UNISINOS UNIVERSITY
DEPARTMENT OF PRODUCTION AND SYSTEMS ENGINEERING
DOCTOR OF SCIENCE DEGREE

LÚCIO CANTARELLI NOAL

FACTORY ECONOMICS:

Economic Efficiency and its Conditions as a foundation for Production System Management

São Leopoldo
2025

LÚCIO CANTARELLI NOAL

FACTORY ECONOMICS:

Economic Efficiency and its Conditions as a foundation for Production System Management

Thesis presented as a partial requirement for the degree of Doctor of Philosophy in Production and Systems Engineering by the Department of Production and Systems Engineering of the University of Vale do Rio dos Sinos (UNISINOS).

São Leopoldo
2025

N743f Noal, Lúcio Cantarelli.
Factory economics : economic efficiency and its conditions as a foundation for production system management / by Lúcio Cantarelli Noal – 2025.
[277] p. : il. ; 30 cm.

Thesis (doctor's degree) — University of Vale do Rio dos Sinos, Department of Production and Systems Engineering, São Leopoldo, RS, 2025.
"Advisor: Daniel Pacheco Lacerda, D.Sc.".

1. Lean. 2. Theory of constraints (TOC). 3. Drum-buffer-rope (DBR). 4. Economic efficiency. 5. Manufacturing systems. I. Title.

UDC: 658.5:65.011

Cataloging in Publication (CIP):
Librarian Alessandro Dietrich - CRB 10/2338

LÚCIO CANTARELLI NOAL

FACTORY ECONOMICS:

Economic Efficiency and its Conditions as a foundation for Production System Management

Thesis presented as a partial requirement for the degree of Doctor of Philosophy in Production and Systems Engineering by the Department of Production and Systems Engineering of the University of Vale do Rio dos Sinos (UNISINOS).

Approved on____ / ___________________ / 2025.

FACULTY COMMITTEE MEMBERS

____

Daniel Pacheco Lacerda, D.Sc. (Supervisor) - UNISINOS

____

Leandro Gauss, D.Sc. - UNISINOS

____

Fabio Piran, D.Sc. - UNISINOS

____

Fernando Bernardi, D.Sc.– UNESP

____

Liane Kipper, D.Sc. - UNISC

“O importante é não parar de questionar; a curiosidade tem sua própria razão de existir”

Albert Einstein

AGRADECIMENTOS

Expresso minha profunda gratidão à minha esposa, Mileni Denardin Portella, e à minha filha, Manuela Portella Noal, pelo apoio inestimável ao longo de todo o processo de elaboração desta pesquisa. Sua compreensão e paciência diante da minha ausência durante o desenvolvimento do estudo foram fundamentais para a concretização deste trabalho.

Aos meus pais, Marion Lange Noal e Eronita Ana Cantarelli Noal, manifesto meu reconhecimento por sempre ressaltarem a importância do conhecimento e incentivarem minha trajetória acadêmica, proporcionando-me valores que foram essenciais ao longo dessa jornada.

Registro, também, meus sinceros agradecimentos ao meu orientador, Professor Daniel Pacheco Lacerda, por sua dedicação incansável, pela generosa partilha de seu vasto conhecimento e pelo apoio constante em todas as etapas deste percurso. Da mesma forma, sou grato aos Professores Fabio Piran, Maria Isabel Morandi e Leandro Gauss por suas contribuições valiosas, pelas produtivas discussões e pelo suporte contínuo ao longo da pesquisa.

Aos meus colegas Reno Schmidt, Daniel Pottker e Rodrigo Santos, agradeço pelo compartilhamento desta jornada acadêmica e profissional, pelo apoio mútuo e pelas enriquecedoras trocas de conhecimento.

Por fim, estendo minha gratidão à Bruning Tecnometal, por proporcionar um ambiente propício ao desenvolvimento desta tese, contribuindo significativamente para a realização deste trabalho.

