalization is a complex process that involves the design and implementation of strategies.

Various studies have identified the main reasons limiting the adoption of 4.0 technologies in manufacturing SMEs. According to Chen et al. (2021), these factors can be grouped into three main dimensions: economic and financial barriers, resistance to organizational transformation, and barriers due to technological complexity. First, reducing access to financing is one of the main priorities that SMEs must address in their digitization process. The very nature of the different processes involved in digitizing a company means that, in some cases, the investment required to upgrade the various technologies exceeds the company's financial capacity to purchase hardware, software, and staff training (Liu et al., 2023). There are also gaps in subsidy and financing programs, which are geared toward large industries and leave SMEs with very limited options for technological innovation (Chen et al., 2021).

Secondly, resistance to change proves to be a fundamental obstacle to adopting new technologies. As Shahi and Sinha (2021) argue, organizations with a conservative organizational structure do not facilitate the adoption of innovation, and this is particularly negative when company directors consider that the disadvantages of digitization outweigh its benefits. Additionally, resistance to change is increased by staff training in new technologies. According to Zhang et al. (2022), many SMEs do not have staff who can handle sophisticated digital systems. For this reason, resistance to change can be increased by uncertainty about the benefits of digital transformation.

Finally, the perception of the technical complexity of 4.0 technologies generates uncertainty among entrepreneurs. Obermayer et al. (2022) argue that the lack of specific knowledge about IoT, artificial intelligence, and advanced automation discourages their adoption in small businesses. In addition, the absence of adequate infrastructure in certain regions also hinders digitization. Factors such as low internet connectivity and lack of access to specialized technology providers affect the implementation of digital solutions in manufacturing SMEs (Palmer-Abbs et al., 2021).

Previous research has analyzed the adoption of 4.0 technologies in different countries and in manufacturing SMEs, finding common patterns regarding opportunities and obstacles to digitization. Veiga and McCahery (2019) studied the impact of digitization on SMEs in Brazil, finding that limited access to financing and a lack of training were the most significant barriers. Gao et al. (2024) addressed risk perception in SMEs in China, highlighting the importance of training programs and government support for the digital transition. Zahoor and Al-Tabbaa (2020) studied the role of inter-institutional collaboration in the adoption of 4.0 technologies and the impact of public-private partnerships as a mechanism for reducing financial and technical barriers. These findings are consistent with the context of Duitama, Boyacá, where manufacturing SMEs share common limitations.

In order to interpret the results obtained from the study, several theoretical frameworks are taken into consideration, the content of which allows for a deeper understanding of the factors that drive the adoption of 4.0 technologies: Davis's Technology Acceptance Model (TAM) (1989), which describes how perceived usefulness and

ease of use influence entrepreneurs' willingness to accept new technologies; Lewin's (1988) theory of organizational change, which describes resistance to change and how to facilitate the process of change towards the digitization of SMEs; and Chesbrough's (2003) open innovation model, which describes the need to collaborate with other companies, universities, and the public sector in order to overcome the barriers to technology adoption. These frameworks allow us to interpret the data collected from the study while serving as a basis for formulating strategies to enable the adoption of 4.0 technologies in manufacturing SMEs in Duitama, Boyacá, Colombia.

The literature review reveals the opportunities and challenges faced by SMEs in the process of adopting 4.0 technologies. The case of Duitama presents barriers similar to those reported in international studies, suggesting that strategies such as training, access to financing, and strengthening collaborative networks may be key to achieving a clear and effective transition to digitization in the local manufacturing sector.

Methodology

The study being conducted is qualitative in nature, as it aims to show in detail aspects specific to the object of study. As Hammersley and Atkinson (1994) state, this type of method offers a broad view of the phenomenon under study, contrasted with the theories that support it.

According to Miles and Huberman (1994), qualitative research is distinguished by its focus on discourse and arguments to interpret phenomena in the social environment, which, given its holistic nature, allows us to understand the qualities of the situation under study. More specifically, the aim is to analyze and interpret the criteria, arguments, opinions, and perspectives of both managers and workers in manufacturing SMEs in the municipality of Duitama, Boyacá, in relation to the reasons or factors that have prevented the incorporation of Fourth Industrial Revolution technologies into organizational processes.

