ENGENHARIAS, TECNOLOGIA, GESTÃO E TURISMO
ENGINEERING, TECHNOLOGY, MANAGEMENT AND TOURISM
INGENIERÍA, TECNOLOGÍA, ADMINISTRACIÓN Y TURISMO

millenium

Millenium, 2(Edição Especial Nº24)

en

A MATURIDADE LEAN E DA INDÚSTRIA 4.0 COMO FATORES CONTINGENCIAIS DO DESEMPENHO DAS EMPRESAS INDUSTRIAIS: UMA PERSPETIVA

LEAN AND INDUSTRY 4.0 MATURITY AS CONTINGENT DRIVERS OF INDUSTRIAL FIRM PERFORMANCE: A PERSPECTIVE

LA MADUREZ LEAN Y DE LA INDUSTRIA 4.0 COMO FACTORES CONTINGENTES DEL DESEMPEÑO DE LAS EMPRESAS INDUSTRIALES: UNA PERSPECTIVA

André Guimarães[1,2,3,4] *https://orcid.org/0000-0001-6346-5719*

[1] Universidade da Beira Interior, Covilhã, Portugal
[2] Universidade Politécnica de Viseu, Viseu, Portugal
[3] CISE -Electromechatronic Systems Research Centre, Covilhã, Portugal
[4] Centro de Investigação em Serviços Digitais (CISeD), Viseu, PortugaL

André Guimarães – aguimaraes@estgv.ipv.pt

CC BY

Corresponding Author:
André Guimarães
Av. Cor. José Maria Vale de Andrade
3504 - 510 - Viseu - Portugal
aguimaraes@estgv.ipv.pt

RECEIVED: 29th June, 2026
REVIEWED: 18th August, 2026
ACCEPTED: 14th September, 2026
PUBLISHED: 18th November, 2026

DOI: https://doi.org/10.29352/mill0224e.48064

RESUMO

Introdução: A investigação sobre a maturidade Lean e a maturidade da Indústria 4.0 tem registado um crescimento significativo, mas continua fragmentada, apresentando resultados empíricos inconsistentes quanto aos seus efeitos no desempenho das empresas.
Objetivo: Reconceptualizar a maturidade Lean e a maturidade da Indústria 4.0 não como impulsionadores diretos do desempenho, mas como capacidades organizacionais contingenciais, cujos efeitos dependem de condições de alinhamento contextual, como a dimensão da empresa, o setor de atividade, a orientação estratégica e a fase de desenvolvimento organizacional.
Métodos: O estudo adota uma abordagem conceptual e interpretativa, baseada numa síntese crítica da literatura contemporânea sobre maturidade Lean, maturidade da Indústria 4.0 e desempenho empresarial. São analisadas contribuições teóricas e empíricas existentes para identificar ambiguidades conceptuais, operacionalizações heterogéneas dos construtos de maturidade e limitações das abordagens atualmente utilizadas para avaliar o desempenho.
Resultados: A análise indica que as limitações conceptuais e metodológicas poderão explicar, pelo menos em parte, a heterogeneidade dos resultados empíricos reportados em estudos anteriores, em vez de indicarem a inexistência de efeitos no desempenho.
Conclusão: O artigo propõe um quadro interpretativo integrador que relaciona os construtos de maturidade com resultados multidimensionais de desempenho em condições contextuais específicas. Contribui para a literatura ao defender modelos de relação entre maturidade e desempenho mais sensíveis ao contexto e fornece orientações para futuras investigações empíricas e para a prática de gestão.

Palavras-chave: maturidade lean; maturidade da indústria 4.0; lean 4.0; desempenho empresarial; capacidades contingenciais; transformação digital

ABSTRACT

Introduction: Research on Lean maturity and Industry 4.0 maturity has grown significantly, but remains fragmented, with inconsistent empirical findings regarding their effects on firm performance.
Objective: Reconceptualize Lean and Industry 4.0 maturity not as direct performance drivers, but as contingent organizational capabilities whose effects depend on conditions of contextual alignment, such as firm size, sector, strategic orientation, and stage of organizational development.
Methods: The study adopts a conceptual and interpretative approach based on a critical synthesis of contemporary literature on Lean maturity, Industry 4.0 maturity, and firm performance. Existing theoretical and empirical contributions are reviewed to identify conceptual ambiguities, heterogeneous operationalizations of maturity constructs, and limitations in current performance measurement approaches.
Results: The analysis suggests that conceptual and methodological limitations may partly explain the heterogeneous empirical findings reported in previous studies, rather than indicating the absence of performance effects.
Conclusion: The paper proposes an integrative interpretative framework linking maturity constructs to multidimensional performance outcomes under specific contextual conditions. It contributes to the literature by supporting more context-sensitive models of maturity performance relationships and offers guidance for future empirical research and managerial practice.

Keywords: lean maturity; Industry 4.0 maturity; lean 4.0; firm performance; contingent capabilities; digital transformation

RESUMEN

Introducción: La investigación sobre la madurez Lean y la madurez de la Industria 4.0 ha experimentado un crecimiento significativo, aunque continúa siendo fragmentada y presenta resultados empíricos inconsistentes en relación con sus efectos sobre el desempeño empresarial.
Objetivo: Reconceptualizar la madurez Lean y la madurez de la Industria 4.0 no como impulsores directos del desempeño, sino como capacidades organizativas contingentes, cuyos efectos dependen de condiciones de alineación contextual, como el tamaño de la empresa, el sector de actividad, la orientación estratégica y la etapa de desarrollo organizativo.
Métodos: El estudio adopta un enfoque conceptual e interpretativo basado en una síntesis crítica de la literatura contemporánea sobre madurez Lean, madurez de la Industria 4.0 y desempeño empresarial. Se revisan las contribuciones teóricas y empíricas existentes para identificar ambigüedades conceptuales, operacionalizaciones heterogéneas de los constructos de madurez y limitaciones de los enfoques actuales de evaluación del desempeño.
Resultados: El análisis sugiere que las limitaciones conceptuales y metodológicas pueden explicar, al menos en parte, la heterogeneidad de los resultados empíricos reportados en estudios previos, en lugar de indicar la ausencia de efectos sobre el desempeño.
Conclusión: El artículo propone un marco interpretativo integrador que vincula los constructos de madurez con resultados multidimensionales de desempeño bajo condiciones contextuales específicas. Contribuye a la literatura al promover modelos de relación entre madurez y desempeño más sensibles al contexto y ofrece orientaciones para futuras investigaciones empíricas y para la práctica de la gestión.

Palabras clave: madurez lean; madurez de la industria 4.0; lean 4.0; desempeño empresarial; capacidades contingentes; transformación digital

DOI: https://doi.org/10.29352/mill0224e.48064

1. INTRODUCTION

Over the last two decades, industrial firms have increasingly adopted Lean management principles and, more recently, Industry 4.0 (I4.0) technologies to respond to competitive pressure, cost constraints, and growing market volatility (Buer et al., 2018; Dalenogare et al., 2018; Frank et al., 2019; Tortorella et al., 2019; Rosin et al., 2020). Lean initiatives aim to enhance efficiency and value creation by eliminating waste, stabilizing processes, and driving continuous improvement. At the same time, Industry 4.0 promotes digital integration, data-driven decision-making, and cyber–physical production systems. As a result, both paradigms have been widely associated with operational and financial performance.