RESUMO

O aprimoramento da produtividade e da eficiência nas organizações configura uma constante ao longo dos anos e objeto de interesse de profissionais e pesquisadores. Enquanto os estudos acerca da eficiência técnica são amplamente abordados, os estudos sobre eficiência econômica são relativamente escassos. Abordagens, como o Lean, predominantemente direcionam seus esforços para melhorar a eficiência técnica nos sistemas de manufatura. Embora a necessidade e a relevância das melhorias técnicas sejam indiscutíveis, é importante salientar que nem sempre os benefícios em eficiência técnica se traduzem proporcionalmente em retornos de eficiência econômica nos sistemas de manufatura. Assim, essa pesquisa defende a tese da necessidade de gerir o sistema produtivo do ponto de vista econômico para direcionar os conceitos, métodos, técnicas e ferramentas nos sistemas de produção. Para tanto, foi conduzida uma Design Science Research (DSR), que inicialmente identificou o problema e realizou o enquadramento teórico, seguindo pela aplicação da intervenção e, por fim, pela avaliação dos efeitos dessa intervenção. O enquadramento teórico foi conduzido por meio de uma RSL buscando a conexão do Lean com a eficiência nos sistemas de manufatura e serviço. Na intervenção, objetivou-se realizar uma primeira análise comparativa em relação à utilização dos conceitos do Lean e da Teoria das Restrições (TOC) para sincronização da manufatura em uma linha automotiva. Os resultados econômicos evidenciaram que a implementação da sincronização da TOC foi mais eficaz que a abordagem do Lean, resultando uma redução de 29,9% dos custos totais. Na terceira análise, os efeitos foram avaliados longitudinalmente por meio de um estudo de caso, onde os resultados indicaram que a implementação da TOC proporcionou um aumento de 66,90% na eficiência econômica. Esses resultados corroboram a necessidade premente de ampliar os estudos sobre eficiência econômica nos sistemas de manufatura. As principais limitações deste trabalho estão relacionadas à não aplicação da pesquisa em mais de um caso, em mais de um sistema de manufatura.

Palavras-chave: Lean, Teoria das Restrições (TOC), Drum-Buffer-Rope (DBR), Eficiência econômica.

ABSTRACT

Enhancing efficiency and productivity in organizations is a fundamental necessity to which we are inextricably linked. While technical efficiency has been widely studied, research on economic efficiency remains relatively scarce in comparison. Methodologies such as Lean primarily focus on optimizing technical efficiency in manufacturing systems. However, while technical improvements are undeniably important, it is crucial to recognize that gains in technical efficiency do not always translate proportionally into gains in economic efficiency. This study argues that understanding the production system from an economic perspective is essential for effectively applying concepts, methods, techniques, and tools in manufacturing systems. To explore this, an design science research (DSR) was conducted, beginning with problem identification and the establishment of a theoretical framework, followed by the implementation of the intervention and an evaluation of its effects. The theoretical framework was developed through a systematic literature review (SLR), examining the relationship between Lean and efficiency in both manufacturing and service systems. The intervention aimed to compare the application of Lean principles and the Theory of Constraints (TOC) in synchronizing production within an automotive assembly line. The economic results revealed that TOC synchronization was more effective than the Lean approach, reducing total costs by 29.9%. In a subsequent longitudinal analysis through a case study, TOC implementation led to a 66.9% increase in economic efficiency. These findings underscore the pressing need for further research on economic efficiency in manufacturing systems. The primary limitation of this study is that the research was conducted on a single case and was not applied across multiple manufacturing systems.

Keywords: Lean, Theory of Constraints (TOC), Drum-Buffer-Rope (DBR), Economic efficiency

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AE	Allocative efficiency
CE	Cost efficiency
CRS	Constant Returns to Scale
CUB	Capacity Utilization Bottleneck
DBR	Drum-Buffer-Rope
DEA	Data Envelopment Analysis
DES	Discrete-event simulation
EDI	Electronic Data Interchange
EMA	Exploratory modeling and analysis
EPR	Equipment Performance Reliability
ETO	Engineering-to-Order
GDP	Gross Domestic Product
GPE	Global Production Effectiveness
HRM	Human Resource Management
ISM	Interpretive Structural Modeling
JIT	Just-in-Time
LGT	Literature Grounded Theory
LM	Lean Manufacturing
MTS	Make-to-Stock
OAE	Overall Asset Effectiveness
OEE	Overall Equipment Effectiveness
OFE	Overall Factory Effectiveness
OPE	Overal Plant Effectiveness
OPT	Optimized Production Timetables
OTD	On-Time Delivery
OTE	Overall Throughput Effectiveness
PEE	Production Equipment Effectiveness
RSL	Revisão Sistemática da Literatura
SD	System Dynamics
S-DBR	Simplified Drum-Buffer-Rope
SLR	*Systematic Literature Review*

SMED	Single Minute Exchange of Die
TQM	Total Quality Management
TA	Throughput accounting
TE	Technical efficiency
TPM	Total Productive Maintenance
TPS	Toyota Production System
TOC	Theory of Constraints
VSM	Value Stream Mapping
WIP	Work-in-process

TABLE OF CONTENTS

1 INTRODUCTION

Productivity and efficiency are widely discussed across academic, governmental, and business sectors, given their intrinsic connection to regional economic development and, consequently, national growth (Kerstens; Sadeghi; Van De Woestyne, 2019; Piran; Lacerda; Camargo, 2020). Productivity refers to the effort applied in converting raw materials into finished products (Charnes; Cooper; Rhodes, 1978; Sukwadi; Felicia; Muafi, 2021), while efficiency measures how productivity compares across different units, such as processes, manufacturing plants, services, and companies (Almeida, 2006).

