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Abstract

This study undertakes a meticulous analysis of the mediating role played by Industry 4.0 in the relationship between the more abstract and technical aspects of Lean philosophy, with the aim of assessing its concrete impact on company performance. Comprised of a representative sample of 270 manufacturing firms, employing the Technology Acceptance Model (TAM) as the underlying theoretical framework, the investigation delves into the intricate interplay between the elements constituting Industry 4.0 and Lean philosophy, utilizing ordinary least squares regression (OLS). The results obtained substantiate the fundamental significance of Industry 4.0 as an effective mediator, enabling companies deeply ingrained in the Lean philosophy to enhance their Just-in-Time operations, Total Productive Maintenance, and Total Quality Management, resulting in a substantial improvement in their overall performance. Additionally, it underscores the significant influence of active leadership, employees, and customers in embracing the Lean culture, thus accentuating the recognition of the value of Industry 4.0. Consequently, the seamless integration of these technologies with the technical aspects of Lean tools emerges as a paramount factor in enhancing organizational performance. This study enriches the body of knowledge by emphasizing the premise that the adoption of Lean philosophy precedes the integration of Industry 4.0 technologies and offers invaluable practical insights for managers seeking to optimize their operational processes. It addresses a critical gap in existing literature by exploring the conditions under which the synergy between Lean and Industry 4.0 yields remarkable performance outcomes for organizations.

Keywords: Lean, Industry 4.0, Soft lean, Hard lean, Firm performance.

1 Introduction

In the search for better performance, companies continually strive to refine their operations. The remarkable success of the Toyota Production System (TPS), later popularized as “Lean Production” by [31], significantly influencing this search. “Lean production” has gained widespread popularity and attracted substantial academic attention due to its impact on enhancing company performance. The essence of Lean lies in its philosophy, employing a set of organizational practices that synergistically collaborate to reduce waste and, subsequently, improve company performance [23]. Existing literature has elucidated that Lean philosophy encompasses both technical tools (hard) and human-centered practices (soft) [5][10][19].

In recent years, the emergence of Industry 4.0 (I4.0) and digital transformation technologies have influenced the Lean philosophy [21]. The implementation of I4.0 technologies is driven by a number of factors, all aimed at improving the efficiency, productivity and competitiveness of companies [7]. It is essential to consider that Lean and I4.0 present different approaches with the same purpose of improving efficiency and performance in industrial operations. Lean is characterized by a set of light practices, such as employee empowerment, customer involvement and top leadership management [5] complemented by Hard tools such as Just-In-Time (JIT), Total Productive Maintenance (TPM) and Total Quality Management (TQM) [24] [23] all involve reducing waste and improving performance. In contrast, I4.0 denotes the integration of digital technologies such as Internet of Things (IoT), Big Data, Cloud Computing and Artificial Intelligence (AI) to create smarter and more efficient production systems. The potential synergies between Lean and I4.0 are extremely recognized and present a positive perspective in the literature [25][30]. Stating that the integration of these two approaches can improve company performance [22][29].

In summary, the relationship between Lean and Industry 4.0 is complex and multifaceted, giving rise to questions about the reasons behind the contradictory evidence in this domain. Firstly, it is necessary to consider whether there is a genuine paradox between two competitors: one based on human elements (Lean) and the other dependent on digital technologies (I4.0) [20][32]. Secondly, it raises the possibility of a misconceptualization regarding the interaction between these two concepts [26]. Alternatively, conflicting evidence may result from researchers' randomness and rigor in their methodologies. In dealing with this issue, we propose that there is a potential misunderstanding regarding the interaction between Lean and I4.0, worthy of further exploration.