With regard to the scope of the research, the descriptive method is used to describe the aspects that occurred during each stage of the research process. According to Ander (1995), the descriptive methodology allows for an in-depth description of the features and characteristics of the phenomenon or situation that is the subject of the research. This is because the initial starting point is a diagnosis of the current state of manufacturing SMEs in Duitama, Boyacá, in terms of the adoption of Industry 4.0 technologies.

In terms of design, the research corresponds to a case study, as it focuses on analyzing the factors that influence the adoption of 4.0 technologies in SMEs in the manufacturing sector in the municipality of Duitama in the department of Boyacá. This choice stems from an interest in gaining an in-depth understanding of the dynamics that occur in the organizational context and the structural barriers that prevent the adoption of technological innovations in this context.

According to Yin (2009), case studies are an appropriate research method when seeking to examine a phenomenon in its natural environment, and when the boundaries between the phenomenon and its context are not clearly defined. In this case, the adoption of 4.0 technologies in manufacturing SMEs in Duitama cannot be analyzed in isolation, as it is influenced by economic, cultural, and organizational factors.

The case study in this research sought to:

1. Analyze the barriers and opportunities identified in a group of manufacturing SMEs.
2. Interpret the interaction between organizational factors and strategic decisions regarding technology adoption.
3. Propose contextualized strategies for overcoming the barriers detected.

In relation to the data categorization process, unlike an inductive approach based on Grounded Theory (Glaser & Strauss, 1967), this study used a deductive strategy for data analysis. The categories of analysis were predefined based on the specialized literature on Industry 4.0 and digitization in SMEs. This methodology allowed the research process to be structured in a clear manner and aligned with the relevant theoretical references.

The qualitative analysis process was carried out in the following stages:

1. Literature review: delimitation of existing studies on barriers and facilitators in the adoption of 4.0 technologies.
2. Definition of categories: dimensions of analysis were defined based on the bibliographic references reviewed, including economic barriers, resistance to change, and organizational capacities.
3. Data collection: semi-structured interviews with key informants and document analysis were implemented.
4. Content analysis: data was systematized using ATLAS.ti software, and the information collected was coded in relation to the previously defined categories.
5. Triangulation of information: The results obtained through the interviews were compared with the documentary information and theoretical references, thus ensuring the validity of the study.

In order to ensure methodological consistency, this study is based on Yin's (2009) theoretical framework for case studies and Miles and Huberman's (1994) qualitative analysis strategies. The choice of a deductive approach

provided clear guidance on how to structure the research and converge with previous studies, facilitating the identification of patterns and relationships between the variables addressed.

This approach ensures that the findings obtained are not the result of exploration without a conceptual framework, but rather respond to research questions grounded in theory and empirically validated through the collection and analysis of qualitative data.

In general terms, this study is structured within a case study design with a qualitative analysis using a deductive approach, which allows for a comprehensive and contextualized approach to the issue of the adoption of 4.0 technologies in manufacturing SMEs in Duitama, Boyacá.

Study propositions

In accordance with Yin (2009) in case studies, this research is based on some explicit theoretical propositions that serve to guide data collection and analysis, as well as to define the object of study. These propositions are fundamental to clarifying the study's contribution and establishing its novelty in relation to previous research. The propositions that guide this research are as follows:

- The lack of financial resources is a structural obstacle that limits the opportunity for manufacturing SMEs in Duitama to adopt Industry 4.0 technologies.
- The perception of the complexity and risk associated with new technologies generates unfounded expectations and resistance among managers and employees to undertake technological innovation processes.
- The existence of a conservative organizational culture, clinging to tradition and generating little confidence in the benefits of change, hinders the digital transformation of companies in the sector.
- The design and implementation of contextualized strategic guidelines to meet the needs of the local environment can help overcome these barriers and benefit the transition to the digitization of SMEs.

These propositions guided the coding and qualitative analysis process, allowing us to identify significant patterns in the narratives of key informants and to formulate practical strategies for the adoption of 4.0 technologies in the specific context of Duitama, Boyacá.

Study unit (Key informants)

Within the framework of the research, 39 manufacturing SMEs were identified from a database provided by the Duitama Chamber of Commerce. Then, using convenience sampling, a deliberate sample of 30 managers and employees was selected. This was done to ensure the participation of informants who, due to their roles and experiences, have a deeper understanding of organizational dynamics, innovation processes, and the problems that arise when adopting emerging technologies in their companies.

