

Exploring Key Factors for Implementing Manufacturing Execution Systems (MES) within the Framework of Industry 4.0 for Small and Medium-Sized Enterprises (SMEs) in the Manufacturing Sector

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Abstract

Paper aims: The present study addresses this challenge by delving into the influential factors guiding small and medium-sized manufacturing companies towards MES adoption in the context of Industry 4.0.

Originality: Given the longstanding existence of Manufacturing Execution Systems (MES) for two decades before the development of Industry 4.0 (I4.0) concept, the already complex understanding of MES in the market, particularly among manufacturing companies, has become even more intricate. This complexity is exacerbated when considering MES as a pivotal element for vertical integration within the realm of I4.0.

Research method: Through in-depth qualitative interviews, six professionals deeply engaged with MES systems, including three from a system development company and three SME experts utilizing the product, were consulted.

Main findings: The results shed light on how manufacturing SMEs are embracing MES. Drawing upon the technological, organizational, and environmental dimensions, as well as the innovation diffusion process, an integrative model was crafted. This model serves as a lens to scrutinize the intricate process of MES adoption.

Implications for theory and practice: the article advances the diffusion of innovation theory and the technological-organizational-environment framework, because it brings a consolidated vision of both for the implementation of systems in Industry 4.0.

Keywords

Industry 4.0 (I4.0). Manufacturing Execution Systems (MES). Vertical Integration. Small and Medium Enterprises (SMEs). Innovation Diffusion (DOI). Technology–Organization–Environment (TOE) framework.

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1. Introduction

The introduction of the term Industry 4.0 (I4.0) in 2011 underscored the pivotal role of seamlessly integrating manufacturing facilities using digital technologies for real-time data capture, storage, and processing. However, as posited by Tabim et al. (2021), the realization of I4.0's potential hinges on the availability of vertically integrated systems equipped with diverse data management capabilities, vital for delivering the anticipated efficiency gains. Vertical integration, in this context, refers to the harmonious fusion of digital manufacturing systems across various hierarchical levels within an organization. It embodies the synergy between production and management tiers within a factory. At the core of this integration lies the interconnection of Enterprise Resource Planning



(ERP) with the Manufacturing Execution System (MES). MES, as highlighted by Tabim et al. (2021), serves as the linchpin for vertical integration in the I4.0. It establishes a direct link with the entire operational fabric of the plant, encompassing machinery, equipment, sensors, Programmable Logic Controllers (PLCs), and Supervisory Control and Data Acquisition (SCADA) systems. Crucially, MES facilitates robust data management and the archival of production data history, forming a foundational basis for informed decision-making processes in the dynamic context of Industry 4.0. Considering that the MES system has existed since the 1990s (Cottyn et al., 2011) - two decades before the advent of I4.0 - the understanding of the MES concept in the market, which already lacked clarity and depth for manufacturing companies, became even more challenging when considered an essential component for vertical integration in the context of I4.0 (Almeida & Pinheiro, 2022). Prior to the advent of Industry 4.0, MES was often purchased and implemented by companies without regard to subsequent system integration. As a result, enterprises today face a complex web of systems, whether legacy or not, and the complexity of different software architectures makes it difficult to transition to I4.0. Therefore, adopting MES for vertical integration is a challenge that requires a robust technology adoption model suited to the I4.0 context.

To illustrate the formidable challenge faced by companies in implementing MES for vertical integration, Schuh et al. (2020) conducted a comprehensive assessment of 70 manufacturing firms in Europe striving to transition into Industry 4.0. Their findings were striking: a mere 4% of these companies succeeded in achieving comprehensive data and information visibility through vertical integration. These findings are aligned with similar findings in Brazil, where research conducted by Dalenogare et al. (2018) indicated that most companies engaged in I4.0 initiatives still prioritize verticalization as their primary investment focus. However, it is essential for companies to also consider the benefits of horizontal integration, which involves accessing new markets and distribution channels and developing synergies and collaboration opportunities. Both vertical and horizontal integration can complement each other in achieving the goals of Industry 4.0. The optimal approach may vary depending on the specific context and objectives of each company. As many companies aim to improve their internal processes to maintain a competitive advantage in the market (mainly small and medium enterprises), vertical integration is a strategy that enables companies to have greater control over their production, access more data from different production levels, customize and make demands flexible, and standardize processes and technologies at different levels of production (Tabim et al., 2021, Enrique et al., 2022a,b). These collective studies underline the persistent challenges faced by businesses worldwide, underscoring the pressing need for innovative solutions in the realm of Industry 4.0 implementation. These findings underscore the critical significance of vertical integration for companies of diverse sizes within the context of I4.0.

Examining the context of Small and Medium Enterprises (SMEs) in the manufacturing sector, the complexity of implementing MES becomes even more pronounced. SMEs recognize the necessity for growth-oriented initiatives, yet they grapple with uncertainty regarding when and where to commence. According to Moëuf et al. (2018), the absence of dedicated support structures tailored for SMEs can significantly deter their adoption of I4.0. Safar et al. (2018) posit that incorporating new technologies into SME operations holds the promise of cost reduction and enhanced efficiency in business processes and environments. However, as noted by Mittal et al. (2018), SMEs generally lack the necessary resources to drive innovations beyond their core competencies. In essence, numerous challenges hinder the effective utilization of Industry 4.0 resources, particularly when it involves implementing a system as intricate as MES, which often lacks clarity and depth.

Consequently, the following question emerges: 'What factors influence the adoption of an MES system among manufacturing SMEs within the framework of Industry 4.0?' This query includes the essence of exploring the intricate dynamics guiding SMEs in their journey toward integrating MES technology amidst the evolving context of I4.0. Considering these aspects, two main aspects must be considered to answer the above question: the process of adopting the technology and the technological, organizational, and environmental aspects that influence its use. First, we use the decision-innovation process model (Rogers, 2010) to study the adoption of the MES system in the context of I4.0 in manufacturing SMEs. We consider the stages of knowledge, persuasion, and decision in this process, because the focus of the article is on the pre-implementation of technologies (Tabim et al., 2021). This theory is mainly based on the characteristics of the technology and users' perception of innovation. Secondly, since the adoption of MES depends not only on factors directly related to it, but also on organizational and environmental aspects, we used the Technology-Organization-Environment (TOE) framework (Tornatzky et al., 1990) as a basis for identifying different socio-technical factors in the adoption of MES in I4.0.