Our proposal states that individuals who are deeply committed to the lean philosophy are more inclined to identify the organization's deficiencies and are more receptive to embracing and effectively implementing I4.0 technologies to improve the implementation of their hard lean tools. Consequently, we propose a perspective where I4.0 can mediate the relationship between soft lean practices and hard lean tools, helping companies achieve better performance. Therefore, our paper addresses a crucial research gap left by existing Lean and I4.0 moderation models: **Under what conditions does the interrelationship between Lean and Industry 4.0 produce meaningful performance outcomes for companies?**

2 Theoretical Foundation

2.1 Industry 4.0 as a moderator or mediator of Lean?

The literature on operations management explores the potential synergy between Industry 4.0 (I4.0) and Lean practices and their impact on company performance. Specifically, many studies address the relationship between I4.0 and lean by considering I4.0 as a moderating effect that influences company performance. Moderation refers to a scenario where the relationship between an independent variable (e.g., Lean) and a dependent variable (e.g., company performance) changes based on the level of a third variable, known as a moderator. (e.g. I4.0). This third variable, the moderator, affects the strength or direction of the relationship between the independent and dependent variables, helping to identify the conditions under which this relationship maintains.

Reviewing the current literature, an increasing number of studies over the past three years have aimed to explain the relationship between Lean and I4.0 through moderation models. These models typically operate from a positivist point of view, postulating that I4.0 increases the effectiveness of Lean practices, consequently improving the company's performance. However, quantitative studies testing this hypothesis often reveal juxtaposed effects [27] or no discernible effect of such synergy [26]. The studies suggest cases in the operations management literature in which I4.0 and related technologies do not necessarily guarantee greater effectiveness of Lean practices in organizations. Given this scenario,

it is imperative to investigate whether scholars have overestimated the influence of I4.0 on Lean, possibly resulting in misconceptualizations in their models.

In light of these considerations, a small part of the current literature has focused on exploring the mediating effect of I4.0 on Lean (Table 2). According to [12], mediation occurs when a third variable (i.e., I4.0), known as a mediator, elucidates how the independent variable affects the dependent variable. In this case, the independent variable influences the mediator, subsequently impacting the dependent variable. Mediation analysis helps in understanding the underlying path of association between the independent and dependent variables [12]. A recent study by [24] presents promising results, indicating that the adoption of I4.0 facilitates the development of Lean practices, consequently improving the company's performance. However, the existing literature on operations management lacks studies that address I4.0 as a mediator of Lean practices. To fill this gap, we propose to propose a model that effectively considers the relationship between I4.0 and Lean practices; To do this, individuals must understand and adopt I4.0 technologies. In the subsequent section, we elaborate on this notion by presenting a Technology Acceptance Model (TAM) perspective.

2.2 Technology Acceptance Model (TAM) in the Lean and Industry 4.0 relationship

The well-established theoretical framework employed in the information systems and technology management literature to understand and predict technology adoption [12][13]. Conceived by Fred Davis in the late 1980s, TAM is deeply rooted in psychology and focuses on the psychological determinants that impact individuals' choices to adopt or refuse new technologies [6]. The essential constituents of TAM encompass perceived usefulness and perceived ease of use.

Perceived usefulness posits that users are more inclined to embrace and adopt a technology if they perceive it as instrumental in enhancing their work performance or simplifying their tasks. Essentially, users assess whether the technology would yield tangible benefits. On the other hand, perceived ease of use pertains to users' perception of the technology's ease of acquisition and utilisation. Users are more likely to accept a technology if they perceive it as hassle-free and user-friendly. TAM posits that users' behavioural intent to employ technology is swayed by their perceptions of its usefulness and ease of use.

Therefore, the TAM perspective can illuminate the adoption of I4.0 technologies in terms of individuals feeling engaged and seeing value from these advances. Specifically, we assert that companies deeply rooted in sophisticated soft lean practices can generate a sense of value among individuals engaged in such practices in relation to I4.0 technologies. Consequently, the company could benefit from assimilating these technologies to develop robust and lean tools. By employing TAM in this context, companies can gain valuable insights into how employees and stakeholders perceive the integration of I4.0 technologies as mediators, along with soft lean practices and relationships with hard lean tools. Furthermore, the TAM perspective helps to understand how users adopt industry 4.0 technologies, especially when considering the use of technologies in a company with a lean culture expressed in its soft lean practices.