The key individuals considered were selected according to the following criteria:

- Position within the organization. In this case, managers and employees performing strategic or technical roles related to decision-making, planning within the organization, and the implementation of technologies related to production processes were included.
- Length of service in the company. The informants have a minimum of three years' service within the organizations that participated in the research, which ensures adequate knowledge of production practices, challenges, and specific organizations.
- Representativeness of the sector: Participants were selected from different subsectors within the manufacturing sector, such as clothing, metalworking, food, and chemicals, in order to gather a diversity of interpretations that represent the reality of the sector in the municipality.
- Interaction with technological processes: Selected collaborators are directly or indirectly involved in innovation processes, the implementation of technological tools, or activities that are influenced by digital transformation.

These criteria ensured that key informants were representative, enabling the study objectives to be met. In this way, managers provided a strategic view of the structural barriers related to organizational planning, while employees offered practical insights into day-to-day operations and a series of specific challenges to implementation.

With the collaboration of 30 key informants, the limitations in the adoption of Industry 4.0 technologies were unraveled and examined from the context of the most relevant characteristics of the locality itself. In turn, sustained interaction with them also made it possible to obtain rich and detailed qualitative data from semi-structured interviews. These were designed as spaces for exploring relevant factors, such as those that contribute to the progress of emerging categories during the analysis process.

Data collection techniques and instruments

To collect data for this study, techniques were used that addressed the factors limiting the adoption of digital innovation in manufacturing SMEs in the municipality of Duitama, Boyacá. These techniques were chosen due to the

need to collect extensive and contextualized information that would allow us to understand the organizational dynamics and aspects faced by the digitization process.

One of the main techniques used was a literature review, based on which existing studies on the adoption of emerging technologies in SMEs were reviewed. Their integration made it possible to identify the obstacles faced by organizations, as well as to contextualize the phenomenon and provide a frame of reference. The instrument used in this technique was a documentary corpus that included academic articles and relevant previous reports selected for their relevance and topicality in the field in question. This technique, typical of the qualitative approach, encouraged critical reflection on previous research and allowed the data to be supplemented with the results obtained.

The second technique used consisted of conducting semi-structured interviews with key informants. This technique was chosen because it facilitates obtaining solid information about the perceptions and experiences of both managers and employees of SMEs in their digitization processes. Semi-structured interviews allowed for flexibility to delve deeper into topics of interest as the conversations progressed. The instrument used was a semi-structured questionnaire validated by experts in digital innovation and qualitative methodologies; open-ended questions were formulated to give interviewees space to contribute their opinions and experiences, helping to facilitate understanding of these aspects from a given context, in terms of challenges for SMEs.

The selection of techniques used reflects the characteristics of the qualitative approach of the study, with the aim of conducting an analysis that allows for the exploration and understanding of the factors that affect the use of digital technology in the context of SMEs. The literature review allowed us to construct a frame of reference, while the semi-structured interviews provided a more internal and direct view of the key subjects in SMEs. Both techniques were mutually reinforcing and suited the research objectives, as they provided a comprehensive view of the phenomenon studied and ensured the validity of the data obtained.

Phases of the study

To achieve the proposed objectives, the research process for this study is structured in three stages, each with a specific purpose that contributes to the fulfillment of the overall objective.

Stage 1: Characterization

In the initial phase of the research, a review of the scientific literature was conducted to identify and describe the factors that limit the implementation of Industry 4.0 paradigm technologies for SMEs in the manufacturing sector, thereby developing a foundation that facilitated the contextualization of the object of study.

On the other hand, exploratory interviews were also conducted with directors and employees of SMEs in the municipality of Duitama. These semi-structured interviews helped to capture initial perceptions, identify specific challenges, and enrich the understanding and knowledge of the organizational and cultural context of these companies.

The triangulation of sources from specialized literature and data extracted from interviews conducted formed the basis for comparing theoretical findings with practical experiences reported by key actors, thus ensuring that the triangulation of results at this stage would provide a broad, comprehensive, and well-founded overview of the main challenges and difficulties faced by manufacturing SMEs in digitization processes.

Stage 2: Formulation of Action Plan

Based on the factors limiting digital innovation, a strategic action plan is formulated in this phase, incorporating specific guidelines and recommendations for addressing the problems encountered. The aim is to generate a set of action tools to integrate emerging technologies into the different departments and processes of manufacturing SMEs in the municipality of Duitama, Boyacá. The action plan is based on the needs and realities identified in the characterization phase.