The primary goal of this study is to investigate the factors influencing the adoption of Manufacturing Execution Systems (MES) by Small and Medium Enterprises (SMEs) within the framework of Industry 4.0. Specifically, this research targets manufacturing SMEs aspiring to incorporate MES aligned with I4.0 principles into their operational goals. The model aims to provide comprehensive support to these companies, offering strategic guidance amidst the challenges encountered during Industry 4.0 implementation. By doing so, it facilitates decision-making processes related to sales and sourcing, ensuring alignment with the specific needs

of the industrial sector. Additionally, the study anticipates contributing valuable insights that can serve as a reference point for the evolution of the MES concept within the context of I4.0.

In collaboration with a management software development company, we conducted an exploratory research initiative to validate the prerequisites for MES adoption. Building upon this research, we developed a framework designed to overcome the obstacles hindering the adoption of MES systems by manufacturing SMEs. Furthermore, the framework identifies a structured approach to enhance the overall adoption process. The main contribution of the article is to help small businesses implement MES so that they can reduce implementation barriers, increasing process flexibility and data use efficiency (Dutta et al., 2022). Our results provide an analysis of the implementation of the MES based on theoretical frameworks from the literature. Companies can use their best attributes highlighted by Estensoro et al. (2022) aligned with our theoretical framework to focus on implementing MES for competitive advantage in industry 4.0.

2. Theoretical background

2.1. MES in the context of manufacturing smes

At its core, the fourth industrial revolution harnesses the power of Internet of Things (IoT) systems, cyber-physical systems (CPS), and the application of Big Data (BD) to elevate industrial parks. These advancements propel these parks to unprecedented levels of production sophistication, significantly enhancing efficiency. This transformative process involves dynamically reconfiguring processes and optimizing resources, amplifying traditional production methods. Indeed, the impact of I4.0 on the work environment, especially within the productive sector, cannot be overstated. However, it's essential to recognize that technology's influence on the labor market traces back to the First Industrial Revolution. During this era, the introduction of mechanization marked the beginning of a shift from traditional artisanal methods. The ongoing evolution of I4.0 is, in essence, a continuation of this historical trajectory, ushering in a new era of industrial advancement and reshaping the very fabric of our workplaces.

Small businesses, in contrast to their larger companies, often grapple with resource constraints when it comes to investing in innovation. Unlike large corporations, they typically lack dedicated research and development departments and frequently navigate uncertainties arising from economic policy changes, shorter product life cycles, and competitors with superior advantages, among other challenges. These factors might suggest that smaller enterprises tend to be less innovative compared to their larger counterparts. However, operating in an environment of uncertainty can foster innovation (Alvarenga Neto, 2002; Scatolin, 2015). It compels companies to seek knowledge beyond their organizational boundaries, leading to a culture of continuous innovation. The success of technological innovation in companies is contingent upon various factors, including the structure of the workforce, adopted strategies, collaborations with other companies or universities, and, notably, the internal organization of the company. The development of technological innovations is profoundly shaped by the presence of an internal environment conducive to generating and effectively applying creative ideas. Furthermore, the ability to accumulate both technological and managerial knowledge plays a pivotal role in this process (Birchall et al., 1996).

Equally vital is the need for the entire team to possess comprehensive knowledge about the usage and implementation of the involved technologies (Brunheroto et al., 2020). Achieving success in the Fourth Industrial Revolution demands not only investments in infrastructure but also a commitment to enhancing the knowledge base of the workforce, ensuring they are well-equipped to navigate the complexities of modern technological advancements. Because of that, SMEs are actively pursuing the implementation of I 4.0 technologies. This implementation is not merely a strategic choice; it has become an essential step for SMEs to maintain their competitive advantage. In a market where technological integration is becoming ubiquitous, companies that fail to incorporate these advancements risk falling behind, placing themselves at a significant disadvantage in comparison to competitors who have already embraced I4.0 technologies (Brunheroto et al., 2020).

The Diffusion of Innovations (DOI) theory has proven instrumental in deciphering the factors influencing the adoption of information systems. This theory incorporates the attributes of innovation and technology (Kapoor et al., 2015) and views IT adoption as a series of processes (Wu & Chuang, 2009), providing a profound understanding of adoption dynamics. Specifically, the innovation decision process model (Rogers, 2010) within DOI theory offers a structured framework for analyzing MES adoption in the context of I4.0. This model encompasses five stages: knowledge, persuasion, decision, implementation, and confirmation. The first three stages involve evaluating the adoption decision, whereas the latter two pertain to post-implementation analysis. Our study focuses on the initial three stages, which encompass the evaluation of adopting or rejecting an innovation.

In essence, managers, before making an adoption decision, need to comprehend the functionality of innovative technology (knowledge) and subsequently form a favorable or unfavorable attitude toward it (persuasion). Figure 1 illustrates the adoption stages outlined in the Innovation Diffusion model. In this study, we specifically emphasize the initial stages highlighted in orange, which were fundamental in shaping our research. Later, the implementation stage was employed to operationalize the frameworks developed.

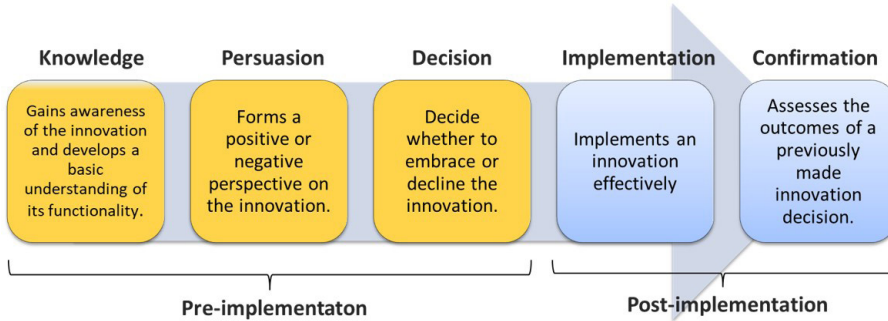


Figure 1. Stages of the decision-innovation process model.

Source: adapted from Nam et al. (2019).