Despite this widespread assumption, the empirical evidence remains inconclusive (Tortorella et al., 2019; Sony & Naik, 2020; Pagliosa et al., 2021; Alsheyadi, 2024; Guimarães et al., 2025a). While several studies report positive associations between Lean practices, digital technologies, and performance indicators such as productivity, quality, or profitability (Buer et al., 2021; Rossini et al., 2022; Ooi et al., 2023; Guimarães et al., 2025a; Guimarães et al., 2025b), others identify weak, heterogeneous, or even non-significant effects (Tlapa et al., 2022; Antony et al., 2022). These discrepancies suggest that the relationship between maturity and performance may be influenced by factors that extend beyond methodological differences, thereby motivating a closer examination of the conceptual assumptions underpinning existing maturity models.

Although these inconsistencies have often been attributed to methodological differences or sector-specific characteristics, they may also reflect deeper conceptual issues regarding how Lean maturity, Industry 4.0 maturity, and firm performance are defined and interpreted. In particular, the assumption that higher maturity levels necessarily translate into superior performance has rarely been critically examined from a theoretical perspective. This observation motivates the need to revisit the underlying conceptual foundations linking maturity and organizational outcomes.

Despite the growing body of empirical and conceptual research, existing studies have largely attempted to explain the maturity-performance relationship by refining maturity models, introducing new technological dimensions, or expanding performance indicators. Although these contributions have advanced the field, they have generally maintained the underlying assumption that higher maturity should ultimately lead to superior performance. Consequently, relatively little attention has been devoted to questioning the theoretical interpretation of maturity itself or to examining how contextual conditions shape the translation of maturity into organizational outcomes.

More recently, increasing attention has been devoted to the integration of Lean principles with Industry 4.0 technologies, giving rise to concepts such as Digital Lean or Lean 4.0 (Pagliosa et al., 2021; Rossini et al., 2022; Komkowski et al., 2025). Rather than viewing Lean and digital transformation as independent initiatives, this emerging research stream emphasizes their complementarity in supporting organizational transformation. Nevertheless, despite this growing interest, important conceptual questions remain unresolved regarding how Lean maturity and Industry 4.0 maturity should be conceptualized and how their interaction influences firm performance. This evolution further reinforces the need for the integrative perspective proposed in this paper.

1.1. Conceptual Approach

This Perspective Paper adopts a critical interpretative conceptual approach rather than an exhaustive systematic literature review. The literature underpinning the proposed perspective was selected according to five general criteria: (i) direct relevance to Lean maturity, Industry 4.0 maturity, firm performance, or Lean 4.0 (Digital Lean); (ii) conceptual or empirical contribution to maturity assessment and performance relationships; (iii) scientific influence, reflected by the prominence of the work within the field; (iv) preference for peer-reviewed journal articles; and (v) emphasis on recent contributions published over approximately the last decade, while retaining earlier seminal studies where necessary to establish the theoretical foundations of the discussion.

Rather than seeking comprehensive coverage, the selected literature was critically examined to identify recurring conceptual assumptions, points of convergence and divergence, and unresolved theoretical ambiguities concerning the relationship between maturity and firm performance. Studies focusing exclusively on Lean tools or Industry 4.0 technologies without explicitly addressing maturity, organizational capabilities, or performance implications were not considered central to the development of the proposed perspective. This comparative interpretative analysis formed the basis for the integrative framework and the theoretical propositions advanced in this paper.

This Perspective Paper contends that the dominant narrative portraying Lean and Industry 4.0 maturity as universal performance drivers is overly simplistic. Instead, it argues that maturity in these domains should be understood as a set of contingent organizational capabilities whose contribution to firm performance depends on contextual and strategic alignment rather than on maturity levels alone. In this paper, contingent organizational capabilities refer to organizational abilities whose contribution to firm performance depends on the fit between complementary capabilities and the strategic and contextual conditions in which they are developed and deployed. Rather than providing an exhaustive systematic review, this paper offers a critical and integrative perspective that seeks not only to clarify the conceptual foundations of maturity and its relationship with firm performance, but also to advance an alternative theoretical interpretation of how maturity should be conceptualized within contemporary organizational theory. Specifically, this paper makes three theoretical contributions. First, it reconceptualizes Lean

DOI: https://doi.org/10.29352/mill0224e.48064

maturity and Industry 4.0 maturity from predominantly implementation-oriented interpretations into contingent organizational capabilities whose contribution to firm performance depends on contextual alignment rather than on maturity levels alone. Second, it shifts the focus of maturity research from explaining performance through maturity levels alone towards explaining performance through the interaction between complementary organizational capabilities and contextual conditions. Third, it proposes an integrative conceptual framework that introduces contextual alignment as the explanatory mechanism linking Lean maturity, Industry 4.0 maturity, and firm performance, thereby providing a theoretical explanation for the heterogeneous maturity performance relationships reported in previous studies.

These contributions are developed by integrating complementary theoretical perspectives from Contingency Theory, the Resource-Based View (Barney, 1991), Dynamic Capabilities (Teece et al., 1997; Eisenhardt & Martin, 2017), Socio-technical Systems Theory (Sony & Naik, 2020), and Configuration Theory (Meyer et al., 1993; Fiss, 2007) into a unified conceptual interpretation of maturity and firm performance.

Accordingly, the interpretations advanced throughout this paper should be understood as theoretically grounded conceptual propositions derived from the critical synthesis of the literature, rather than as empirically validated causal claims.

2. CONCEPTUAL AMBIGUITY IN LEAN AND INDUSTRY 4.0 MATURITY

Although Lean maturity and Industry 4.0 maturity have evolved through distinct research traditions, both constructs share a common challenge: the absence of a universally accepted conceptualization. Across the literature, maturity is variously interpreted as the adoption of practices, the implementation of technologies, organizational readiness, or the development of capabilities. These conceptual differences complicate comparisons among studies and partly explain the heterogeneity of empirical findings. The following sections discuss these ambiguities separately before considering their common implications.

2.1. Lean maturity: philosophy, practices, or capability?

The concept of Lean maturity has been inconsistently defined across studies (Tortorella et al., 2021). Several authors have proposed Lean maturity models to assess organizations' progression through different stages or dimensions of Lean implementation, often based on distinct conceptual assumptions (SAE, 1999; Cezar Lucato et al., 2014; Guimarães et al., 2025c; Närvä & Bicheno, 2025).

Some studies equate Lean maturity with the extent of Lean tool and practice adoption, such as 5S, Kanban, or SMED (Bento & Tontini, 2019; Guimarães et al., 2025a; Guimarães et al., 2025b). Others emphasize cultural and human dimensions, including employee involvement, leadership commitment, and continuous improvement (Beraldin et al., 2022). A third stream conceptualizes Lean maturity as an organizational capability, embedded in routines, learning mechanisms, and managerial systems that support sustained improvement over time (Amaro & Alves, 2023; Slavickova & Zemanova, 2025; Guimarães et al., 2026).