Despite the widespread acknowledgment of these issues, Brazil faces significant challenges in improving productivity and efficiency. Brazilian companies have shown stagnation in these areas since the 1980s (Piran; Lacerda; Camargo, 2021; Silva; Menezes-Filho; Komatsu, 2016). Efforts to control inflation between the 1970s and 1990s, followed by initiatives to reduce inequality in the 2000s, took priority, diverting attention from productivity-related discussions. Even during periods of Gross Domestic Product (GDP) growth, productivity remained on the sidelines of economic debates (De Negri; Cavalcante, 2014; Tsukada et al., 2024).

Brazil's sluggish productivity growth has become a major constraint on its economic advancement. Studies indicate that Brazilian workers take four times longer than their American counterparts and three times longer than German or South Korean workers to complete the same tasks or services, revealing a significant efficiency gap. This disparity underscores a critical productivity issue within the country (De Negri; Cavalcante, 2014; FGV, 2019). Several factors contribute to this productivity gap, including deficiencies in education, technology, infrastructure, and external competition (BBC, 2014).

Since the primary goal of profit-driven organizations is to generate revenue both now and in the future (Stefano et al., 2022), there is a fundamental need for efficient production systems that can transform resources into products or services that meet customer demands (Ikeziri et al., 2023). Companies face fierce competition both globally and in Brazil (Piran et al., 2021a).

In this context, enhancing operational performance is crucial for achieving profitability levels that ensure business consolidation (Zhang; Narkhede; Chaple, 2017; Sugiarto et al., 2023). Additionally, understanding customer behavior is essential, yet often challenging to predict, adding complexity and dynamism to business processes (Mohanavelu; Krishnaswamy; Marimuthu, 2017). In such a dynamic environment, flexibility in both companies and production processes becomes a key factor. The ability to respond swiftly to market changes is critical, driving companies to adopt agile and lean approaches in product development and manufacturing (Abdelouahed et al., 2023; Netland; Schloetzer; Ferdows, 2021).

An ideal manufacturing process would be perfectly synchronized with planned customer demand, eliminating inventory while maximizing resource utilization. This would create a system free of waste and inefficiencies (Land et al., 2021). However, it is important to acknowledge that this ideal is practically unattainable (Luz et al., 2022), due to the inherent variability within organizations (Hopp; Spearman, 2021).

To address these challenges, organizations across various industries have adopted a range of management practices and philosophies over the past decades. Lean Manufacturing (Lean), Total Quality Management (TQM), and the Theory of Constraints (TOC) are among the most prominent approaches, gaining significant attention in both academic and managerial circles. The manufacturing industry, in particular, has been shaped by two influential figures: Henry Ford and Taiichi Ohno. Ford revolutionized mass production with the introduction of assembly line systems, while Ohno advanced these concepts through the Toyota Production System (TPS), fundamentally shifting the industry’s perception of inventory from an asset to a liability (Goldratt, 2009).

Toyota’s success is largely attributed to the Toyota Production System (TPS), which initially gained global recognition as Just-In-Time (JIT) before evolving into what is now known as Lean Production. However, Toyota itself argues that Lean Production does not fully capture the essence of TPS due to misinterpretations and inconsistent implementations. According to Toyota’s management, the company’s primary challenge is to preserve TPS as its organizational DNA and effectively pass it on to future generations (Goldratt, 2009).

Organizations worldwide are showing a growing interest in adopting Lean Manufacturing, first in the industrial sector and more recently in the service industry. Implementing Lean in manufacturing enables organizations to optimize their processes by boosting production efficiency, enhancing product quality, reducing costs, and fostering a better work environment for employees (Vega-alvites, 2022).

However, most Lean implementations face significant challenges in fully achieving their efficiency goals (Hopp, 2018). Additionally, the success rate of this approach has been remarkably low (Hardcopf; Liu; Shah, 2021). This is not a new issue an *Industry Week* study found that only 2% of companies that adopted Lean Manufacturing successfully met their objectives (Liker; Rother, 2011). Similarly, research on British and Australian organizations across various industries concluded that fewer than 10% of those implementing Lean achieved a high level of performance (Baker, 2002). In the United States, a study of 433 companies revealed that only 26% saw significant improvements in their results after implementing Lean Manufacturing (Blanchard, 2007).

Given Toyota's prominence in Japanese industry, one might expect Lean Manufacturing to be widely implemented in Japan. However, it is well known that fewer than 20% of Japanese manufacturers have adopted Lean. Many companies in Japan have made considerable efforts to implement it, yet a significant number have failed (Goldratt, 2009).