2.3 Development of hypotheses and Econometric Model

Such understanding can inform strategies to promote acceptance, efficient implementation and optimal utilization of these technologies to enhance Lean practices and improve overall organizational performance and competitiveness. Thus, we propose a theoretical model indicating that the mediation effect of I4.0 technologies on soft lean practices and hard lean tools can reinforce company performance. Accordingly, it is important to define mediation and moderation to understand the proposed model better; when a variable mediates, it means that it affects the behaviours of the dependent variable in the model, affecting correlation and significance, especially when considering the direct and indirect effects of the independent variables along the model, furthermore, mediation could be total,

partial, or nonexistent; in the other hand, moderation refers to variables association, when two variables have increased effect when associated, in other words, the moderating variable modify or condition the effect of the independent variable on the dependent variable [11][12].

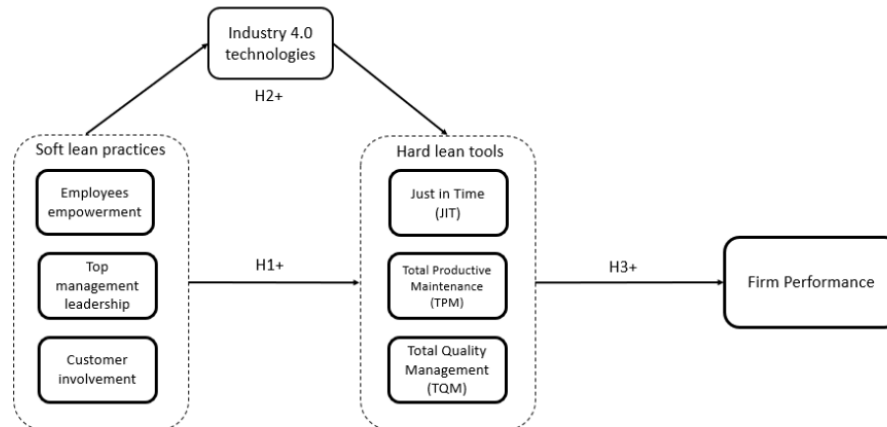


Fig. 1. Econometric model for mediating Industry 4.0 technologies in soft lean practices and hard lean tools.

Both soft lean practices and hard lean tools effectively synergize in the successful implementation of the lean philosophy, consequently boosting organizational performance [5]. Soft practices cultivate a culture that leads to continuous improvement, while hard tools provide specific methodologies for achieving tangible results. In summary, soft lean practices establish the environment and mindset necessary for the effective application of hard lean tools. We assert that companies characterized by committed leadership, empowered employees, and engaged customers can realize additional benefits by incorporating lean tools such as JIT, TPM, and TQM [7]. These lightweight practices ensure that these tools are implemented not just as a set of techniques, but that they are ingrained in the organizational culture, aligning with an overarching commitment to continuous improvement. This integration could improve efficient implementation and significantly increase efficiency and quality. Therefore, we propose the following hypothesis:

H1. There is a positive relationship between soft lean practices and hard lean tools.

Based on the Technology Acceptance Model (TAM) perspective, we posit that companies can benefit from an indirect relationship facilitated by the adoption of I4.0 technologies in their lean practices. In essence, when companies promote engagement and commitment to the Lean philosophy among their workforce and stakeholders, their perception of the usefulness and value of I4.0 technologies is increased and more accurate, thus facilitating integration perfection of such technologies. Consequently, companies entrenched in a high degree of soft lean practices are more likely to reap the benefits of adopting I4.0 technologies to improve the implementation of their hard lean tools. Therefore, based on this point of view, we assert that companies that have a robust Lean culture and emphasize soft practices stand to gain from adopting I4.0 technologies to enhance the operational facets of Lean, i.e., hard Lean tools, consequently driving companies to improve performance. We propose this:

H2. Industry 4.0 technologies act as a mediating factor in the relationship between soft lean practices and hard lean tools.

Previous research has extensively investigated the performance implications of Lean practices [7][28]; In alignment with much of the previous literature, we recognize that robust tools such as JIT, TPM and TQM improve organizational performance [20]. These tools are fundamental in optimizing production processes and increasing operational efficiency, leading to notable improvements in organizational performance. We pose this hypothesis as a logical result of the perceived utility and value derived from I4.0 technologies in companies that have matured soft lean practices. In essence, we

infer that, following the mediation effect of I4.0 technologies on soft lean practices and hard lean tools, companies can achieve better performance by applying JIT, TPM and TQM. Consequently, we propose:

H3. There is a positive relationship between lean tools and company performance.