Stage 3: Discussion

In the final stage of the study, we reflect on the importance and implications of technological innovation in manufacturing organizations. This is based on an analysis of the possible solutions generated during the articulation of the action plan and an evaluation of the consequences of not properly carrying out the digitization process. In this sense, the ultimate goal is to create a space for critical reflection that leads to a deeper understanding of the significance of emerging technologies in the world of business organizations and what it may mean to fail to act in this regard.

Results

Stage 1: Characterization

During the research process, all factors influencing the adoption of Industry 4.0 technologies were considered simultaneously from different perspectives. Thus, at the outset of the research process, in addition to reviewing and analyzing the existing literature on this topic, in-depth semi-structured interviews were conducted with directors,

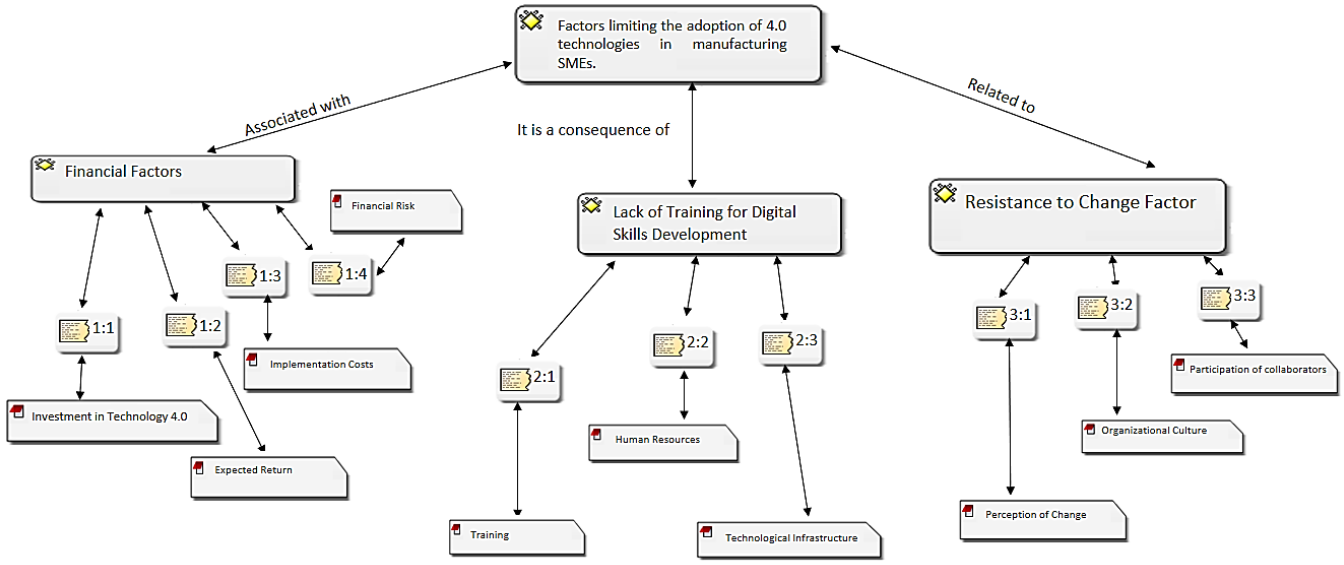
managers, and workers at manufacturing SMEs in the municipality of Duitama. These interviews provided key information for data collection in the strict sense, in the words of the actors directly involved in the study.

The qualitative analysis process in this study followed a structured approach to identify relevant categories of factors limiting the adoption of 4.0 technologies in manufacturing SMEs in Duitama, Boyacá. Data coding was performed based on content analysis using ATLAS.ti software, allowing for the segmentation and classification of information obtained from semi-structured interviews and document review.

The development of emerging categories was carried out in different stages. First, an exploratory reading of the data collected was conducted with the aim of extracting common patterns present in the participants' discourses and the documents analyzed. Second, an initial coding process was carried out, in which fragments of the information collected related to issues and challenges in the adoption of 4.0 technologies were coded. These codes were grouped into subcategories that were refined through constant comparative analysis, ensuring their internal consistency and alignment with the existing literature.

This analysis yielded a semantic network (Figure 1) representing each of the categories and subcategories that emerged from the respondents' answers. This graphic representation specifies and systematizes the factors that, taken together, restrict the adoption of technologies in this area, forming the basis for the subsequent phases of the study.