The challenges in applying the Toyota Production System (TPS) across different production contexts stem from fundamental differences in manufacturing environments. When Taiichi Ohno developed TPS, it was specifically designed to meet the unique needs of his company. As a result, it is unsurprising that a system tailored to a particular setting may not deliver the same performance in vastly different production environments (Goldratt, 2009). However, this does not diminish the significance of Ohno's work in other contexts. His brilliance lies in his deep understanding of the challenges he encountered and his ability to develop a system that addressed them effectively (Goldratt, 2009).

One of the biggest challenges in implementing Lean Manufacturing within organizations is the lack of clear and effective performance indicators, a factor frequently cited as a critical obstacle (Marodin; Saurin, 2015). Among the most significant barriers to the adoption and long-term sustainability of Lean Manufacturing is the absence of tangible economic benefits in organizations that apply this approach (Costa et al., 2019; Kumar; Kumar, 2014; Schulze; Dallasega, 2023). This limitation can compromise both the efficiency and long-term viability of Lean Manufacturing.

In this context, assessing efficiency based solely on technical parameters such as production time and volume while neglecting economic factors significantly limits the information available for managerial decision-making. This limitation can hinder an organization's ability to accurately evaluate the economic impact of Lean Manufacturing, affecting its strategic implementation and long-term feasibility. Moreover, technical improvements resulting from Lean Manufacturing adoption do not inherently translate into economic benefits, as its effectiveness depends heavily on the specific context in which it is applied (Marodin; Saurin, 2015; Schulze; Dallasega, 2023).

The lack of clear integration between economic efficiency and Lean Manufacturing can greatly diminish the impact of its improvements, even when technical efficiency sees substantial gains. While continuous improvement and waste elimination are core pillars of Lean Manufacturing, these efforts do not always translate directly into economic benefits. Factors such as market fluctuations, indirect costs associated with implementing and sustaining Lean Manufacturing, and organizational barriers often impede the conversion of technical advancements into measurable economic outcomes (Qureshi et al., 2022). This challenge highlights the importance of a more holistic approach one that integrates both operational and economic dimensions to fully maximize the effectiveness and long-term impact of Lean Manufacturing within organizations.

The absence of an integrated perspective can result in narrow and inaccurate interpretations, leading to inefficient and ineffective operational practices in real-world applications (Watson; Blackstone; Gardiner, 2007). Moreover, this conceptual limitation hampers the development of a broader, more comprehensive theory for operations management (Land et al., 2021). The next section presents the research focus and problem, objectives, justifications, scope, and the overall structure of the study.

1.1 RESEARCH OBJECT AND PROBLEM

Amid intensifying global competition and rapid technological advancements, customer expectations have significantly increased, demanding higher quality, faster delivery times, lower costs, and more innovative products (Gupta et al., 2022). To achieve operational excellence, organizations are adopting various strategies, including continuous improvement (Gupta et al., 2022), innovation, and process and product optimization, all aimed at sustaining their competitive advantage (Dias; Silva; Tenera, 2019).

Enhancing production efficiency while reducing costs is a major challenge for organizations, particularly since competitiveness hinges on balancing fair pricing with high-quality products and services. In this context, adopting waste elimination strategies is crucial to achieving maximum operational efficiency (Alzubi et al., 2019). To address this, organizations seek to implement strategies that improve their production capacity, operational efficiency, product quality, and organizational resilience (Mohd Aripin et al., 2023). The literature highlights several methodologies for business process improvement, with Lean Manufacturing emerging as one of the most effective. Lean Manufacturing is strongly linked to continuous improvement and waste elimination in both manufacturing and service environments. This structured approach aims to streamline processes, lower costs, and boost organizational efficiency (Costa; Varejão; Gaspar, 2024; Memari et al., 2022).

Within this approach, four structured groups of practices, tools, and principles known as Lean Bundles stand out (Furlan; Vinelli; Pont, 2011; Pont; Furlan; Vinelli, 2009a). These bundles combine complementary elements that operate in a cohesive and synergistic way to reduce waste, improve operational efficiency, and support continuous improvement in production systems.

The Just-in-Time (JIT) bundle includes practices designed to ensure a continuous and efficient production flow, minimizing inventory and optimizing synchronization across production stages (Pont; Furlan; Vinelli, 2009a). O *bundle* de The Total Quality Management (TQM) bundle focuses on continuous improvement, ensuring high-quality products and processes by prioritizing customer satisfaction and defect reduction (Narasimhan; Swink; Kim, 2006). The Total Productive Maintenance (TPM) bundle aims to enhance equipment performance and reliability, leveraging predictive and preventive maintenance strategies to minimize downtime and maximize operational efficiency (Furlan; Vinelli; Pont, 2011a). Finally, the Human Resource Management (HRM) bundle encompasses practices that support organizational development, fostering employee engagement, skill enhancement, and strong leadership support—key factors in the successful implementation of Lean Manufacturing (Galeazzo; Furlan, 2018).