Recent empirical evidence further supports the multidimensional nature of Lean maturity, showing that it encompasses interconnected managerial, human, informational, relational, product-related, and process capabilities rather than isolated operational practices (Guimarães et al., 2026d). These perspectives often coexist without clear conceptual distinctions, limiting comparability across empirical studies. In addition, Lean maturity is frequently operationalized as a static index or checklist, overlooking its evolutionary nature as an organizational capability. This simplification may conflate superficial adoption with genuine organizational internalization because organizations exhibiting similar implementation levels may differ substantially in their ability to embed, sustain, and continuously improve Lean capabilities. Consequently, maturity scores alone may provide only a partial explanation of organizational performance, thereby weakening the explanatory power of empirical studies investigating the relationship between Lean maturity and firm performance.

The conceptual ambiguities identified in Lean maturity are not unique to the Lean literature. Similar inconsistencies can be observed in studies addressing Industry 4.0 maturity, although they stem from different theoretical traditions and reflect the rapid evolution of digital technologies and organizational transformation. As a result, the concept of Industry 4.0 maturity has also been interpreted in multiple ways, giving rise to heterogeneous assessment approaches and further complicating comparisons across empirical studies.

2.2. Industry 4.0 maturity: technology versus transformation

A similar ambiguity characterizes Industry 4.0 maturity (Mittal et al., 2018; Frank et al., 2019; Szász et al., 2021; Guimarães et al., 2023). Numerous studies have proposed digital and Industry 4.0 maturity assessment models to evaluate organizations' readiness and progress towards advanced digitalization, often based on different conceptual assumptions and assessment dimensions (Guimarães et al., 2025d; Guimarães et al., 2025e).

In some studies, Industry 4.0 maturity is defined mainly in technological terms, focusing on the presence and integration of digital technologies such as sensors, ERP systems, automation, or cyber–physical systems (Santos & Martinho, 2020; Motia et al., 2024;

DOI: https://doi.org/10.29352/mill0224e.48064

Queiroz et al., 2025; Guimarães et al., 2025a; Vilarinho et al., 2026). In others, maturity is understood as a broader organizational transformation, encompassing strategic alignment, data governance, workforce skills, and organizational readiness (Guimarães et al., 2023; Guimarães et al., 2024; Kumar & Sharma, 2025).

These differences are particularly relevant for small and medium-sized enterprises (SMEs), where digital adoption often follows an incremental and resource-constrained trajectory (Guimarães et al., 2025a; Guimarães et al., 2023; Guimarães et al., 2024; Guimarães et al., 2025f; Vilarinho et al., 2026). In such contexts, digital investments may not be accompanied by sufficient organizational change, resulting in uneven maturity profiles.

Overall, treating Industry 4.0 maturity as a purely technological construct overlooks its socio-technical nature because the organizational value of digital technologies depends on their integration with organizational processes, managerial routines, and human capabilities (Sony & Naik, 2020). Consequently, technology-oriented maturity assessments may provide only a partial explanation of why digital initiatives do not consistently translate into improved performance.

2.3. Digital Lean (Lean 4.0): Bridging Lean and Industry 4.0 Maturity

The increasing convergence between Lean principles and Industry 4.0 technologies has given rise to the concepts of Digital Lean or Lean 4.0, which have become one of the most active research streams in operations management and digital transformation (Pagliosa et al., 2021; Rossini et al., 2022; Citybabu & Yamini, 2024; Komkowski et al., 2025). Rather than treating Lean and Industry 4.0 as independent improvement initiatives, this perspective recognizes that process excellence and digital technologies should evolve jointly to maximize firm performance.

Recent studies argue that Lean provides the organizational stability, standardized processes, and continuous improvement culture required for successful digital transformation, whereas Industry 4.0 technologies enhance Lean implementation by improving process visibility, real-time monitoring, information transparency, and data-driven decision-making (Tortorella et al., 2021; Komkowski et al., 2025). This reciprocal relationship suggests that the benefits of digitalization depend not only on technological adoption but also on the maturity of the underlying organizational processes.

Despite this growing consensus, most existing studies focus on the complementarity between Lean practices and digital technologies or propose conceptual integration frameworks for Lean 4.0 (Citybabu & Yamini, 2024), rather than examining the interaction between Lean maturity and Industry 4.0 maturity as organizational capability constructs. Consequently, although Lean 4.0 reinforces the importance of integrating process and digital transformation, important conceptual questions remain regarding how maturity in both domains should be defined, assessed, and linked to firm performance. These unresolved issues provide the foundation for the integrative perspective proposed in this paper.

Accordingly, the central issue addressed in this paper is not the absence of maturity definitions, but the absence of a coherent theoretical interpretation capable of explaining how maturity translates into firm performance across different organizational contexts.

3. PERFORMANCE MEASUREMENT: A PERSISTENT SOURCE OF INCONSISTENCY

Firm performance is widely acknowledged as a multidimensional construct, encompassing financial, operational, and strategic outcomes (Dalenogare et al., 2018; Tortorella et al., 2020; Ahmad et al., 2023; Guimarães et al., 2026a). However, many studies still rely on a limited and heterogeneous set of indicators, such as Return on Assets (ROA), productivity, cost reduction, or self-reported measures, often without clearly justifying their relevance or alignment with Lean or digital transformation initiatives.

This selective use of performance indicators poses significant challenges for cross-study comparability. Financial indicators, although widely used due to their availability and objectivity, tend to capture long-term outcomes and may overlook the short- to medium-term effects of process-oriented initiatives. In addition, financial performance is influenced by external factors, such as market conditions and sectoral dynamics, that may mask the specific impact of maturity-related efforts.

Operational performance indicators, including productivity, quality, lead time, or flexibility, are generally more sensitive to Lean practices and digital interventions, particularly in early implementation stages (Masoud et al., 2025; Guimarães et al., 2026a). However, their limited standardization and strong contextual dependence often hinder direct comparisons across firms and sectors, contributing to divergent empirical findings.

Strategic performance dimensions, such as competitiveness, internationalization, innovation capability, or long-term resilience, are even less consistently operationalized, despite being frequently cited as expected outcomes of Lean and Industry 4.0 adoption (Komkowski et al., 2025; Gomaa, 2025). This uneven treatment of performance dimensions further reinforces the perception of inconsistent effects.

Overall, the coexistence of diverse performance measures, combined with short observation windows and predominantly cross-sectional research designs, significantly contributes to the heterogeneity of reported results. This fragmentation suggests that inconsistent empirical findings may partly reflect differences in how organizational performance is conceptualized and operationalized, rather than differences in the effectiveness of Lean or Industry 4.0 maturity themselves. Consequently, more

DOI: https://doi.org/10.29352/mill0224e.48064

integrated and temporally sensitive performance frameworks are required capable of capturing the differentiated, time-lagged effects associated with the development of Lean and Industry 4.0 maturity.

4. WHY DO EMPIRICAL RESULTS DIVERGE? A CRITICAL DISCUSSION

The heterogeneity of empirical findings cannot be fully explained by methodological differences alone because studies frequently rely on different conceptualizations of maturity, heterogeneous performance indicators, and distinct contextual settings. Collectively, these differences suggest that variability in empirical results may also originate from the way maturity is theoretically interpreted rather than exclusively from methodological choices. It may also reflect the inherently contingent nature of organizational transformation processes and the diverse configurations through which Lean principles and digital technologies are implemented in practice.