Figure 1
Emerging semantic network from the responses provided by informants in the administered interview



Source: own elaboration.

Analysis Category Lack of financial resources

Key informants state that difficulty in accessing financial resources is one of the most significant barriers preventing SMEs in the municipality of Duitama from adopting Industry 4.0 technologies. This means they are unable to purchase the appropriate hardware and software and cannot hire people with the necessary training. For them, small businesses tend to prioritize their own operational survival, ruling out investments in technology due to high initial costs and uncertainty about return on investment. They also believe that competition in local markets, together with the limited availability of financing, jeopardizes the existence of these organizations.

These perceptions are reflected in current academic literature. For example, Bittencourt et al. (2021) observe that the cost of implementing disruptive technologies often exceeds the financing capabilities of SMEs, especially in emerging contexts. A similar observation can be found in Morozko (2023), who states that the lack of specific financing for small businesses prevents the transition to digital models, forcing them to continue using traditional paradigms that are not conducive to globalized international contexts.

According to the informants, existing financing programs are geared toward large companies, excluding SMEs from taking advantage of relevant benefits. This perspective is in line with that of Ardito et al. (2021), who argue that financial incentive policies tend to be disconnected from the specific needs of small businesses. This creates a vicious circle where a lack of resources limits the use of technology and, with it, innovation, which in turn restricts the sustainable development of organizations.

The scarcity of financial resources not only influences the purchase of technology, but also limits the ability of SMEs to adapt to market changes and make improvements to their production processes. According to Sousa and Rocha (2019), this limitation reduces the ability to establish long-term plans, including a plan for developing digital skills or technological infrastructure. This leaves SMEs in a vulnerable position against more established and technologically advanced competitors.

From an analytical point of view, addressing this problem requires a holistic intervention that includes the design of public policies that consider the promotion of SME financing, the establishment of flexible credit programs, and the definition of inter-institutional alliances. In this regard, Matt et al. (2021) suggest that collaboration between the public, private, and academic sectors would promote the effective design of inclusive innovation ecosystems, with the aim of helping to overcome financial constraints and, in this sense, facilitate an equitable transition to Industry 4.0, with positive effects on businesses and the economic development of the region.

Analysis Category Complexity and perceived risk

The interviewees believe that the perception of complexity and risk associated with adopting Industry 4.0 technologies is a major obstacle for SMEs in the municipality of Duitama. For them, such adoption implies a thorough understanding of all aspects of the functions of Industry 4.0 technologies, which generates uncertainty among entrepreneurs, especially those with limited ICT training. In the opinion of the informants, this technical complexity equates to fear of the possibility of failure or not obtaining the expected return on investment, which, on the other hand, causes greater resistance to change in organizations.

This perspective is supported by recent research highlighting the challenges small businesses face when adopting emerging technologies. On the one hand, Haohan and Beinan (2023) argue that the perception of technological risk and lack of technical capabilities are specific obstacles for SMEs that can slow down their digital transformation. Similarly, Bekmurzaeva and Kovalev (2023) point out that companies often underestimate the potential benefits of Industry 4.0 due to its perceived complexity and uncertainty about the results of its implementation.

The informants mention that the perceived risk is also associated with economic and organizational factors. For example, they argue that a flawed implementation could lead to significant losses or even jeopardize the company's survival. This reasoning is in line with the argument presented by Ardito et al. (2021) when they indicate that the fear of disruption to daily operations and the costs associated with training and learning are among the reasons that often deter SMEs from investing in the adoption of cutting-edge technologies.

Likewise, informants believe that the lack of specific guidance is another factor that increases the sense of danger, since many companies do not have sufficient guidance to develop a proposal that will carry out this technological transition correctly. This aspect is corroborated by Moeuf et al. (2020), who show that a certain amount of technical support and training can serve to significantly reduce the sense of complexity and risk, as well as enable a more natural integration of Industry 4.0 technologies. However, this lack of guidance is a gap that continues to exist in regions such as Duitama.

From a critical perspective, overcoming barriers of complexity and perceived risk requires strengthening training programs in digital technologies and promoting collaboration with experts who focus on digital transformation. To this end, Garzoni et al. (2020) recommend gradual support strategies through which SMEs can develop technical skills while exploring the advantages of digital technologies. This can build confidence in the adoption process, which, in turn, will increase the competitiveness and sustainable development of companies in the region.