The literature widely documents successful implementations of Lean Manufacturing across various sectors and organizational environments (Elkhairi; Fedouaki; El Alami, 2019). Among its key benefits are shorter lead times, higher customer satisfaction, enhanced employee motivation, and stronger supplier relationships (Vega-Alvites, 2022). However, the effectiveness of Lean Manufacturing implementation is influenced by several critical factors that directly impact its success rate (Marodin; Saurin, 2015; Bortolotti; Boscari; Danese, 2015; Marodin et al., 2018; Sahwan; Rahman; Deros, 2012; Spear; Bowen, 1999).

The work of Spear e Bowen (1999) identify four essential conditions for the successful implementation of Lean Manufacturing in organizations: (i) Standardized work to ensure consistency and efficiency; (ii) Clearly defined responsibilities at every level of the organizational structure; (iii) Simple and precise process specifications to facilitate execution and improvement; e (iv) Empowerment of operational-level employees through delegated authority.

Organizational culture plays a critical role in the adoption of Lean Manufacturing, acting as a key differentiator between organizations that successfully implement it and those that struggle. This is the central focus of the research by (Bortolotti; Boscari; Danese, 2015), which underscores the importance of structured preparation for a successful Lean Manufacturing adoption. To support this process, they propose a set of essential practices, including: (i) Multifunctional training; (ii) Formation of cross-functional teams; (iii) Top management leadership committed to quality; (iv) Establishing collaborative relationships with customers and suppliers; e (v) A strong focus on continuous improvement (Bortolotti; Boscari; Danese, 2015). This approach highlights the need for a structured and culturally aligned strategy to maximize the effectiveness of Lean Manufacturing, reinforcing the importance of careful planning and organizational commitment in its implementation.

However, the findings of these studies cannot be universally applied (Marodin et al., 2019). The limited success of Lean Manufacturing implementation in organizations is often linked to several factors, with one of the most significant being the overlooking of essential prerequisites required for its effective adoption. In this context, there is a common assumption that Lean Manufacturing principles can be implemented uniformly across all organizations. Research on barriers to Lean Manufacturing implementation highlights key challenges related to sociocultural dynamics, technical and economic factors, and organizational control systems.

A study by Sahwan, Rahman e Deros (2012), conducted across 250 automotive companies in Malaysia, identified 18 key barriers to Lean Manufacturing implementation. Among the most significant challenges were insufficient employee training to support the process and low managerial commitment, both of which posed major obstacles to the successful adoption of Lean Manufacturing.

The study by Marodin e Saurin (2015) explores the relationship between barriers to Lean Manufacturing implementation and contextual factors. They note that the nature, origins, interconnections, and relative importance of these barriers remain insufficiently understood. The barrier list presented in their research is derived from a systematic literature review rather than an empirical case study analysis. Additionally, (Marodin; Saurin, 2015) do not clearly define the criteria used for selecting contextual factors.

To better understand the challenges associated with Lean Manufacturing implementation in both manufacturing and service sectors, it is essential to highlight research that identifies the lack of economic benefits as a major barrier to the continuation and sustainability of this approach within organizations (Bhasin, 2012; Frankowska; Czerniachowicz, 2020; Kumar; Kumar, 2014; Schulze; Dallasega, 2023; Staudacher; Tantardini, 2007). Moreover, the absence of clear performance indicators is frequently cited as a significant obstacle in the Lean Manufacturing implementation process (Marodin; Saurin, 2015).

In this context, efficiency analysis that focuses solely on technical components (such as time and physical quantities) while overlooking economic factors limits the information available for managerial decision-making within organizations. Many companies measure efficiency using the ratio of actual working hours to available working hours (De Souza et al., 2018). Alternatively, some organizations prefer to use the Overall Equipment Effectiveness (OEE) indicator (Dobra; Jósvai, 2022). Initially developed for manufacturing, OEE was primarily applied within Total Productive Maintenance (TPM) to assess equipment performance in production (Corrales et al., 2020).

The Overall Equipment Effectiveness (OEE) indicator measures a machine's actual performance against its expected performance, incorporating three key components: (i) performance, (ii) quality, and (iii) availability and/or utilization (Corrales et al., 2020; Dobra; Jósvai, 2022; Lanza et al., 2013). However, it is important to recognize that relying solely on the ratio of worked hours to available hours, or even OEE itself, is often insufficient for informed decision-making aimed at enhancing overall efficiency (Andersson; Bellgran, 2015; De Souza et al., 2018).

Building on OEE, several additional techniques have been developed for efficiency analysis, as outlined in Table 1 below.