Empirical evidence increasingly suggests that performance outcomes depend on how maturity dimensions are combined and aligned within specific organizational contexts (Bititci et al., 2015; Buer et al., 2018; Colli et al., 2019; Tortorella et al., 2021; Guimarães et al., 2026a; Vilarinho et al., 2026). Recent empirical evidence also shows that neither knowledge of Industry 4.0 concepts nor structural variables such as firm size and geographical location are sufficient to explain differences in digital maturity, reinforcing the argument that organizational capabilities must be interpreted within a broader contextual configuration (Guimarães et al., 2026b). Firm size influences the availability of financial and human resources, while sectoral characteristics shape process complexity and technology intensity (Guimarães et al., 2024; Guimarães et al., 2026c). Moreover, organizational readiness, leadership commitment, and workforce skills determine the extent to which maturity initiatives are effectively internalized.

To support the interpretation of these divergent results, Figure 1 presents a conceptual typology of industrial firms based on different combinations of Lean maturity and Industry 4.0 maturity. The typology does not constitute a classification to be empirically tested, but rather an interpretative lens that helps explain why similar maturity initiatives may yield different performance outcomes across firms. Rather than proposing additional maturity levels, the typology operationalizes the conceptual interpretation advanced in this paper by illustrating how different configurations of Lean maturity and Industry 4.0 maturity may be associated with distinct organizational transformation trajectories. As such, it serves as an interpretative bridge between the conceptual ambiguities discussed in the preceding sections and the integrative framework proposed in Figure 2. Rather than simply describing alternative maturity profiles, the proposed typology identifies alternative organizational capability configurations through which Lean and Industry 4.0 maturity may interact. These capability configurations provide the conceptual foundation for the explanatory mechanism formalized in the integrative framework presented in Figure 2.

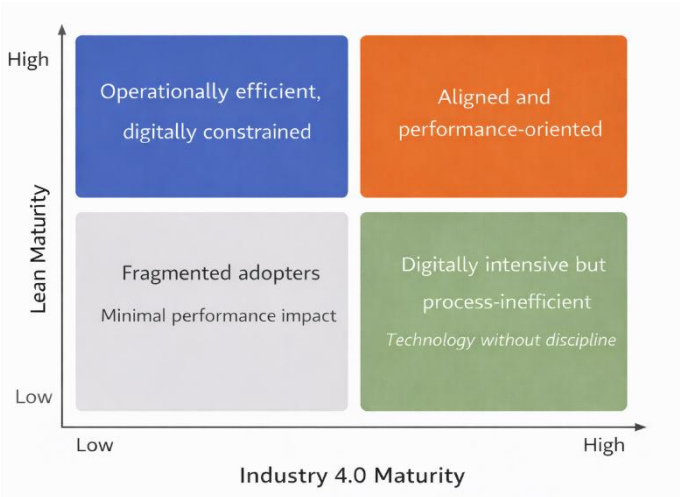


Figure 1 - Conceptual typology illustrating alternative organizational capability configurations that provide the conceptual foundation for the explanatory mechanism proposed in Figure 2

Firms with low Lean and Industry 4.0 maturity are characterized as fragmented adopters. In these organizations, improvement initiatives are often sporadic, poorly coordinated, and weakly aligned with strategic objectives, resulting in limited and unstable performance gains. At the opposite end of the spectrum, firms with high Lean and Industry 4.0 maturity are aligned and

DOI: https://doi.org/10.29352/mill0224e.48064

performance-oriented organizations, where process discipline and digital capabilities reinforce each other, enabling sustained improvements across operational, financial, and strategic dimensions.

Intermediate configurations further illustrate the contingent nature of performance effects. Firms with high Lean maturity but low Industry 4.0 maturity may achieve operational efficiency and stability but face constraints related to scalability, responsiveness, and real-time decision-making. Conversely, firms with low Lean maturity but high Industry 4.0 maturity often invest heavily in digital technologies without sufficient process standardization, leading to technology-driven complexity and disappointing performance, a situation usually described as "*technology without discipline*".

This typological perspective offers one possible conceptual explanation for the inconsistent empirical evidence reported in the literature. It reinforces the argument that maturity should not be assessed in isolation, but rather as part of a broader organizational configuration.

5. AN INTEGRATIVE PERSPECTIVE: LEAN AND INDUSTRY 4.0 MATURITY AS CONTINGENT CAPABILITIES

The integrative framework proposed in this paper is grounded in several complementary theoretical perspectives that collectively explain how Lean maturity and Industry 4.0 maturity contribute to firm performance. Rather than offering competing explanations, these perspectives provide complementary theoretical lenses that illuminate different dimensions of the maturity performance relationship. Each theory contributes a distinct explanatory role within the proposed framework, collectively supporting the reinterpretation of maturity advanced in this paper as a contingent organizational capability rather than a cumulative implementation outcome.

Collectively, these theoretical perspectives provide the conceptual architecture of the proposed framework. Contingency Theory explains the role of contextual alignment, the Resource-Based View and Dynamic Capabilities underpin the capability-based interpretation of Lean and Industry 4.0 maturity, Socio-technical Systems Theory supports the joint consideration of processes, technologies, and human capabilities, whereas Configuration Theory explains how different combinations of these elements may generate heterogeneous performance outcomes.

Contingency Theory provides the overarching premise that organizational effectiveness depends on the alignment between organizational capabilities and contextual conditions rather than on universally applicable best practices. The Resource-Based View (Barney, 1991) and Dynamic Capabilities perspectives (Teece et al., 1997; Eisenhardt & Martin, 2017) together with recent empirical evidence on Lean maturity (Guimarães et al., 2026d), support the interpretation of Lean maturity and Industry 4.0 maturity as organizational capabilities that enable firms to develop, integrate, and continuously reconfigure organizational resources and competencies in response to changing competitive environments. The socio-technical perspective further suggests that sustainable performance requires the joint optimization of organizational processes, digital technologies, and human capabilities rather than isolated technological implementation (Sony & Naik, 2020), while Configuration Theory (Meyer et al., 1993; Fiss, 2007) explains why different combinations of organizational capabilities and contextual conditions may produce distinct performance outcomes despite similar maturity profiles. Together, these complementary theoretical perspectives provide the conceptual foundation for interpreting maturity not as an implementation level, but as a contingent organizational capability whose contribution depends on contextual alignment.

Figure 2 illustrates this integrative framework by positioning Lean maturity and Industry 4.0 maturity as two distinct but interconnected capability domains. Although each maturity dimension reflects different organizational competencies, their interaction is represented as bidirectional, emphasizing that process excellence and digital transformation should evolve in a complementary rather than isolated manner. Lean maturity reflects the organization's capability to establish stable processes, institutionalize continuous improvement, and sustain problem-solving routines. Industry 4.0 maturity, in turn, reflects the capability to integrate digital technologies, exploit organizational data, enhance information transparency, and support data-driven decision-making.

This interpretation follows logically from the complementary assumptions of the theoretical perspectives discussed above, all of which emphasize that organizational outcomes emerge from the interaction between capabilities and context rather than from isolated organizational attributes.