However, given the profound implications of adopting a MES within the framework of I4.0 for SMEs, our research problem necessitates a holistic perspective that considers various dimensions of adoption across diverse contexts. The traditional Decision-Innovation Process Model, while valuable, falls short as it primarily focuses on the technological aspects, omitting other critical dimensions. To address this limitation and capture the complexities of vertical integration adoption comprehensively, we integrated the Decision-Innovation Process Model with the Technology-Organization-Environment (TOE) framework (Tornatzky et al., 1990). This framework allowed us to adopt a broader perspective, encompassing not only technological aspects but also organizational and environmental factors (Figure 2).

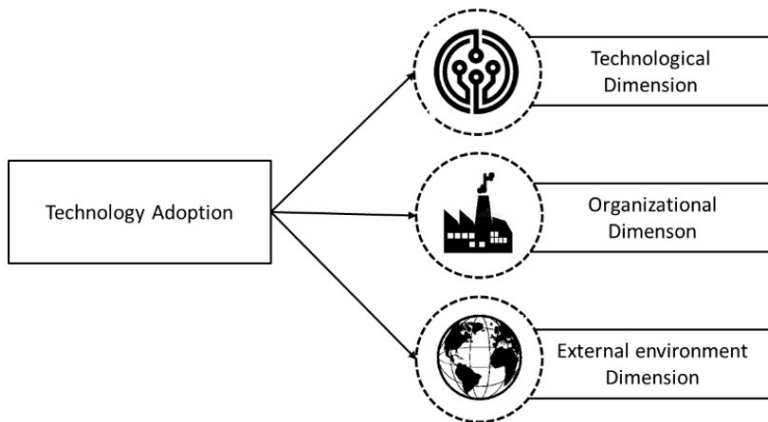


Figure 2. Dimensions of the TOE framework.

Source: adapted from El-Haddadeh et al. (2021).

The TOE framework, operating at the organizational level, provides a theoretical lens through which to comprehend the multifaceted adoption process of new information systems. It delves into technological, organizational, and environmental perspectives, considering factors that influence the adoption process. Unlike models focusing solely on individual beliefs or characteristics within an organization, TOE broadens the scope. The technological dimension pertains to the innovative features of the system, whereas the organizational context

encapsulates internal factors such as size, centralization, formalization, management structure, hierarchy, and procedures. Lastly, the environmental context considers industry dynamics, competitors, and the company's relationships with external entities, including governmental institutions. By integrating these dimensions, our approach captures the nuanced interplay of technology, organization, and environment in the MES adoption process, offering a comprehensive understanding of this intricate phenomenon.

The effectiveness of the TOE framework has been verified by numerous empirical studies on the adoption of various information systems and technologies. Previous scholars have considered the TOE framework as a theoretical basis for understanding the adoption of information technology, including open systems (Chau & Tam, 1997), electronic data interchange (EDI) (Kuan & Chau, 2001), e-business (Zhu et al., 2006), and knowledge management systems (Lee et al., 2009). The theory has also been used for information systems in the context of I4.0, but there is still no study that identifies the factors of adoption specifically of MES in the context of I4.0 in manufacturing SMEs.

In this study, we employ a comprehensive approach, integrating both the TOE framework and the Diffusion of Innovation theory, to unravel the complexities of MES adoption within I4.0 in SMEs. Our research endeavors to unveil the pivotal drivers of MES adoption within the context of I.0 in SMEs, employing a three-fold analysis involving stages of knowledge, persuasion, and decision-making. This exploration spans three distinct dimensions: technology, organization, and the external environment. By delving into these dimensions and comparing their varied impacts across scenarios, our study aims to discern the nuanced effects of MES adoption. Figure 3 visually encapsulates our conceptual model, integrating both adoption theories, illustrating the multifaceted approach adopted in this research.

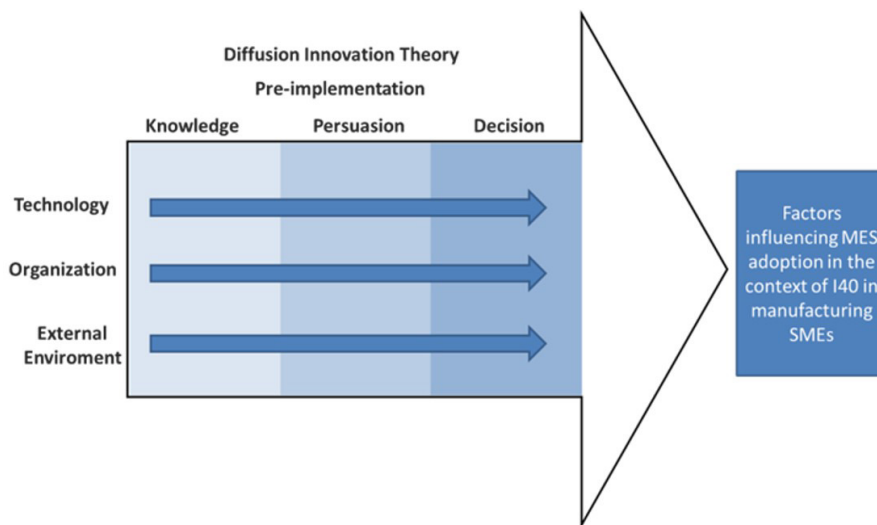


Figure 3. Conceptual model.
Source: adapted from Tabim et al. (2021).

Our proposed model complements existing literature models that focus on the adoption of Industry 4.0 technologies by providing additional paths for adoption (Ghobakhloo et al., 2022). Additionally, our model is specific to MES adoption in the context of vertical integration. Furthermore, our framework can complement the ontological and semantic vision of the implementation of MES in practice for engineers (Jaskó et al., 2020) by providing a pre-implementation view. The literature can help companies and engineers understand MES within the context of Industry 4.0, including its potential uses and benefits, as well as how to initiate their Industry 4.0 journey with MES. To ensure a successful implementation of MES for SMEs, our conceptual model covers various aspects that need to be considered.