Table 1 - Efficiency Analysis Techniques

Indicator	Indicator Description	Analysis unit	Authors
Global Production Effectiveness (GPE)	It uses a sequence of individual measurements combined to determine system performance after each integration between processes.	Factory	Lanza et al. (2013)
Equipment Performance Reliability (EPR)	Measures the reliability of the equipment, related to its ability to meet the technical characteristics for which it was designed.	Equipment	Muchiri and Pintelon (2008)
Overall Throughput Effectiveness (OTE)	Used to measure factory performance and identify bottlenecks and hidden capabilities.	Factory	Muthiah and Huang (2007)
Overall Factory Effectiveness (OFE)	Measures combined activities in which there is a relationship between different machines and equipment.	Production cells	Oechsner et al. (2002)
Overall Asset Effectiveness (OAE)	Performance metric used to assess the utilization and efficiency of assets in a manufacturing or operational environment..	Factory	Neely, Gregory and Platts (2002)
Overall Plant Effectiveness (OPE)	It proposes measuring the actual outputs of the factory in relation to the predicted outputs.	Factory	Scott and Pisa (1998)
Capacity Utilization Bottleneck (CUB)	Measures the output of the bottleneck in relation to the theoretical production that it should be producing.	Equipment	Konopka (1995)
Production Equipment Effectiveness (PEE)	It uses the same OEE indicators, however, it assigns different weights to each of them, according to the importance of each one in the process in which it is being measured.	Factory	Raouf (1994)

Source: Piran, Lacerda and Camargo (2018).

While technical efficiency analysis is crucial in practical applications, it is often insufficient, as most managers require broader insights that also consider economic factors (Piran et al., 2021b). Some studies have advanced efficiency analysis by moving beyond time-based measurements and incorporating physical quantity variables, such as raw materials (Barbosa et al., 2017; De Souza et al., 2018; Piran et al., 2016; Von Gilsa et al., 2017). However, it is important to recognize that these analyses have limitations, as they do not fully account for economic considerations.

Analyses that incorporate economic efficiency offer a more comprehensive perspective, considering not only technical efficiency but also identifying the optimal combination of inputs and outputs to minimize costs or maximize revenue and profit (Aparicio et al., 2013; Piran et al., 2021b). A purely technical evaluation can narrow a manager's perspective on potential system improvements, potentially leading to missed cost-reduction opportunities, as highlighted by economic analyses.

A manager may perceive their operation as technically efficient, which can lead to overlooking the need for improvement initiatives that could further enhance the organization's economic performance. This perception is often driven by the assumption that technical efficiency alone inherently results in economic efficiency.

Against this backdrop, this study seeks to address the following research question: Does continuous improvement invariably lead to increased economic efficiency?

1.2 GENERAL AND SPECIFIC OBJECTIVES

This section presents the general objective and the specific objectives of the study.

1.2.1 General Objective

The general objective is to establish economic efficiency and the key conditions for achieving it as a foundation for evaluating continuous improvement initiatives in production systems.

1.2.2 Specific Objectives

To achieve the general objective of the research, the following specific objectives will be pursued:

- Explore the relationship between continuous improvement, technical efficiency, and economic efficiency within the framework of Lean

Manufacturing, analyzing how the key underlying assumptions of this relationship have evolved over time;

- Assess the validity of Lean Manufacturing’s assumptions, principles, and techniques in supporting the hypothesis that continuous improvement enhances economic efficiency;
- Compare the performance of Lean Manufacturing and the Theory of Constraints (TOC) in a single-product automotive production line designed based on Lean Manufacturing principles;

The following section presents the justifications supporting this study.

1.3 JUSTIFICATIONS

The core focus of this study is to investigate and understand the impact of continuous improvement and technical efficiency on economic efficiency in manufacturing systems. Organizations that embrace continuous improvement—both in manufacturing and services—are more likely to achieve their quality, delivery performance, lead time reduction, and cost minimization goals, ultimately enhancing customer satisfaction. By driving process optimization, waste elimination, and operational efficiency, continuous improvement plays a pivotal role in strengthening competitiveness and ensuring long-term organizational sustainability. Therefore, maintaining a structured continuous improvement process is fundamental to fostering more efficient, innovative, and sustainable operations over time.

The lack of a continuous improvement process in manufacturing systems can have severe consequences, directly affecting an organization's competitiveness, operational efficiency, and long-term sustainability. Some of the most significant impacts include: (i) Reduced competitiveness; (ii) Increased operational costs; (iii) Compromised product and service quality; e (iv) Decline in productivity and efficiency (Costa et al., 2019; González Aleu; Garza-Reyes, 2020). Without continuous improvement initiatives, organizations risk stagnation, compromising their growth and long-term viability. Therefore, cultivating an organizational culture that prioritizes continuous improvement is crucial for fostering innovation, optimizing efficiency, and maintaining a competitive edge in an increasingly dynamic and globalized market.