Within the framework, firm performance is conceptualized as a multidimensional construct comprising operational, financial, and strategic outcomes. This representation acknowledges that organizational transformation generates heterogeneous performance effects that may emerge with varying magnitudes and over different time horizons. Operational improvements are typically expected to become visible earlier, whereas financial and strategic outcomes generally require a longer period for organizational capabilities to mature and become fully embedded.

The framework also explicitly incorporates the role of contextual conditions. Firm size, industrial sector, organizational readiness, and strategic alignment are not considered direct determinants of firm performance. Rather, they represent contextual factors that influence the extent to which Lean maturity and Industry 4.0 maturity can be translated into superior performance outcomes. Consequently, organizations displaying similar maturity levels may experience substantially different performance trajectories

DOI: https://doi.org/10.29352/mill0224e.48064

depending on the degree of alignment between their organizational capabilities and their contextual environment. Within the proposed framework, contextual alignment constitutes the explanatory mechanism through which Lean maturity and Industry 4.0 maturity are translated into firm performance. Rather than assuming a direct causal relationship between higher maturity and superior performance, the framework proposes that performance is more likely to emerge when complementary organizational capabilities are coherently configured within specific organizational contexts.

Accordingly, the proposed framework shifts the interpretation of maturity away from a static performance predictor towards a context-dependent organizational capability. Unlike previous perspectives that primarily emphasize the complementarity between Lean practices and Industry 4.0 technologies, the present framework argues that performance improvements arise not simply from higher maturity levels, but from the coherent alignment between complementary capabilities and the organizational conditions under which they are developed. This perspective provides a conceptual explanation for the heterogeneous empirical findings reported in the literature and offers a foundation for future empirical studies adopting contingency and configuration-based approaches.

Accordingly, this paper does not seek to replace existing definitions of maturity or existing maturity models. Instead, it advances a conceptual reinterpretation that provides the operational conceptualization of maturity adopted within the proposed framework. For the purposes of this Perspective Paper, maturity is conceptualized as:

The organizational capability to coherently develop, integrate, and continuously deploy complementary operational and digital capabilities under specific contextual conditions so as to enable sustainable organizational performance.

This conceptualization is intended to support the theoretical framework proposed in this paper rather than to replace existing maturity definitions. From this perspective, maturity is not viewed as a fixed implementation level, organizational state, or readiness indicator, but as a dynamic organizational capability whose contribution to firm performance depends on contextual alignment.

Unlike existing maturity models, which primarily assess implementation levels or technological adoption, the proposed framework introduces contextual alignment as the explanatory mechanism through which complementary organizational capabilities are translated into firm performance. Consequently, the framework is intended not merely to summarize existing knowledge, but to reinterpret the maturity performance relationship through the interaction between complementary capabilities and contextual conditions.



Figure 2 - Integrative conceptual framework explaining the contingent mechanism linking Lean maturity, Industry 4.0 maturity, and firm performance

The proposed framework is consistent with recent capability-based perspectives on the integration of Lean and Industry 4.0 (Tortorella et al., 2021; Pagliosa et al., 2021; Tissir et al., 2023), as well as with recent conceptual efforts to integrate both paradigms within unified theoretical frameworks (Citybabu & Yamini, 2024). However, unlike previous studies, which primarily emphasize the complementarity between Lean practices and Industry 4.0 technologies or propose integrative Lean 4.0 frameworks, the present framework explicitly conceptualizes Lean maturity and Industry 4.0 maturity as contingent organizational capabilities whose contribution to firm performance depends on contextual alignment rather than on maturity levels alone. The novelty of the proposed framework therefore does not lie in introducing contingency theory or capability-based reasoning, both of which are well established, but in providing a theoretical lens through which the heterogeneous maturity performance relationships reported in previous studies can be more coherently interpreted. Rather than proposing another maturity model or additional assessment dimensions, the framework explains why organizations exhibiting similar maturity profiles may experience substantially different performance outcomes by shifting the unit of interpretation from maturity levels to capability

DOI: https://doi.org/10.29352/mill0224e.48064

configurations embedded within specific organizational contexts. This perspective establishes a theoretical foundation for future contingency and configuration-based empirical research.

Importantly, the theoretical contribution of the proposed framework does not reside in extending contingency theory itself or introducing new organizational constructs. Instead, it resides in redefining the conceptual role of maturity within organizational theory. Existing perspectives generally treat maturity as an organizational state, implementation level, or readiness indicator that precedes performance. The proposed framework instead conceptualizes maturity as a contingent organizational capability whose value emerges through the interaction between complementary capabilities and contextual conditions. This shift transforms maturity from a descriptive assessment construct into an explanatory organizational mechanism capable of accounting for the heterogeneous maturity performance relationships repeatedly reported in the literature.

Accordingly, the theoretical novelty of the framework lies not in introducing additional maturity dimensions, but in redefining the causal logic underlying maturity performance relationships. Rather than assuming that maturity directly determines performance, the framework proposes that contextual alignment operates as the explanatory mechanism through which complementary organizational capabilities generate differentiated organizational outcomes.

5.1. Theoretical Propositions

Collectively, these propositions translate the conceptual reinterpretation advanced in this paper into a theoretically grounded set of causal relationships that can guide future empirical research. The integrative framework proposed in this paper provides the basis for a set of theoretical propositions that can guide future empirical research. Rather than constituting hypotheses to be tested within this study, these propositions synthesize the conceptual relationships derived from the proposed framework and offer directions for contingency and configuration-based investigations of the maturity performance relationship.

Proposition 1. *The relationship between Lean maturity and firm performance is contingent upon its alignment with Industry 4.0 maturity and the organizational context, rather than on Lean maturity levels alone*.

This proposition reflects the argument that Lean maturity should not be interpreted as an independent predictor of organizational performance. Instead, its contribution depends on the extent to which Lean capabilities are coherently integrated with digital capabilities and aligned with the contextual conditions in which they are developed and deployed.

Proposition 2. *Firms simultaneously exhibiting high levels of Lean maturity and Industry 4.0 maturity are more likely to achieve sustained operational, financial, and strategic performance when complementary organizational capabilities are coherently aligned*.

This proposition emphasizes the complementary nature of Lean and Industry 4.0 maturity. Superior performance is expected to emerge not simply from the accumulation of maturity in both domains, but from the coherent interaction between process excellence, digital transformation, and organizational context.

Proposition 3. *Contextual alignment constitutes the central explanatory mechanism governing the translation of Lean maturity and Industry 4.0 maturity into firm performance by shaping how complementary organizational capabilities are configured within specific organizational environments*.

This proposition identifies contextual alignment as the central explanatory mechanism of the proposed framework. It suggests that organizations exhibiting similar maturity profiles may experience substantially different performance outcomes because the effectiveness of maturity depends on the coherence between organizational capabilities and contextual conditions.

6. IMPLICATIONS FOR RESEARCH AND PRACTICE

6.1. Implications for research

The perspective advanced in this paper carries several implications for future research on Lean and Industry 4.0 maturity. First, empirical studies should move beyond universalistic assumptions regarding the performance effects of maturity and explicitly adopt contingency and configuration-based research designs (Szász et al., 2021). This implies systematically accounting for firm size, industrial sector, organizational readiness, and strategic alignment as moderating factors shaping maturity-performance relationships.