Analysis Conservative organizational culture

Resistance to change has emerged as one of the most significant factors in explaining the difficulty manufacturing SMEs in the municipality of Duitama have in adopting 4.0 technologies. As revealed by the interviews conducted, many workers and managers showed a strong preference for traditional working methods, as well as uncertainty about the benefits that digital innovations could bring to organizational processes. This result coincides with Kotter's (1997) observation that organizational change is often subject to cultural barriers generated by inertia and the lack of a clear vision that allows the expected benefits to be anticipated.

The data analyzed using Atlas. TI software shows that this resistance can be divided into two subcategories: fear of failure and mistrust of technology. Fear of failure has been found to be linked to fear of taking the risk of implementing technologies; which is particularly relevant given the financial constraints and the consequences that mistakes could have on the sustainability of the company. Therefore, in a way, they manifest themselves as a restraining force within organizations (Lewin, 1988), a state that continues to exist today and restricts the transition to new practices. Along the same lines, mistrust of technology responds to the idea that digital tools could replace human labor or cause dependence on external solutions, but which do not necessarily adapt to the conditions of SMEs in the area. These reflections coincide with those of Davis (1989) regarding the acceptance of technology, in which a lack of confidence in its perceived usefulness and ease of use becomes a significant barrier.

The existence of conservative attitudes among organizational leaders, which are fundamental to the adoption of technologies, was clearly evident. One of the interviewees summed it up as follows: “We have always worked this way and we have done well, we don't know why we should change something that is working fine.” This approach highlights an organizational culture rooted in tradition, which becomes an obstacle to the transition to digital transformation. In the words of Khazanchi et al. (2007), attitudes reveal values rooted in organizations that determine how we respond to innovation and change.

Resistance to change is also supported by the lack of appropriate training and education (adequate knowledge) in technological matters. On this point, virtually all employees stated that they did not feel prepared to apply new technological tools in their work, creating a vicious circle of stagnation and resistance. Similar to what Di Sabato and Savov (2024) have already pointed out, training and awareness-raising are among the main strategies for overcoming these barriers and encouraging favorable behavior towards organizational change. Another cultural and organizational barrier arises from the way in which daily operations are prioritized over innovation. In this case, cultural and organizational barriers to change are reinforced, coinciding with the findings of Majama and Magang (2017), who specified that SMEs tend to prioritize solutions to day-to-day problems over strategic planning and innovation.

Finally, the category analyzed warns that this resistance must be overcome through strategies ranging from continuous training, constantly replacing people's mental models, internal communication, and a progressive transformation from senior management; in other words, it not only involves continuous training, but also putting it into practice together with the correct introduction of major technological transformations in the organization.

Second phase results – Action plan

Based on the information obtained in the characterization phase, the second phase of the research process involves developing a strategic action plan to help overcome problems such as the lack of financial resources, the difficulties and risks identified, and the traditional organizational culture that prevails in manufacturing SMEs in Duitama. This plan is based on the specific reality of the organizations and includes specific guidelines and actions aimed at facilitating the implementation of emerging technologies and improving the competitiveness of the sector. Below are the proposals to address the most significant barriers identified in the diagnosis.

To address the shortage of economic resources, the creation of a mutual fund is proposed to finance digitization projects for the most lagging SMEs in the sector. This fund would be jointly managed by financial institutions, public administrations, and private entities, thus facilitating access to low-interest loans and subsidies specifically aimed at the acquisition and implementation of digital infrastructure. At the same time, it is proposed to launch training programs on innovation finance management, which will enable SMEs to prioritize strategic investments in essential technologies that would enhance their digital transformation.

In relation to the complexity and perceived risk of adopting technologies, we advocate implementing a phased training plan that combines theoretical and practical training. This plan should focus on success stories applicable in the local context, demonstrating the tangible benefits of digitization. It also proposes the incorporation of simulations and practical exercises to help employees and managers become familiar with the technological tools and reduce the perception of uncertainty, increasing ownership of the implementation process.

Resistance to change, as a result of a conservative organizational culture, must be addressed through awareness-raising and cultural change strategies. To this end, participatory workshops are proposed, where employees can reflect on the benefits of digitization for personal and organizational performance. It is also proposed to promote internal communication campaigns that reinforce a shared vision of innovation, highlighting the importance of digitization as a key pillar for business sustainability and continuous improvement.