Understanding continuous improvement from an economic perspective is essential, as it allows organizations to not only streamline operations but also align improvements with maximizing economic outcomes. While continuous improvement is often linked to technical efficiency, such as reducing cycle times and eliminating waste, its economic impact must also be considered. Without this perspective, operational advancements may fail to deliver meaningful financial benefits, potentially undermining return on investment.

By integrating economic efficiency into the continuous improvement approach, organizations can strategically allocate investments toward initiatives that drive sustainable economic returns, fostering a more results-oriented management approach. Furthermore, incorporating economic considerations enables companies to prioritize high-impact initiatives, such as reducing indirect costs, optimizing resource utilization, and maximizing investments in innovative technologies.

This integrated approach facilitates more informed decision-making, ensuring a balanced focus on both operational and economic efficiency. As a result, organizations not only optimize internal performance but also reinforce their competitive position, driving long-term sustainable growth. Within this framework, this study outlines the key contributions identified throughout the research, emphasizing both theoretical insights and practical advancements.

The first key contribution of this study is a literature review that explores Lean Manufacturing through the lens of continuous improvement and technical efficiency, highlighting the economic benefits generated by manufacturing systems within organizations. Research on Lean Manufacturing applications is broad and extensive, spanning multiple sectors, including manufacturing, healthcare, construction, services, and environmental management. Rather than being widely recognized as a comprehensive approach to improving technical efficiency, Lean Manufacturing is primarily viewed as a strategy for waste reduction (Hopp; Spearman, 2021).

Thus, the existing literature falls short in addressing the continuous improvement process and the transition from technical efficiency to economic efficiency within manufacturing systems. A literature review on this topic could make a significant contribution by identifying gaps and guiding future research, both theoretical and empirical, on the limitations of continuous improvement and technical efficiency as proposed by Lean Manufacturing, particularly from the perspective of economic efficiency in manufacturing systems. Furthermore, this literature review reinforces the originality of this thesis.

The second key contribution of this study is the modeling of a production line using System Dynamics (SD), initially designed to operate under Lean Manufacturing principles. The production line was originally conceived with 100% technical efficiency; however, once operations began, process variability emerged, reducing its capacity below customer demand. To address this challenge, compensatory measures were implemented, including introducing intermediate stock, adding extra shifts, and increasing the number of operators in the production flow all aimed at balancing production capacity with demand.

In this context, System Dynamics-based modeling, combined with the Drum-Buffer-Rope (DBR) approach, enabled a comparative analysis of the impacts of Lean Manufacturing and the Theory of Constraints (TOC). This approach helped identify the key factors behind the superior performance of DBR-TOC over Lean Manufacturing, as demonstrated in the case study. Although the production line was originally designed to operate with balanced capacity under Lean Manufacturing principles, significant variations in production resource capacity were observed in practice.

The lack of protective mechanisms in the system, particularly the absence of strategic inventory, made production highly vulnerable to constraints imposed by the lowest-capacity resource. As a result, overall system efficiency became entirely dependent on the multiplication of individual resource efficiencies. In contrast, the strategic introduction of inventory, as advocated by TOC, at key points in the production flow, helped absorb fluctuations in resource capacity, ensuring a consistent supply to the constraint resource. As a result, the system became susceptible only to variability associated with the constraint resource, minimizing disruptions and reducing the negative impact on overall production performance.

The third key contribution of this research is its assessment of whether the variabilities present in the production system enable the full implementation of Lean Manufacturing principles, as suggested in the literature. Attempting to eliminate all sources of variability within the system is cost-inefficient, indicating that a more effective approach is the strategic placement of a buffer at the constraint, as proposed by (Gupta et al., 2022), to safeguard system stability.

A fourth key contribution of this study is the implementation of dynamic buffer management. Without continuous monitoring, protective buffers can exceed the necessary levels, leading to overprotection and inefficiencies that do not align with the desired output rate. Therefore, once buffers are established, it is essential to regularly monitor and adjust them to ensure consistent throughput generation within the production system. System Dynamics modeling plays a crucial role by allowing for buffer visualization and optimization before actual implementation. As the product mix expands, the need for System Dynamics modeling, continuous buffer evaluation, and ongoing assessment of implementation outcomes becomes even more critical.

The fifth key contribution of this study is the empirical support it provides for comparative analyses between Lean Manufacturing and the Theory of Constraints (TOC). Through meticulous control of competing factors, this research enables the isolation of variables, ensuring that the results accurately reflect the impact of the applied theoretical models. It is important to note that the objective is not to position TOC as superior to Lean Manufacturing, but rather to expand the discussion and research on the critical requirements for effective Lean Manufacturing implementation, ensuring it achieves the expected outcomes.