Second, greater conceptual and methodological clarity is required in the operationalization of maturity constructs. Future research should clearly distinguish between the superficial adoption of tools or technologies and deeper forms of organizational capability development, embedded in routines, learning mechanisms, and managerial systems (Guimarães et al., 2026d). In this regard, longitudinal research designs and mixed-method approaches appear particularly valuable for capturing the dynamic and evolutionary nature of Lean and Industry 4.0 maturity trajectories, as well as for validating maturity assessment models over time (Rossini et al., 2022; Eriksson et al., 2024).

Finally, performance measurement deserves renewed and more systematic attention. Future studies should adopt multidimensional performance frameworks and explicitly align performance indicators with the expected time horizons of Lean and digital transformation initiatives, thereby improving the interpretability and comparability of empirical findings.

DOI: https://doi.org/10.29352/mill0224e.48064

6.2. Implications for managerial practice

From a managerial perspective, the findings of this Perspective Paper caution against viewing Lean maturity and Industry 4.0 maturity as standalone solutions or prescriptive best-practice recipes. Instead, maturity assessments should be used primarily as diagnostic and learning-oriented tools to support the identification of organizational misalignments and the prioritization of coherent, context-sensitive transformation paths.

Managers should recognize that investments in digital technologies are unlikely to yield significant performance gains in the absence of stable, well-designed processes. In contrast, Lean initiatives that neglect digital enablement may face limitations in scalability, responsiveness, and data-driven decision-making. Consequently, effective transformation strategies require a balanced, aligned development of Lean and digital capabilities, tailored to the organizational context and maturity stage rather than driven by benchmarking pressures or technological trends.

CONCLUSION

This Perspective Paper argues that Lean maturity and Industry 4.0 maturity should not be interpreted as universal or direct levers of industrial firm performance, but rather as contingent organizational capabilities whose effects depend on the coherence between operational practices, digital technologies, and strategic orientation. By addressing persistent conceptual ambiguities and highlighting the role of alignment conditions, this paper offers an integrative perspective that reconciles heterogeneous and sometimes contradictory empirical findings reported in the literature (Biondo et al., 2024).

The analysis suggests that the performance implications of Lean and digital maturity are inherently configuration dependent. Organizations exhibiting high levels of both Lean and Industry 4.0 maturity, when strategically aligned, are more likely to achieve sustained performance improvements across operational, financial, and strategic dimensions. In contrast, partial or misaligned maturity trajectories, such as technology-driven initiatives unsupported by process discipline or Lean implementations lacking digital enablement, tend to generate limited or unstable performance outcomes. This interpretative insight helps explain why similar maturity initiatives may yield divergent outcomes across firms and contexts. This interpretation is consistent with the complementary theoretical perspectives integrated throughout this paper, particularly Contingency Theory, Dynamic Capabilities, the Resource-Based View, Socio-technical Systems Theory, and Configuration Theory, all of which suggest that organizational performance depends on the coherent alignment of complementary capabilities with the strategic and contextual conditions in which they are developed and deployed.

From a research perspective, future studies should move beyond linear and universalistic models and adopt configuration and contingency-based approaches that explicitly account for organizational heterogeneity. Greater conceptual rigor in the definition and operationalization of maturity constructs is required, along with increased transparency regarding the assumptions embedded in maturity assessment models. Longitudinal research designs, mixed-method approaches, and comparative studies across sectors and firm sizes would be particularly valuable in capturing the dynamic and evolutionary nature of Lean and Industry 4.0 maturity trajectories.

From a managerial standpoint, this perspective underscores the importance of using maturity assessments as diagnostic and learning-oriented tools, rather than as prescriptive benchmarks or end goals. Managers should prioritize alignment among process stability, digital investments, and organizational readiness, recognizing that maturity development is a gradual, context-specific process rather than a standardized transformation pathway.

Overall, rather than proposing another maturity model, this Perspective Paper contributes to the ongoing debate on Lean and Industry 4.0 by reframing how maturity itself should be interpreted within contemporary organizational theory. Specifically, it provides a unified conceptual interpretation in which Lean maturity and Industry 4.0 maturity are understood not as universal performance drivers or cumulative implementation outcomes, but as contingent organizational capabilities whose contribution to firm performance depends on contextual alignment. By integrating complementary insights from Contingency Theory, the Resource-Based View, Dynamic Capabilities, Socio-technical Systems Theory, and Configuration Theory, this perspective offers a coherent theoretical explanation for the heterogeneous maturity performance relationships reported in the literature. Rather than extending these theories individually, the proposed framework combines them into a unified conceptual interpretation that explains how contextual alignment governs the translation of Lean maturity and Industry 4.0 maturity into firm performance. In doing so, it establishes a theoretical foundation for future contingency and configuration-based empirical research and may support the development of more robust, context-sensitive maturity models and more effective transformation strategies in industrial settings.

ACKNOWLEDGMENTS

This work was supported by the Portuguese Foundation for Science and Technology (FCT) under Projects UID/4131/2025 (https://doi.org/10.54499/UID/04131/2025), UID/PRR/4131/2025 (https://doi.org/10.54499/UID/PRR/04131/2025), UIDB/05583/2020, and UI/BD/154507/2022 (https://doi.org/10.54499/UI/BD/154507/2022). The authors would also like to thank CISE - Electromechatronic Systems Research Centre, University of Beira Interior (UBI), and CISeD - Research Centre for Digital Services, Polytechnic of Viseu (IPV).

AUTHOR´S CONTRIBUTION

Conceptualization, A.G.; data curation, A.G.; formal analysis, A.G.; investigation, A.G.; methodology, A.G.; supervision, A.G.; validation, A.G.; writing – original draft, A.G.; writing – review & editing, A.G.

DOI: https://doi.org/10.29352/mill0224e.48064

CONFLICT OF INTERESTS

The author declare no conflict of interests.

REFERENCES

Ahmad, K., Mohamed Zabri, S., & Atan, S. A. (2023). Multidimensional performance measures and factors and their linkage with performance. *International Journal of Emerging Markets*, 18(11), 5338-5358. https://doi.org/10.1108/IJOEM-05-2021-0797

Alsheyadi, A. K. (2024). A literature review on industry 4.0 implementation and performance: A contingency perspective. *The TQM Journal*, *36*(7), 2048-2070. https://doi.org/10.1108/TQM-03-2023-0073

Amaro, P., & Alves, A. C. (2023). The integration of lean thinking principles in the organizational culture model. *Organizational Cultures*, *24*(1), 1. https://shre.ink/Gtwx

Antony, J., Swarnakar, V., Cudney, E., & Pepper, M. (2022). A meta-analytic investigation of lean practices and their impact on organisational performance. *Total Quality Management & Business Excellence*, *33*(15-16), 1799-1825. https://doi.org/10.1080/14783363.2021.2003194

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management*, *17*(1), 99-120. https://doi.org/10.1177/014920639101700108

Bento, G. D. S., & Tontini, G. (2019). Maturity of lean practices in Brazilian manufacturing companies. *Total Quality Management & Business Excellence*, *30*(sup1), S114-S128. https://doi.org/10.1080/14783363.2019.1665827

Beraldin, A. R., Danese, P., & Romano, P. (2022). Employee involvement for continuous improvement and production repetitiveness: a contingency perspective for achieving organisational outcomes. *Production Planning & Control*, *33*(4), 323-339. https://doi.org/10.1080/09537287.2020.1823024