3. Method

The analyzed company has played a pivotal role in the digitization journey of businesses across various scales. Their expertise offers holistic solutions that can redefine industry standards. With a focus on manufacturing, the

company endeavors to digitize operations. Leveraging automation solutions, advanced production planning, and IoT technologies, they focus on manufacturing and operational practices. Despite their remarkable track record, a challenge persists: expanding the adoption of their MES solutions in SMEs within the manufacturing sector. Despite the introduction of I4.0 as a means for SMEs in developing countries to achieve higher productivity (Ghobakhloo & Ching, 2019), current research shows that the adoption of Industry 4.0 has been primarily limited to large companies, with only a few SMEs embarking on this journey. Currently, the literature is examining the impact of Industry 4.0, vertical integration, and MES implementation in small and medium-sized companies (Dutta et al., 2022; Estensoro et al., 2022; Ghobakhloo et al., 2022; Jaskó et al., 2020). Furthermore, Stentoft et al. (2020) found that SMEs effectively overcome barriers to Industry 4.0 implementation. This challenge stems from the limited understanding of I4.0 and its driving factors among these SMEs. Considering this situation, the company is proactively addressing this issue. Their strategy involves an in-depth analysis of the SME manufacturing context, analyzing the unique challenges and motivations of these enterprises. By identifying the key factors influencing MES adoption in this context, the company aims not only to overcome this challenge but also to extend its transformative solutions.

3.1. Search ranking

The nature of this study is distinctly practical, generating knowledge aimed at solving real-world issues and aligning with genuine interests (Almeida & Pinheiro, 2022); Faced with the challenge of generating actionable knowledge, this research adopts a descriptive character. Considering Gil's (2002) definition, descriptive research endeavors to relationships between variables, specially related to TOE framework and Diffusion of Innovation theory. Considering these aspects, this study aims to discern similarities and correlations among these factors. In this study, notes gathered were meticulously examined from diverse angles, ensuring a profound understanding of their meanings and relevance within the study's framework.

The approach undertaken for this research is qualitative, emphasizing the collection of visual and verbal information obtained systematically. The qualitative approach delves into the nuanced aspects, offering in-depth analysis and interpretation. It describes the intricate complexities of behaviors, providing a detailed examination of investigations, attitudes, and behavioral trends (Oppong, 2013). This emphasis on processes and meanings distinguishes qualitative research, offering a profound understanding of the subject matter.

Ultimately, this study endeavors to identify and articulate the challenges and prerequisites faced by the interviewed companies. Through a meticulous analysis of this data, it aims to unravel the potential viability and attractiveness of MES solutions. The central question revolves around whether MES can prove advantageous for SMEs and the companies providing this technology. By addressing these questions, this research seeks to shed light on how MES can evolve into a compelling and practical solution, making a substantial impact in the context of SMEs and their technology providers.

In the implementation of these methodologies, interviews featuring open-ended questions served as the primary research tools, delving deep into the subjective perspectives of the interviewees, and embracing a qualitative approach. Following the interview phase, conducted with a diverse group comprising three employees from a different company and three representatives from SMEs utilizing the MES of that company, the obtained data underwent meticulous analysis using a prioritization matrix. This matrix factored in elements such as impact, urgency, cost, and complexity, along with other project-relevant criteria, based on the assigned scores for each factor. The utilization of a prioritization matrix proved invaluable, offering an efficient and objective framework for evaluating usability issues. This approach enabled informed decision-making, guiding the focus of improvement efforts with precision and clarity (Nielsen & Loranger, 2006).

3.2. Work steps

To deepen this research, which seeks to identify the factors that influence SMEs in the adoption of the MES of the mentioned company in the context of I4.0, a research method was used to develop the framework that sought to understand the reasons why companies do not adopt the MES system of the referred company. To achieve this objective, a qualitative approach was employed.

In the first interview script, three companies that showed interest in the implementation of the MES system were selected. The goal was to understand the factors that influence the adoption of these systems by small and medium-sized businesses.

The choice of the three companies interviewed followed the recommendation of the aforementioned company, opting for those that had already tried to implement the MES system previously. It was intentional to select

companies from different sectors of the industry, such as packaging and rubber, to obtain contrasting results and provide a broader view, facilitating the generalization of the results obtained.

In the first stage, six qualitative interviews were conducted with questions structured online with professionals specialized in MES, three of these professionals' employees of the company that developed the MES (Appendix 1), and the other three professionals from SMEs that have already implemented the MES of the company (Appendix 2). All interviews were recorded, with the interviewee's authorization, thus allowing a later analysis of the dialogues carried out. The objective of these interviews was to understand the perception of these professionals in relation to how manufacturing SMEs seek to implement this system in the context of Industry 4.0. In this way, it was possible to gain insights from the point of view of both the adopter and the vendor of the MES. The interviews were conducted through a script of questions, which can be seen in Appendix 1, designed to understand the processes and production needs involved. In addition, an analysis of the documentation available on the company's website and a data collection were carried out.

In the subsequent phase, the amassed data from interviews and documentary research underwent meticulous analysis. This thorough examination led to the identification of factors shaping the adoption of MES by SMEs, which were systematically categorized into three dimensions: technological, organizational, and external environment. This structured classification provided a nuanced understanding of the multifaceted aspects influencing MES adoption among SMEs.

Subsequently, the insights gleaned from the interviews were methodically organized into topics within the three dimensions, culminating in the development of a comprehensive framework. This framework serves as the foundation for constructing a maturity model, a strategic tool designed to offer an in-depth perspective on the specificities and requirements of the studied companies. The maturity model plays a crucial role by exploring the developmental stage of SMEs concerning MES adoption. This valuable insight not only aids in process enhancement but also informs strategic decision-making, empowering businesses to make informed choices that align with their growth trajectory.

4. Case description

The selection of the three interviewed companies was guided by the recommendation of the company, deliberately choosing entities that had previously attempted MES system implementation. This intentional selection spanned diverse sectors within the industry, including packaging, paper, and rubber, aiming for a deliberate contrast to enrich the breadth of perspectives and facilitate the generalization of the obtained results. Second, the second part of the study was aimed at the salespeople of the MES system, seeking to identify the perceptions of these professionals in relation to the potential companies that could adopt the system.

4.1. Company A

The initial company, denoted as "Company A," operates within the rubber transformation sector, boasting a workforce of 21 employees and an impressive annual turnover of 9 million reais. The interviewee representing this organization was the company's director, as detailed in Table 1, providing a key executive viewpoint for the analysis.

Table 1. Analysis of the rubber company.