Another key action is the creation of a digital innovation committee at each SME, made up of representatives from different areas and organizational levels. This group would be responsible for leading and controlling the digital transformation process, ensuring that all proposed actions are aligned with the organization's strategic objectives. This committee would also function as a channel of communication between management and employees, resolving doubts,

managing resistance, and ensuring the commitment of all stakeholders involved in the organization's digital transformation.

Planning will include the implementation of a continuous evaluation stage, based on key performance indicators that measure the effectiveness of the technologies adopted and the results of the organizational transformation. The evaluation will serve to identify areas where progress can be made and adjustments and corrections can be made where necessary to ensure that planning objectives are met effectively and sustainably.

Finally, it is considered essential to integrate this action plan with regional and local public policies that are enacted through public programs promoting the digitization of SMEs. At the same time, the establishment of cooperation networks with universities, research centers, or companies in the industry itself will be encouraged, with the aim of benefiting from additional resources, technical advice, and new technologies that would increase the innovative capacities of local organizations.

At a global level, this strategic action plan aims, among other things, to overcome the barriers that have been identified before laying the foundations for a process that has led to a digital transformation, which we consider to be sustainable and effective for manufacturing SMEs in Duitama, which in turn can serve to improve the competitiveness of the sector and the economic development of the region.

Third stage results – Discussion

In the final phase of the research process, an analysis was conducted on the importance and effects of technological innovation in manufacturing SMEs in Duitama, Boyacá. The argument is based on the fact that digitization is essential for the sustainability of the company in a highly competitive business environment. For Ramadan et al. (2022), the integration of new technologies not only contributes to the modernization of processes, but also promotes the enhancement of the company's strategic capabilities, which is essential for positioning itself in a competitive environment. Thus, companies that do not develop these technologies run a high risk of quickly becoming outdated, which could result in significant economic and structural losses.

One of the most notable findings was the impact of conservative organizational structures on change. SMEs that do not develop a culture of innovation have a certain impact on limiting the technological tools that could contribute to their productivity and market positioning. In this vein, authors such as Hanelt et al. (2021) emphasize that organizational transformation is necessary to make effective use of technology, as it entails challenging traditional frameworks and exploring alternative ways of working. Promoting an organizational culture of change and innovation is a key aspect of effective digitization.

Similarly, training and human talent development were considered a strategic focus of discussion. SMEs must face the challenge of addressing any gaps in their employees' digital skills, which is corroborated by the findings of Uzule and Verina (2023), who state that a lack of competence in the use of new technologies is a common barrier to the digital transformation of organizations. For this reason, it is essential that companies invest in continuous training and implement systems in their corporate culture that enhance the technological capabilities of their human capital.

From a strategic point of view, it was pointed out that the digitization process must be aligned with the company's long-term goals, since digitization cannot be limited to the simple adoption of technological tools, but must pursue process optimization, market diversification, and improved customer experience. According to Kalluri (2023), companies that integrate digital technologies as part of their organizational strategy achieve better performance in terms of profitability and sustainability, while companies that do not take this approach into account and try to stay afloat face limitations that put them at a disadvantage compared to more innovative competitors.

With regard to external support, the discussion highlighted the role of collaborative environments and public policies in promoting digital transformation. Ahmad et al. (2021) emphasize that tax incentives, technical training, and strategic partnerships between companies and universities are mechanisms that can help SMEs adopt technology. This collaborative strategy offers the possibility of overcoming the economic and technical barriers that often facilitate the inclusion of digital mechanisms.

Similarly, the regional implications of the digitization of manufacturing SMEs were discussed. Manufacturing SMEs are central to Duitama's economy, and their technological modernization could have positive repercussions on both employment and competitiveness in the area. However, Mohamed et al. (2022) warn that the lack of technological innovation in key economic sectors could be a source of economic backwardness, particularly in regions where a significant proportion of SMEs are the backbone of the provincial economic fabric.

Digitization is a key priority in today's business landscape. Ignoring new technologies and their evolution can have an irreversible impact on businesses and even on the regional economic ecosystem. As Warner and Wäger (2019) point out, the success of digital transformation is not limited to technical implementation; it also requires a

strategic approach and the collaboration of all stakeholders to take full advantage of new technologies. Therefore, it is crucial that each component of Duitama's business ecosystem commits to promoting digital culture and creating an environment conducive to the modernization of its manufacturing SMEs.