Biondo, D., Kai, D. A., Pinheiro de Lima, E., & Benitez, G. B. (2024). The contradictory effect of lean and industry 4.0 synergy on firm performance: a meta-analysis. *Journal of Manufacturing Technology Management*, *35*(3), 405-433. https://doi.org/10.1108/JMTM-10-2023-0447

Bititci, U. S., Garengo, P., Ates, A., & Nudurupati, S. S. (2015). Value of maturity models in performance measurement. *International journal of production research*, *53*(10), 3062-3085. https://doi.org/10.1080/00207543.2014.970709

Buer, S. V., Semini, M., Strandhagen, J. O., & Sgarbossa, F. (2021). The complementary effect of lean manufacturing and digitalisation on operational performance. *International Journal of Production Research*, *59*(7), 1976-1992. https://doi.org/10.1080/00207543.2020.1790684

Buer, S. V., Strandhagen, J. O., & Chan, F. T. (2018). The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. *International journal of production research*, 56(8), 2924-2940. https://doi.org/10.1080/00207543.2018.1442945

Cezar Lucato, W., Araujo Calarge, F., Loureiro Junior, M., & Damasceno Calado, R. (2014). Performance evaluation of lean manufacturing implementation in Brazil. *International Journal of Productivity and Performance Management*, *63*(5), 529-549. https://doi.org/10.1108/IJPPM-04-2013-0085

Citybabu, G., & Yamini, S. (2024). Lean Six Sigma and Industry 4.0–a bibliometric analysis and conceptual framework development for future research agenda. *International Journal of Productivity and Performance Management*, *73*(5), 1502-1534. https://doi.org/10.1108/IJPPM-10-2022-0549

Colli, M., Berger, U., Bockholt, M., Madsen, O., Møller, C., & Wæhrens, B. V. (2019). A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era. *Annual Reviews in Control*, *48*, 165-177. https://doi.org/10.1016/j.arcontrol.2019.06.001

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of production economics*, *204*, 383-394. https://doi.org/10.1016/j.ijpe.2018.08.019

Eisenhardt, K. M., & Martin, J. A. (2017). Dynamic capabilities: what are they? *The SMS Blackwell handbook of organizational capabilities*, 341-363. https://doi.org/10.1002/9781405164054.ch21

Eriksson, K. M., Olsson, A. K., & Carlsson, L. (2024). Beyond lean production practices and Industry 4.0 technologies toward the human-centric Industry 5.0. *Technological Sustainability*, *3*(3), 286-308. https://doi.org/10.1108/TECHS-11-2023-0049

Fiss, P. C. (2007). A set-theoretic approach to organizational configurations. *Academy of management review*, *32*(4), 1180-1198. https://www.jstor.org/stable/20159362

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International journal of production economics*, 210, 15-26. https://doi.org/10.1016/j.ijpe.2019.01.004

Gomaa, A. H. (2025). Lean 4.0: A Strategic Roadmap for Operational Excellence and Innovation in Smart Manufacturing. *International Journal of Emerging Science and Engineering* (IJESE), *13*(4), 1-14. https://doi.org/10.35940/ijese.

Guimarães, A., e Oliveira, E., Oliveira, M., & Pereira, T. (2025a). Effects of Lean Tools and Industry 4.0 technology on productivity: An empirical study. *Journal of Industrial Information Integration*, *44*, 100787. http://hdl.handle.net/10400.19/9719

DOI: https://doi.org/10.29352/mill0224e.48064

Guimarães, A., Enrique, D., Gaspar, D., Reis, P., & Marques Cardoso, A. J. (2026c). Overview of the Use of Data Assets in the Context of Portuguese Companies: Comparison Between Micro, SMEs and Large Companies. *In Case Studies in Digital Transformation: Integration of Digital Technologies to Enhance Asset Management Processes* (pp. 359-383). Springer Nature Switzerland.

Guimarães, A., Moura, L. R., & Marques Cardoso, A. J. (2025f). Industry 4.0 readiness assessment-A comparative analysis of Portuguese and Brazilian Companies. *Journal of Industrial Integration and Management*, 1-26. https://doi.org/10.1142/S2424862225500046

Guimarães, A., Pereira, R., Pereira, M. T., Carvalho, A., Reis, P., & Cardoso, A. J. M. M. (2026b). The Paradox Between Concept Knowledge and Digital Maturity Level for Industry 4.0: The Portuguese Case. *International Journal of Business Intelligence Research (IJBIR)*, *17*(1), 1-17. http://hdl.handle.net/10400.19/9699

Guimarães, A., Pereira, R., Pereira, M., & Pereira, M. T. (2025b). Business productivity and the adoption of lean and Industry 4.0 tools: a regional study. *Journal of Mechanical Engineering and Manufacturing*, *1*(1), 6. https://doi.org/10.53941/jmem.2025.100006

Guimarães, A., Reis, P., & Cardoso, A. J. M. (2024). Industry 4.0 in Portugal-Economic Sectors Maturity. *In 2024 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 496-500). IEEE. http://hdl.handle.net/10400.19/9689

Guimarães, A., Reis, P., & Cardoso, A. J. M. (2025c). Bibliometric analysis of studies on Lean maturity assessment in SMEs. *Millenium-Journal of Education, Technologies, and Health*, (18e), e40029. https://doi.org/10.29352/mill0218e.40029

Guimarães, A., Reis, P., & Cardoso, A. J. M. (2025d). Bibliometric Analysis of Studies on Industry 4.0 Maturity Assessment in SMEs. *Millenium-Journal of Education, Technologies, and Health*, (16e), e36472. https://doi.org/10.29352/mill0216e.34672

Guimarães, A., Reis, P., & Charrua-Santos, F. (2023). Industry 4.0-Assessment of digital readiness of manufacturing companies in Portugal. *In 2023 IEEE International Conference on Industrial Engineering and Engineering Management* (IEEM) (pp. 0557-0561). IEEE. https://doi.org/10.1109/IEEM58616.2023.10406601

Guimarães, A., Reis, P., & Marques Cardoso, A. J. (2026a). Digital maturity and business performance in industry 4.0: evidence from industrial firms in Portugal's Dão Lafões region. *International Journal of Productivity and Performance Management*, 1-37. http://hdl.handle.net/10400.19/9692

Guimarães, A., Reis, P., Pereira, T., & Marques Cardoso, A. J. (2025e). Industry 4.0 in Portugal: validation of a readiness assessment model through an empirical approach. *Benchmarking: An International Journal*, 1-27. http://hdl.handle.net/10400.19/9690

Guimarães, A., Reis, P., Ribeiro Pereira, M. T., & Marques Cardoso, A. J. (2026d). Lean manufacturing implementation: validation of a readiness assessment model through an empirical approach. *International Journal of Lean Six Sigma*, 1-41. https://doi.org/10.1108/IJLSS-12-2025-0363

Kolberg, D., Knobloch, J., & Zühlke, D. (2017). Towards a lean automation interface for workstations. *International Journal of Production Research*, *55*(10), 2845-2856. https://doi.org/10.1080/00207543.2016.1223384