	KNOWLEDGE	PERSUASION	DECISION
TECHNOLOGY	Advantages of the MES system; ERP integration; Potential impact on operations; Complexity	Understanding the benefits	Balance between cost and benefit
ORGANIZATION	Competence of the IT team; Development of data culture and data company; The company's capacity for innovation	Communication with the IT team; Promoting cultural change	Defining a data management culture; Lean Manufacturing process planning
EXTERNAL ENVIRONMENT	Regulatory compliance; Potential for changes in the market	Influence of success stories; Benchmarking; Feedback from customers and suppliers	Supplier's solidity

Company A embarked on the MES System implementation with the aim of enhancing visibility into production capacity and identifying avenues for revenue growth, all without substantial investments. At the core of this

decision was the pivotal role played by the Director, GR, who spearheaded the selection process. Opting for this system was a strategic move due to its seamless integration with the existing ERP and its favorable cost/benefit. The implementation spanned four months, preceded by an intensive Lean Manufacturing initiative. However, the journey encountered challenges; the system’s performance proved average, facing issues related to support and structural instabilities within the company.

This experience highlighted the need for enhancements, particularly in interconnecting machines and refining the user interface for notetaking. Intriguingly, alterations in the system’s layout led to its eventual discontinuation. It’s noteworthy that the company’s maturity level significantly influences the integration of manufacturing monitoring systems. The decision to suspend system use stemmed more from internal limitations within the company than from the inherent capabilities of the solution.

From a technological standpoint, the director highlighted the manifold advantages a well-utilized MES system could bring to the company. On the organizational front, he emphasized the critical role of support from top management and a proficient IT team. Additionally, he stressed the imperative of fostering a culture of data management over time, recognizing its pivotal role in driving long-term success.

Despite the challenges encountered, the MES system implementation journey provided valuable insights and lessons. While not entirely satisfactory, the interview shed light on the vital importance of considering both technological and organizational factors when adopting MES systems. This underscores the necessity for a strategic, long-term approach that considers the dynamic interplay of various elements for successful implementation and sustained benefits.

4.2. Company B

Company B, the second entity under consideration, boasts a workforce of 200 employees and an impressive annual turnover of approximately R\$80 million. Specializing in the fast-food packaging industry, it specifically concentrates on manufacturing pizza delivery boxes. The interviewee representing this organization held the position of Operations Coordinator, as indicated in Table 2, offering a significant operational perspective for the analysis.

Table 2. Analysis of the packaging company.

	KNOWLEDGE	PERSUASION	DECISION
TECHNOLOGY	System integration; Impact on material handling; Process compatibility; Complexity	Cybersecurity; System Functionalities	Customization; Balance between cost and benefit
ORGANIZATION	Prior digital transformation; Culture adaptive to change; Capacity for innovation; Cross-sector integration	Digital culture	Defining a digital strategy
EXTERNAL ENVIRONMENT	Business change	Influence of suppliers and customers	Competitive impact; Growth and innovation

The pivotal role of the operations coordinator proved indispensable in both companies’ adoption of the MES System, primarily focused on establishing precise control over material movements to enhance inventory accuracy and streamline accounting processes. The implementation process encountered diverse challenges. In the first instance, utilizing Multitask PPI led to compatibility issues, resulting in project failure. However, upon transitioning to GTR’s MES, the company achieved success, primarily owing to the system’s customization capabilities that catered to specific requirements. This implementation notably impacted the first factory positively, although minor adjustments were required. The second challenge revolved around adapting the factory to align with the business’s unique intricacies.

The interviewee from the operations department underscored the significance of fostering a culture adaptable to change and the constant pursuit of innovation for maintaining competitiveness in the market. Reflecting on the PPI experience, it became apparent that a major obstacle was from a sales error. The customer was not clearly informed about the availability of a new version of the product and the option to transition directly to this updated solution, which would have better aligned with the customer’s needs. Consequently, a situation of discontent ensued, with the client refusing to pay for the update service, leading to a breakdown in trust and several associated problems. This interview highlighted the complexities inherent in adopting MES Systems.

The contrasting experiences with different vendors underscore the importance of selecting the right solution tailored to customization needs. Organizational flexibility, innovation capacity, and adaptability to digital transformation emerged as critical elements for success in implementing intricate systems such as MES, emphasizing the significance of strategic decision-making and meticulous vendor selection in this transformative process.

4.3. Company C

Company C, our third focal organization, specializes in the plastic packaging sector, encompassing various segments such as converting (food), sacks (coffee, sugar), and big bags (raw materials). With a workforce of 3,500 employees and an impressive annual turnover of 2 billion reais, the company holds a prominent position in the market. During the interview, the senior systems analyst from the Automation and Manufacturing department shed light on the intricacies of the shop floor operations, as illustrated in Table 3.

Table 3. Analysis of the packaging company.

	KNOWLEDGE	PERSUASION	DECISION
TECHNOLOGY	Native integration and online control; Use of sensors for control; Infrastructure	Perception of benefits of MES; Ease of integration systems	Evaluation of integration and communication links; Previous experience of supplier
ORGANIZATION	Culture adaptive to change; Constant training of staff; Critical role of the operator in control	Value chain alignment; Top management support	Definition of processes and procedures; Training planning
EXTERNAL ENVIRONMENT	Competitive pressure; Impact of the market	Influence of suppliers and customers	Supplier's solidity

The interviewed expert, who played a pivotal role in implementing the MES System within the factory, aimed to enhance operational efficiency and enable real-time control of machines and processes. The company, opting for PPI Multitask, was driven by its integration capabilities and an existing partnership. The implementation spanned two years across all factories, involving continuous refinements and analytical enhancements to streamline inventory control and bolster productivity. Notably, the experience with PPI Multitask emerged as a game-changer, bringing agility to processes and information flow. PPI's MES system stood out for its comprehensive integration capabilities.

The interview underscored the profound impact of MES on optimizing productivity and inventory management. Key to this success was the integration with the ERP system and the customization of the solution to align with the company's unique requirements, as emphasized in the interview. The collaboration between TOTVS and PPI was also highlighted, underscoring its pivotal role in the implementation's success. Moreover, the significance of organizational culture, robust senior management support, and the comprehensive training of employees became evident, proving essential in navigating the challenges associated with adopting MES systems within a large-scale enterprise.