3 Methodology

We carried out research aimed at administrative executives of Brazilian industrial companies, targeting directors, managers and CEOs. The survey employed a single-respondent approach, sending emails to over 10,000 business emails. The survey was disseminated through weekly emails for three months, from March to May 2023. After filtering outliers, null and duplicated data, we filtered 270 valuable responses out of 353 respondents. Duplicated data was deleted by comparing companies' data, such as their names and control variables. The survey questions used a 7-point Likert scale, ranging from "1 – Strongly disagree" to "7 – Strongly agree", with an additional option for "0 – Not applicable", as recommended in academic literature [11]. The survey questions were selected from validated constructs in the literature of journals with Academic Journal Guide rank (AJG) 3, 4, and 4* [1][2][5][8][9][14][15][16][17][24][30]. To mitigate survey bias, we implemented measures to address self-selection and response bias. We specifically target participants in managerial and strategic roles to combat selection victory. Furthermore, to strengthen the response rate, we structured a survey by grouping the questions into thematic blocks and randomizing their order in the questionnaire. The thematic blocks included (i) Contextual data; (ii) Gentle and lean practices; (iii) Lean Hard Tools; (iv) Industry 4.0 technologies; and (v) Company performance metrics. The majority of companies represented the machinery and equipment sector (21%), with several industrial sectors categorized as Others (27%). During the research, we ensured alignment with the National Classification of Economic Activities (CNAE) of the Brazilian Institute of Geography and Statistics (IBGE), revealing that many industrial sectors had a representation of less than 1%. The majority of companies had a revenue distribution greater than US\$3.2 million (62%). The final sample comprised 28% large companies, 45% medium-sized companies, 24% small companies and 3% micro-enterprises, classified according to the OECD (2021) classification for company size. The profile of the survey respondents is detailed as follows: 19% Director, 28% Manager, 18% Coordinator/Supervisor, 7% President/Vice/CEO, 18% Owner/Partner and 10% Others. The majority of companies fell into Level 2 (63%), indicating a business-to-business orientation. Additionally, most of these companies have been operating in the market for more than ten years, demonstrating a certain level of maturity in operational practices in their respective segments. Finally, a significant portion of companies had an international network (53%) within their supply chain, indicating strong links with practices in other countries.

4 Results

To test our hypotheses H1 and H3, we conducted a series of ordinary least squares linear regression models. In these models, we examine the influence of soft lean practices on hard lean tools for H1 and the influence of hard lean tools on company performance for H3. The results of the hierarchical regressions are presented in Table 1; in model 1 the soft lean practice independent variables were added [EMPLOYEES, LEADERSHIP, CUSTOMERS], in the sequence, the industry 4.0 technologies independent variables were added to the model [INDUSTRY 4.0], these independent variables effects were tested individually, on model 1, and combined, on model 2, for the dependent variables of hard lean tools [JIT, TPM, TQM]. It is important to say the following control variables were added on models 1 and 2: number of employees [employees]; time of experience implementing lean practices [time_lean]; time of experience implementing digital transformation practices [time_DT]; the existence of a lean department [lean_depart]; the existence of a digital transformation department [DT_depart]; supply chain tier [tier1; tier2]; and supply chain extension [region1; region2]. Afterwards, the direct

effect of hard lean tools in firm performance was tested, accordingly we report the unstandardized regression coefficients following the previous standardization of the constructs.

Table 1. Results of hierarchical regression (n = 270).