Komkowski, T., Sony, M., Antony, J., Lizarelli, F. L., Garza-Reyes, J. A., & Tortorella, G. L. (2025). Operational practices for integrating lean and industry 4.0–a dynamic capabilities perspective. *International Journal of Production Research*, *63*(4), 1517-1537. https://doi.org/10.1080/00207543.2024.2381127

Kumar, L., & Sharma, R. K. (2025). Adapting to Industry 4.0: evaluating SMEs preparedness through a comprehensive digital readiness assessment maturity model by validating stakeholders' perceptions. *Business Process Management Journal*, 31(7), 2755-2800. https://doi.org/10.1108/BPMJ-07-2024-0546

Maia, D. D. R. P., Lizarelli, F. L., & Gambi, L. D. N. (2024). Industry 4.0 and Six Sigma: a systematic review of the literature and research agenda proposal. *Benchmarking: An International Journal*, 31(3), 1009-1037. https://doi.org/10.1108/BIJ-05-2022-0289

Masoud, E., Alahmed, A., Alsuwaidi, F., & Alahmed, S. (2025). Analyzing the influence of Lean Management strategies on organizational performance: A case study of Majan Printing & Packaging company in the UAE. *Quality Management Journal*, *32*(2), 92-108. https://doi.org/10.1080/10686967.2025.2483173

Meyer, A. D., Tsui, A. S., & Hinings, C. R. (1993). Configurational approaches to organizational analysis. *Academy of Management Journal*, *36*(6), 1175-1195. https://doi.org/10.2307/256809

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

Motia, K., Kumar, R., & Akhai, S. (2024). Navigating the Fourth Industrial Revolution: A Comprehensive Review of Industry 4.0 Technologies and Their Global Adoption. *In International Conference on Design and Manufacturing Technologies* (pp. 317-333). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-7659-0_28

Närvä, M., & Bicheno, J. (2025). Leanness-Comparison of Different Assessment Methods. *In European Lean Educator Conference* (pp. 136-145). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-032-10111-2_11

DOI: https://doi.org/10.29352/mill0224e.48064

Ooi, Y. H., Ng, T. C., & Cheong, W. C. (2023). Implementing Industry 4.0 and lean practices for business performance in manufacturing: Case of Malaysia. *International Journal of Advanced and Applied Sciences*, *10*(3), 143-156. https://doi.org/10.21833/ijaas.2023.03.019

Pagliosa, M., Tortorella, G., & Ferreira, J. C. E. (2021). Industry 4.0 and Lean Manufacturing: A systematic literature review and future research directions. *Journal of Manufacturing Technology Management*, *32*(3), 543-569. https://doi.org/10.1108/JMTM-12-2018-0446

Queiroz, M. M., Fosso Wamba, S., Chiappetta Jabbour, C. J., Lopes de Sousa Jabbour, A. B., & Machado, M. C. (2025). Adoption of Industry 4.0 technologies by organizations: a maturity levels perspective. *Annals of Operations Research*, *348*(3), 1989-2015. https://doi.org/10.1007/s10479-022-05006-6

Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2020). Impacts of Industry 4.0 technologies on Lean principles. *International Journal of Production Research*, *58*(6), 1644-1661. https://doi.org/10.1080/00207543.2019.1672902

Rossini, M., Costa, F., Portioli-Staudacher, A., & Tortorella, G. L. (2022). The Impact of Lean on Introduction of Industry 4.0 Technologies: A Longitudinal Study. *In European Lean Educator Conference* (pp. 143-147). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-25741-4_13

Rossini, M., Costa, F., Tortorella, G. L., Valvo, A., & Portioli-Staudacher, A. (2022). Lean Production and Industry 4.0 integration: how Lean Automation is emerging in manufacturing industry. *International Journal of Production Research*, *60*(21), 6430-6450. https://doi.org/10.1080/00207543.2021.1992031

SAE International. (1999). *J4000: Identification and measurement of best practice in implementation of Lean operation.* SAE International. https://doi.org/10.4271/J4000_202104

Santos, R. C., & Martinho, J. L. (2020). An Industry 4.0 maturity model proposal. *Journal of Manufacturing Technology Management*, *31*(5), 1023-1043. https://doi.org/10.1108/JMTM-09-2018-0284

Skalli, D., Charkaoui, A., Cherrafi, A., Garza-Reyes, J. A., Antony, J., & Shokri, A. (2023). Industry 4.0 and Lean Six Sigma integration in manufacturing: A literature review, an integrated framework and proposed research perspectives. *Quality Management Journal*, *30*(1), 16-40. https://shre.ink/Gxc6

Slavickova, J., & Zemanova, B. (2025). Changes in lean culture as organizations mature: is there a relationship between lean culture attributes and organizational life cycle stages?*European Business Review*. https://doi.org/10.1108/EBR-08-2024-0237

Sony, M., & Naik, S. (2020). Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model. *Technology in Society*, *61*, 101248. https://doi.org/10.1016/j.techsoc.2020.101248

Szász, L., Demeter, K., Rácz, B. G., & Losonci, D. (2021). Industry 4.0: a review and analysis of contingency and performance effects. *Journal of Manufacturing Technology Management*, *32*(3), 667-694. https://doi.org/10.1108/JMTM-10-2019-0371

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509-533. https://encurtador.com.br/hMfl

Tissir, S., Cherrafi, A., Chiarini, A., Elfezazi, S., & Bag, S. (2023). Lean Six Sigma and Industry 4.0 combination: Scoping review and perspectives. *Total Quality Management & Business Excellence*, *34*(3-4), 261-290. https://doi.org/10.1080/14783363.2022.2043740

Tlapa, D., Tortorella, G., Fogliatto, F., Kumar, M., Mac Cawley, A., Vassolo, R., ... & Baez-Lopez, Y. (2022). Effects of lean interventions supported by digital technologies on healthcare services: a systematic review. *International Journal of Environmental Research and Public Health*, *19*(15), 9018. https://doi.org/10.3390/ijerph19159018

Tortorella, G. L., Giglio, R., & Van Dun, D. H. (2019). Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement. *International journal of operations & production management*, *39*(6/7/8), 860-886. https://doi.org/10.1108/IJOPM-01-2019-0005

Tortorella, G. L., Vergara, A. M. C., Garza-Reyes, J. A., & Sawhney, R. (2020). Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers. *International Journal of Production Economics*, *219,* 284-294. https://doi.org/10.1016/j.ijpe.2019.06.023

Tortorella, G.L., Fettermann, D., & Frank, A.G. (2021). Lean manufacturing and Industry 4.0 integration: A capability-based perspective. *International Journal of Production Economics, 231,* 107907. https://doi.org/10.1108/jmtm-12-2018-0446

Vilarinho, H., Guimarães, A., e Oliveira, E., & Pereira, T. (2026). From scores to decision: Unveiling company maturity for Industry 4.0 using Benefit-of-the-Doubt models. *International Journal of Production Economics*, 110191. https://doi.org/10.1016/j.ijpe.2026.110191

Zhang, A., Luo, W., Shi, Y., Chia, S. T., & Sim, Z. H. X. (2016). Lean and Six Sigma in logistics: a pilot survey study in Singapore. *International Journal of Operations & Production Management*, *36*(11), 1625-1643. https://doi.org/0.1108/IJOPM-02-2015-0093