Regarding the novelty of the study and its contribution, it provides a contextualized analysis of the adoption of 4.0 technologies in manufacturing SMEs in Duitama, an approach that has been little explored in previous research. While previous studies have addressed the digitization of SMEs in global and national contexts, this work provides specific empirical evidence from a region with particular socioeconomic characteristics that influence technology adoption.

Unlike previous research that highlights general factors of resistance to change, this research precisely identifies the structural, cultural, and financial elements that hinder digital transformation in manufacturing SMEs in Duitama. Likewise, the proposal of strategies based on local evidence allows for more accurate and applicable recommendations in this context.

Finally, this research contributes to the literature by providing a comprehensive overview of the challenges and opportunities in adopting Industry 4.0 in manufacturing SMEs in intermediate regions. The combination of a detailed qualitative analysis with an approach based on collaborative networks and organizational strategies allows for expanding knowledge about digital transformation processes in business environments with characteristics similar to those of Duitama, Boyacá.

Originality and contribution of the study

This study presents a novel and contextualized view of the factors that limit the adoption of 4.0 technologies in SMEs in the manufacturing industry in the municipality of Duitama, Boyacá; Most studies on digital transformation in industry have focused their attention on urban contexts, highly industrialized environments, or large companies. This study, on the other hand, delves into the particularities of an intermediate economy in a regional productive environment with traditional organizational structures, persistent financial limitations, and significant technological gaps.

The most valuable feature of this research is the territorialization of the field of study. By placing the analysis in a context that has been scarcely addressed in scientific literature, an empirical view is generated that allows us to understand how local socioeconomic conditions affect the digitization of SMEs. The research not only highlights a latent problem in the region's productive fabric, but also bears witness to the discourses of key actors facing the challenges of the fourth industrial revolution from the perspective of structural disadvantage.

Another distinguishing feature is the use of a case study with a qualitative approach guided by explicit theoretical propositions, in line with Yin (2009). This approach made it possible not only to clearly define the phenomenon under study, but also to structure the analysis based on relevant conceptual frameworks, facilitating rigorous interpretation of the data and identification of significant patterns in the narratives of key informants.

Finally, the development of a strategic action plan based on specific local evidence constitutes a valuable practical contribution. The recommendations derived from this study are tailored to the real context of the participating organizations and can be implemented by managers, trade associations, public entities, and other actors in the regional productive ecosystem. This applied approach enhances the usefulness of the study beyond the academic sphere, transforming it into a strategic input for the design of policies and programs that promote an effective transition to digitization in similar regions.

Conclusions

The research has revealed a series of interesting findings regarding the barriers faced by small and medium-sized enterprises (SMEs) in Duitama, Boyacá, in adopting Industry 4.0 technologies. Determining factors have been identified that hinder the successful integration of technology into the region's business environment. The main barrier was the inability of entrepreneurs to understand and lack of knowledge about the benefits and projections of these new technologies. This lack of understanding generates reluctance to change and can lead to the perception of change as a risk related to the complexity inherent in new technologies. These aspects can affect entrepreneurs' willingness to adopt these new technologies, thus limiting their ability to improve the competitiveness and efficiency of SMEs. These limitations will not facilitate the success of their companies' professional activities if they so desire.

Likewise, the provision of financial resources is a fundamental obstacle. SMEs may have difficulty accessing the funds necessary to invest in state-of-the-art technologies, which can result in incomplete implementation or the selection of technological resources with lower capabilities. This financial constraint can limit companies' ability to keep up to date and remain competitive in an environment of continuous development.

The persistence of a conservative organizational culture has also been identified as a major challenge. This culture can show signs of resistance to change in organizations, hindering the adoption of new technologies and innovations. This is consistent with existing literature, which shows that culture, lack of understanding, and money are aspects that can undermine the ability of SMEs to adopt and implement disruptive technologies.

It is worth taking these conclusions into account when developing strategies and guidelines that overcome these barriers and promote the effective adoption of Industry 4.0 technologies in manufacturing SMEs. A systemic approach is needed that considers training programs, access to financing, and a line of action for cultural change to carry out this adoption of emerging technologies, which, in turn, will enable the competitiveness and sustainability of these companies in an increasingly technological and globalized business world.

Ethical considerations

Approval from a Scientific Ethics Committee was not required.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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