Key to this success was the seamless integration with the ERP system, highlighted in the persuasion section of the table. The integration facilitated seamless data exchange, enabling real-time decision-making and enhancing operational efficiency. Furthermore, the interview emphasized the importance of ease of integration systems and the evaluation of integration and communication links in persuading stakeholders of the system's benefits.

The decision-making process was shaped by various organizational factors, as outlined in the organization section of the table. The company's adaptive culture to change, constant training of staff, and recognition of the critical role of operators in control were instrumental in driving decision-making. Top management support, coupled with the alignment of the value chain and meticulous planning of training, further solidified the decision to implement the MES system.

External environmental factors also played a crucial role in the decision-making process, as elucidated in the external environment section of the table. Competitive pressures and market dynamics influenced the company's approach, alongside the influence of suppliers and customers. Supplier solidity emerged as a critical consideration in navigating the external environment.

4.4. MES supplier analysis

The initial interview conducted with the commercial team delved into key challenges and perceptions associated with the MES domain. The results of the interviews with suppliers A, B and C were compiled in

Table 4. Interviewee A emphasized that the performance of MES transcends mere product provision, emphasizing the need to offer tailored solutions to address specific customer operational issues. He also underscored his active involvement in the implementation of MES across diverse industrial sectors. When discussing challenges, Interviewee A highlighted significant obstacles such as digital culture and people readiness, alongside investments concerns, particularly for smaller enterprises. Interestingly, clarifying the functionalities of MES per se was not deemed a challenge, given its clear conceptual understanding. However, conveying this clarity to the customer often posed difficulties, pointing to potential comprehension challenges on the customer’s end. Furthermore, concerning the implementation phase, the duration varied based on the project’s scope, ranging from several months to over a year. Notably, it was observed that many companies opted for a simplified MES approach primarily centered around productivity enhancements, despite the system’s capacity to extend its coverage across multiple organizational domains, spanning production, logistics, and finance.

Table 4. Case studies analysis.

	KNOWLEDGE	PERSUASION	DECISION
TECHNOLOGY	Customization; Complete and reliable database; Conceptual understanding of MES; Investment in technology	Complexity	Trialability
ORGANIZATION	Uncertainty; Growth strategies; Feasibility of implementation; Customer maturity; Cultural change	Digital culture; People readiness; Continuous improvement; Defined processes	Opportunity for growth; Innovative practices
EXTERNAL ENVIRONMENT	Technology pressure; Industry 4.0 trends	Regulatory standards. External Expertise	Economic changes; Government policies; Competitive advantages; Opportunity for growth; Global competitiveness

In the second interview, Interviewee B outlined his key responsibilities, which encompass conducting customer visits to evaluate the maturity of manufacturing processes and proposing MES implementation projects. His primary focus lies in optimizing machine productivity and ensuring machine availability. Although not directly involved in the implementation phase, Interviewee B stressed the critical importance of having well-defined processes and a conducive organizational culture to ensure the successful deployment of MES. He underscored that most companies engaged in machine-based production are adopting MES solutions. Furthermore, the interviewee highlighted the significance of enabling technologies and stressed the necessity for appropriate data collection devices. Addressing organizational factors, he emphasized the role of organizational culture, active engagement in continuous improvement initiatives, and the imperative to leverage MES-generated information for driving productivity enhancements and cost reduction efforts.

In the third interview (a 19-year expert in product development), the vendor disclosed undergoing rigorous training. Supplier specialization primarily revolves around software deployment, while a partnering entity handles the hardware integration of MES. Interviewee C highlighted the challenges in implementation arising when data lacks organization and when expectations diverge from the solution’s actual capabilities. Additionally, he pointed out a common misconception among managers: many are disillusioned with MES systems because they often misunderstand its full scope. There’s a prevalent misconception that implementing the system will magically address all the company’s demands, leading to unmet expectations and dissatisfaction among users. This insight underscores the importance of clear communication and realistic expectations in the successful adoption of MES solutions.

After a comprehensive analysis of the cases of Companies A, B, and C, it becomes evident that the implementation of MES systems is a journey fraught with challenges and opportunities for companies across different industrial sectors. All companies shared the central goal of improving operational efficiency and driving revenue growth through the adoption of these systems, although their specific motivations and operational contexts varied considerably. While Company A faced challenges related to system performance and machine integration, Company B dealt with compatibility issues and communication errors during the sales process. On the other hand, Company C succeeded in implementation due to its adaptive organizational culture and support from reliable suppliers. In all cases, critical success factors such as support from top management, competence of the IT team, and effective collaboration among suppliers emerged as essential elements for implementation success. The lessons learned highlight the importance of a strategic, long-term approach, considering the dynamic interplay of various elements to ensure successful implementation and sustained benefits over time.

These insights offer valuable guidance for companies seeking to maximize the benefits of their MES systems and avoid common pitfalls along the way.

5. Results and discussion

During the preliminary data analysis essential for shaping this study and crafting two crucial frameworks, several pertinent elements tied to the proposed solution emerge. This analysis hinges on the detailed exploration of Tables 1 to 4 mentioned earlier. Through this meticulous process, certain key aspects come to the forefront:

- **Functional and Structural Boundaries of the Target System:** The analysis commences with a thorough examination of the functional and structural boundaries within the solution's target system. Implementing MES in companies constitutes a multifaceted process involving crucial steps like proposal and delivery. It's imperative to underscore the seller's pivotal role in guaranteeing that deliveries align with the contractor's specifications. This becomes especially critical to prevent potential quality decline in deliveries when multiple simultaneous implementations are underway (Brad & Brad, 2021);
- **Impact on Stakeholders and the External Environment:** The analysis delves into the broader repercussions of the solution beyond the target system. It becomes crucial to maintain a delicate balance: while emphasizing MES implementation in small and medium-sized businesses, it should not disrupt ongoing implementations or support for customers outside the program. The external environment plays a pivotal role in shaping the solution's effectiveness and efficiency, necessitating financial investments from client companies and the presence of skilled employees to ensure its seamless operation. This multifaceted perspective underscores the need for a comprehensive approach in addressing both internal and external dynamics (Marquet-Pondeville et al., 2007);
- **Meeting Customer Requirements:** In the subsequent analysis, we delve into how the solution caters to the demands of both external and internal customers. Sales teams adeptly comprehend the nuanced requirements of small and medium-sized businesses, fine-tuning negotiation tactics and delivery strategies to bolster satisfaction levels and entice new clients. On the internal front, implementing the solution necessitates judicious allocation of financial resources and the establishment of clearly defined processes to ensure optimal functioning and efficiency (Pereira & Romero, 2017);
- **Impact on People and Organizational Culture:** the solution has a significant impact on the company's workforce, providing training opportunities to employees. This training not only equips them to effectively market the service but also presents opportunities for commissions, ultimately enhancing both individual and organizational outcomes and fostering growth. Equally important is evaluating the compatibility of the solution with the existing organizational culture. It should promote values such as creativity, teamwork, and adaptability, ensuring seamless integration and sustainable growth within the company (Ziaei Nafchi & Mohelská, 2020);
- **Assumptions, Applicability and Propriety of the Solution:** The keen interest exhibited by the company from the project's inception underscores the economic and technical viability of the MES system, emphasizing the organization's vested interest in its successful implementation for small and medium-sized businesses. However, there are different scenarios wherein the solution might prove inapplicable or irrelevant, centering our evaluation on the shared interests of both the company and the customer during the implementation phase (Schumacher et al., 2016);
- **Proposal Based on Technical/Scientific Foundation:** a crucial aspect involves scrutinizing the technical and scientific underpinnings of the solution. The team anchored their approach in the doctoral thesis of the project supervisor, establishing a direct link with the realm of industrial organization. This foundation not only bolstered the solution's approach but also facilitated its development, ensuring a robust and well-informed proposal (Tabim et al., 2021).

Drawing from the outcomes of the frameworks derived from interviews and the essential elements highlighted during the data analysis, we have meticulously compiled two standardized frameworks. These frameworks encompass analogous technological, environmental, and organizational dimensions, effectively identifying shared points that emerged consistently from interviews conducted with both customers and sales professionals. This meticulous synthesis allows for a comprehensive understanding of the converging elements, facilitating nuanced insights and strategic applications (Table 5).

Tables 5 was designated for both customers and sales professionals, offering a holistic overview of pivotal factors influencing the successful adoption of an MES by customers. Simultaneously, they serve as a strategic compass for salespeople, guiding them through the intricate sales process. This table prove versatile, serving multiple purposes within the company. They aid in evaluating a customer's compatibility with the MES system

Table 5. Case studies analysis.

	KNOWLEDGE	PERSUASION	DECISION
TECHNOLOGY	Importance of MES systems for optimization; Integration between MES and ERP; Use of automation and process control	Recognition of the benefits of MES systems; Use of automation and process control; Impact of MES on productivity	Choice of MES systems based on integration; Cost-benefit assessment; Choice of system with relevant features
ORGANIZATION	Need for data management and culture; Importance of internal collaboration and efficiency; Training of the team to Use MES	Alignment with organizational goals; Persuasion about positive outcomes; Impact on efficiency and collaboration	Senior management support; Definition of implementation team; Planning the implementation process
EXTERNAL ENVIRONMENT	Market competitiveness and regulations; Relationships with partners and suppliers	Recognition of the importance of innovation; Competitive advantages in MES systems	Trend and market assessment; Consideration of impact on competitors

and inform targeted sales strategies, providing invaluable insights for tailored interactions and fostering effective customer-company relationships.

In the clients' analysis, the evaluation process for adopting the MES needs to consider several crucial factors:

- **Strategic Assessment:** utilizing the developed tables allows for a comprehensive evaluation of the client's alignment with the technological, organizational, and external environmental facets crucial for a successful MES system implementation. This assessment discerns whether the customer possesses the necessary groundwork for adopting the solution effectively (Lerman et al., 2022);
- **Identifying Gaps:** By cross-referencing the factors in the tables with the client's specific situation, the company can pinpoint disparities in maturity, organizational culture, technology, and other critical areas. This analysis aids in recognizing the specific areas that require enhancement before the MES system implementation, offering valuable insights into areas of improvement (Wackerle-Hollman et al., 2021);
- **Definition of Digital Strategies:** Drawing from the information within the tables, the company can tailor bespoke strategies for each client, precisely addressing the identified areas of deficiency. These customized strategies ensure a more streamlined and efficient adoption process, maximizing the potential for successful technological implementation (Lerman et al., 2022).
- In the suppliers' analysis, the evaluation process for adopting the MES needs to consider several crucial factors:
- **Proactive Analytics:** Sales professionals can use the tables for proactive prospect analysis. This empowers them to pinpoint negotiation focal points and ensures clients are well-prepared for implementation, enhancing the overall efficiency of the process. However, it is very important that they know the context of the company (Echchakoui & Ladhari, 2023);
- **Personalization of Approach:** based on these tables, salespeople can finely tailor their strategies to align with the specific concerns and needs of each customer. This personalized approach significantly amplifies the likelihood of successful negotiations, establishing stronger connections with clients. When a digital transformation strategy is carried out, it facilitates the development of several organizational aspects, including delivery flexibility, better relationships with customers and suppliers and the development of better purchasing systems (Enrique et al., 2022a,b; Lerman et al., 2022, 2023);
- **Managing Expectations:** The tables serve as a vital tool for sales professionals in managing customer expectations pragmatically. Open discussions about potential challenges, coupled with viable solutions outlined in the tables, facilitate transparent communication, and build trust between the sales team and the client. The development of a trusting relationship provides a better understanding of the use of technology, because sellers will be responsible for passing on knowledge in the best possible way (Echchakoui & Ladhari, 2023);
- **Value Statement:** Demonstrating how the MES system aligns with the identified points in the tables allows salespeople to articulate the value the solution brings to the customer's company. This substantiates the sales pitch, showcasing the tangible benefits and making a compelling case for the adoption of the system. The use of technology adoption cases makes it easier to understand the benefits of using technology, showing that many companies are adopting it and increasing their productivity, for example (Mullins et al., 2020).

In conclusion, the introduction of this framework signifies a significant milestone, aiding the company in evaluating its operational maturity level. The primary objective of this framework is to provide a systematic and all-encompassing method to gauge the company's preparedness for embracing the MES system. The decision

to implement MES is strategic, offering manifold advantages; however, its effectiveness is intricately tied to a profound comprehension of the company's requisites and capacities. This framework offers a panoramic view of diverse domains influencing MES adoption, encapsulating three pivotal perspectives: knowledge, persuasion, and decision-making, as elucidated by the insights from our interviews with various companies.