	JIT		TPM		TQM		Firm Performance
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1
EMPLOYEES	.481** (p = .000)	.435** (p = .000)	.542** (p = .000)	.480** (p = .001)	.470** (p = .001)	.335* (p = .016)	
LEADERSHIP	.359** (p = .003)	.342** (p = .005)	.171	.148	.250	.199	
CUSTOMERS	.412** (p = .000)	.397** (p = .000)	.276* (p = .018)	.257* (p = .027)	.495** (p = .000)	.451** (p = .000)	
INDUSTRY 4.0		.161* (p = .020)		.215* (p = .020)		.470** (p = .000)	
JIT							.316** (p = .000)
TPM							.124* (p = .047)
TQM							.269** (p = .001)
F-value	19,263** (p = .000)	18,587** (p = .000)	8,429** (p = .000)	8,371** (p = .000)	14,556** (p = .000)	17,346** (p = .000)	13,118** (p = .000)
R ²	.524	.536	.325	.342	.454	.519	.428
Adjusted R ²	.497	.507	.287	.302	.423	.489	.396
Change in R ²	.357** (p = .000)	.012* (p = .020)	.187** (p = .000)	.017* (p = .020)	.212** (p = .000)	.065** (p = .000)	.284** (p = .000)

The results validate our hypothesis H1, demonstrating that companies that adopt soft lean practices are more inclined to develop and effectively implement hard lean tools. The increase in the coefficients of determination (R²) from models 1 to 2, as observed in Table 1, expresses the quality of the model, showing the incremental contribution of the independent variables that were added to the models to explain the dependable variables, [JIT], [TPM], [TQM] and [FIRM PERFORMANCE]. However, it is important to highlight that the interactions between [TOP_MANAGEMENT_LEADERSHIP] with [TPM] and [TQM] were considered statistically insignificant. Regarding hypothesis H3, in line with existing literature [29] [30], our results suggest that hard lean tools contribute significantly to company performance. company, thus supporting H3.

Hypothesis H2, we examine the mediating effect of the variable [BASE_I4.0_TECHS] between soft lean practices and hard lean tools. The mediating effects of [BASE_I4.0_TECHS] are statistically significant, showing partial mediation in the direct and indirect cumulative effects, thus affirming our hypothesis H2. In essence, we assert that [BASE_I4.0_TECHS] assists companies with well-established soft lean practices in developing hard lean tools, consequently leading to better performance.

5 Conclusion

Our findings substantiate our central argument that previous inconclusive statistical inferences, or even contrasting results, regarding the moderating effect of Industry 4.0 on Lean practices in previous literature [24] and [28] can be attributed to the presence of a mediating effect resulting from I4.0, which offers a more coherent explanation for this relationship. In essence, our results highlight a misconception among operations management scholars when it comes to examining the interaction between I4.0 and Lean in the context of company performance. Our findings illustrate that I4.0 has an indirect path between soft lean practices and hard lean tools. Simply put, our findings suggest that when companies have well-established soft lean practices and leverage I4.0 technologies, these technologies act as mediators, influencing and increasing the association between the softer facets of lean practices and the implementation and effectiveness of hard tools. lean. such as JIT, TPM and TQM. Consequently, this culminates in greater operational efficiency, quality and overall effectiveness within the organization.

However, it is critical to recognize that the term “partial mediation” means that although I4.0 technologies play a mediating role, other contributing factors or processes may also influence the relationship between soft lean practices and hard lean tools. As stated in our initial hypothesis, we reinforce previous studies [3][4][27], which have already proposed that a strong lean mindset emerging from mature soft practices can help companies in more effective deployment of your hard lean tools. Supported by our findings, we establish that the adoption of I4.0 technologies may not be the only determinant that leads companies to superior performance when they already have a well-established lean philosophy. This finding is interesting, as additional factors that act as complete mediators between soft and hard lean practices may be related to other sociotechnical elements.

Based on the TAM perspective, we posit that the successful integration of Lean and I4.0 is intrinsically linked to individuals' acceptance and perceived usefulness of I4.0 technologies. To some extent, previous literature on I4.0 [12] corroborates such assumptions by highlighting the central role of human factors in organizational performance when adopting I4.0 technologies [33] [34] [35] [36]. Among our conclusions, we did not identify a direct association between top management leadership and TPM and TQM. This implies that when leadership is committed to Lean, it does not automatically improve TPM and TQM. This observation is in line with the principles of TPM and TQM, articulated by [6] and [18], suggesting that these tools are more closely related to the tactical and operational levels of a factory. This observation is validated by its strong and direct correlation with employee empowerment found in our results. However, in cases where companies have leaders committed to the Lean philosophy and realize the usefulness of I4.0 technologies, their direct impact on the development of TPM and TQM tools becomes significant.

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