Each of these perspectives encompasses technological, organizational, and external environmental factors that can profoundly impact the successful deployment of an MES system. By evaluating the company's maturity concerning these factors, the organization can adeptly identify its strengths and pinpoint areas that necessitate enhancement in the context of MES adoption. This strategic evaluation equips the company to make well-informed decisions, comprehending the implications and prerequisites essential for a seamless and efficient MES implementation process.

The utilization of these frameworks not only assists the company in devising a robust strategic plan for MES implementation but also considers not just the technological facets but also the organizational transformations and the external environmental conditions. This brings a new perspective to the problem because it not only evaluates the adoption of technology, but its impact on several fronts, which guarantees a more holistic view of technology adoption. Therefore, this framework serves as a valuable instrument, furnishing the company with a structured guide for assessing its maturity and readiness concerning MES implementation. With a clearer comprehension of the company's capabilities and requirements, the organization is poised to make better decisions, steering its path towards the modernization and optimization of its operations with confidence. This trust provides an improvement in quality in the implementation of technologies, because companies and people are aware of what will be done, how it will be done and what the objectives are.

6. Final consideration

Considering the insights gleaned from the frameworks devised to aid the company in evaluating the operational maturity of its clients concerning MES system adoption, several actionable steps are recommended to attain the desired outcomes:

1. **Maturity Score Development:** Establish a tailored maturity score for each client, meticulously identifying strengths and weaknesses across technological, organizational, and external environmental factors. Devise individualized strategies for each client, focusing on their unique profile;
2. **Strategic Recommendations:** Formulate a comprehensive set of recommendations to address deficient areas, adapting strategies based on each client's specific challenges. Empower the sales team with a deep understanding of the consolidation tables. Encourage proactive analysis of potential customers, evaluating their maturity levels. This proactive approach aids in identifying sales opportunities and enables personalized, informed approaches, enhancing the likelihood of successful engagements;
3. **Solution Presentation:** Emphasize how the MES system can effectively address the identified challenges and deliver tangible benefits. Utilize pertinent case studies and success stories to demonstrate the system's applicability. Address potential adoption hurdles openly, offering viable solutions and strategies to overcome these challenges;
4. **Transparent Communication:** Implement a transparent communication plan to keep customers informed about the progress. Highlight the positive impact that adopting the MES system will have on efficiency, collaboration, and customer outcomes, fostering confidence and enthusiasm;
5. **Ongoing Engagement:** Establish a continuous follow-up cycle to monitor progress and make necessary adjustments. Conduct hands-on demonstrations of the system's functionalities to showcase its alignment with customer needs and goals. This proactive approach ensures that the MES system remains tailored to evolving requirements, enhancing customer satisfaction and long-term success.

Adhering to these strategies equips the company to deliver tailored solutions that effectively address the unique challenges and requirements of its clientele, ultimately strengthening its competitive position in the market and enabling it to thrive in a dynamic business environment.

Additionally, it's essential to acknowledge the limitations of the study and identify avenues for future research. Limitations may include constraints related to sample size, scope, or data collection methods, which could impact the generalizability of the findings. Future research endeavors could focus on expanding the study to include a broader range of industries or exploring alternative methodologies to deepen our understanding of MES system adoption dynamics. Additionally, investigating the long-term effects of MES implementation

and evaluating emerging technologies' impact on operational maturity could provide valuable insights for both academia and industry practitioners.

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Appendix 1. Supplier interviews.

1. INTRODUCTION

- a. Name
- b. Position
- c. Explain your involvement with MES and actions aimed at the MES system in the company.

2. MES SYSTEM

- a. How did you get to know MES (from where did you acquire the information, within the company? Training?)
- b. Level of familiarity with the tool
- c. Have you implemented MES in any client?
- d. Have you ever participated in a case where the company did not have adherence?
- e. Have you noticed any commonalities that make implementation difficult?
- f. Did you have difficulty explaining the features of MES?

3. IMPLEMENTATION

- a. Average time to implement the solution?
- b. Have companies in any industry found it easier to implement than others?
- c. Have you noticed any commonalities that make implementation difficult?
- d. Did you have difficulty explaining the features of MES?
- e. Was there a difference in the solution sold for the running product?
- f. If so, what functionalities were not met? Was it due to the inability of the provider or the client?
- g. Would you include any pre-implementation steps to make the process easier?
- h. Do you have any steps that you consider indispensable in the implementation?
- i. What was the stage with the most problems/rework?
- j. What is the most important feature that the customer must have in order to have a good implementation?
- k. Overall, how was the experience?

Appendix 2. Customer interviews.

1. INTRODUCTION

About the interviewee

- a. Name
- b. Position
- c. Explain your involvement with MES and actions aimed at the MES system in the company.
- d. What was your role in the adoption of the MES system?

About the company

- e. Company Name
- f. Number of employees
- g. Annual Billing
- h. Sector
- i. Domestic/Overseas Market
- j. Key customers (end consumer/other industries)
- k. Already implemented MES
- l. If so, did you use another system before MES?
- m. If not, do you currently use another system?

2. MES SYSTEM

- a. Explain how the demand for the MES system came about.
- b. Explain the MES selection process within the company, considering the variety of options available in the market.
- c. Explain the process for making the final decision to adopt this information system.

3. IMPLEMENTATION

- a. How long did the implementation take?
- b. Explain the process of improvements and changes made in the company to complete the implementation.
- c. Explain if there was any difference in the solution sold to the final product being executed.
- d. Overall, how was the experience?
- e. Does the product meet the company's needs today?

4. IMPACT OF TOE FACTORS

- a. What technological factors (relative advantage, uncertainty, compatibility, complexity, connectivity, expansion) do you think could impact the adoption of MES systems in your company? Why?
- b. What organizational factors (company size, senior management support, innovation capacity, culture, IT change) do you think might affect the adoption of MES systems in your company? Why?
- c. What environmental factors (competitive pressure, industry, market scope, vendor partnerships) do you think could affect the adoption of MES systems in your company? Why?