The benefits of the Theory of Constraints (TOC) have been widely explored in the literature. However, the sixth key contribution of this study lies in its empirical focus, enabling a comparative evaluation with controlled external variables. This approach effectively isolates the outcomes of DBR (Drum-Buffer-Rope) within TOC and Lean Manufacturing, with particular attention to the Heijunka concept. As a result, the empirical evidence collected enhances the reliability of the expected outcomes for both Lean Manufacturing and TOC, providing a more precise and controlled framework for comparing these methodologies.

The seventh contribution of this research, providing an additional managerial perspective, is closely tied to the advantages of System Dynamics. The positive outcomes achieved through this model helped mitigate resistance to adopting the DBR (Drum-Buffer-Rope) approach in manufacturing, while also allowing for the simulation of multiple scenarios before actual implementation. This study reinforces efficiency metrics and validates the benefits of DBR implementation in the production line, highlighting its potential for replication in other production lines with similar characteristics. This model serves as a strong foundation for informed decision-making, particularly in managing urgent orders, as it ensures greater stability in the production line's output.

The eighth contribution of this study is the application of DBR (Drum-Buffer-Rope), followed by an evaluation of its impact on economic efficiency over time, considering the variables present in the model. While numerous studies have explored

DBR outcomes (Darlington et al., 2015; Puche et al., 2019; Telles et al., 2020), no recorded applications have assessed economic efficiency using Data Envelopment Analysis (DEA) in the context of DBR implementation. By integrating DBR implementation analysis with a DEA-based evaluation of economic efficiency, this study fills a gap in the existing literature, offering a significant theoretical contribution to the field.

The ninth key contribution of this research is its support for efficiency measurements and the validation of the benefits derived from DBR implementation in the studied production line. Presenting the results to company specialists led to their confirmation, reinforcing the feasibility of adopting DBR in future projects. While analyzing individual results based on a single parameter is relatively simple, assessments involving multiple parameters where the combination of inputs significantly impacts outcomes require specialized tools to support the evaluation process effectively.

By leveraging productive efficiency results, managers can define and quantify goals to improve organizational performance, establishing a strong foundation for ensuring the business's sustainability in both the short and long term. Moreover, managers typically favor information that integrates economic considerations into the decision-making process (Hatami-Marbini; Arabmaldar, 2021).

1.4 RESEARCH DELIMITATIONS

The delimitations of this study are defined to refine its scope and ensure analytical precision. First, the literature review on continuous improvement, Lean Manufacturing, and efficiency excludes studies in finance, healthcare, and environmental analysis, focusing solely on manufacturing and service processes.

Second, this research will be conducted within a for-profit company, focusing on a discrete manufacturing system, thereby excluding continuous production processes. The third delimitation relates to performance indicators, which will focus on operational performance and manufacturing system efficiency. Consequently, financial metrics such as revenue and profit will not be included in the analysis. The fourth delimitation specifies that case studies will be applied exclusively to manufacturing systems, without extending to service system processes.

Finally, the fifth delimitation concerns the practical intervention of this study, which is conducted in an automotive production line, specifically focusing on the welding process. The manufacturing of components and the painting process are beyond the scope of this research.

1.5 THESIS STRUCTURE

The study consists of a thesis supported by articles and is structured into six chapters. Chapter 1 presents the introductory aspects, while Chapter 2 describes the research methodology and procedures. Chapters 3, 4, and 5 contain the structured research articles, based on the methodological procedures outlined in the study.

The first article (Chapter 3) presents a systematic literature review that examines the relationship between continuous improvement and economic efficiency from the perspective of Lean Manufacturing. Additionally, it explores how the key underlying assumptions shaping this relationship have evolved over time.

The second article (Chapter 4) presents an intervention-based study conducted in a manufacturing company to compare the effectiveness of Lean Manufacturing principles and the Theory of Constraints (TOC) in synchronizing production within an automotive assembly line. System Dynamics (SD) modeling played a key role in developing and analyzing comparative scenarios.

The third article (Chapter 5) presents a case study that empirically examines the impact of continuous improvement on economic efficiency. To this end, the study evaluates the effects of implementing the Drum-Buffer-Rope (DBR) system on the economic efficiency of an automotive company's production process. These effects were assessed over time using Data Envelopment Analysis (DEA). The article aims to explore DBR's effectiveness as a management approach that not only meets performance objectives but also provides valuable insights to drive continuous process improvement.

Finally, Chapter 6 presents the conclusions, limitations, research discussions, and suggestions for future studies.

2 METHODOLOGICAL PROCEDURES

Design Science Research (DSR), is a methodological approach focused on solving complex problems through the design, development, and evaluation of innovative artifacts. Its primary goal is to generate knowledge that is both applicable and useful while maintaining a balance between academic rigor and practical relevance. Unlike purely descriptive or explanatory methods, DSR takes an interventionist approach, emphasizing the creation of solutions as a means to better understand and refine the phenomena under investigation (GAUSS et al., 2024).

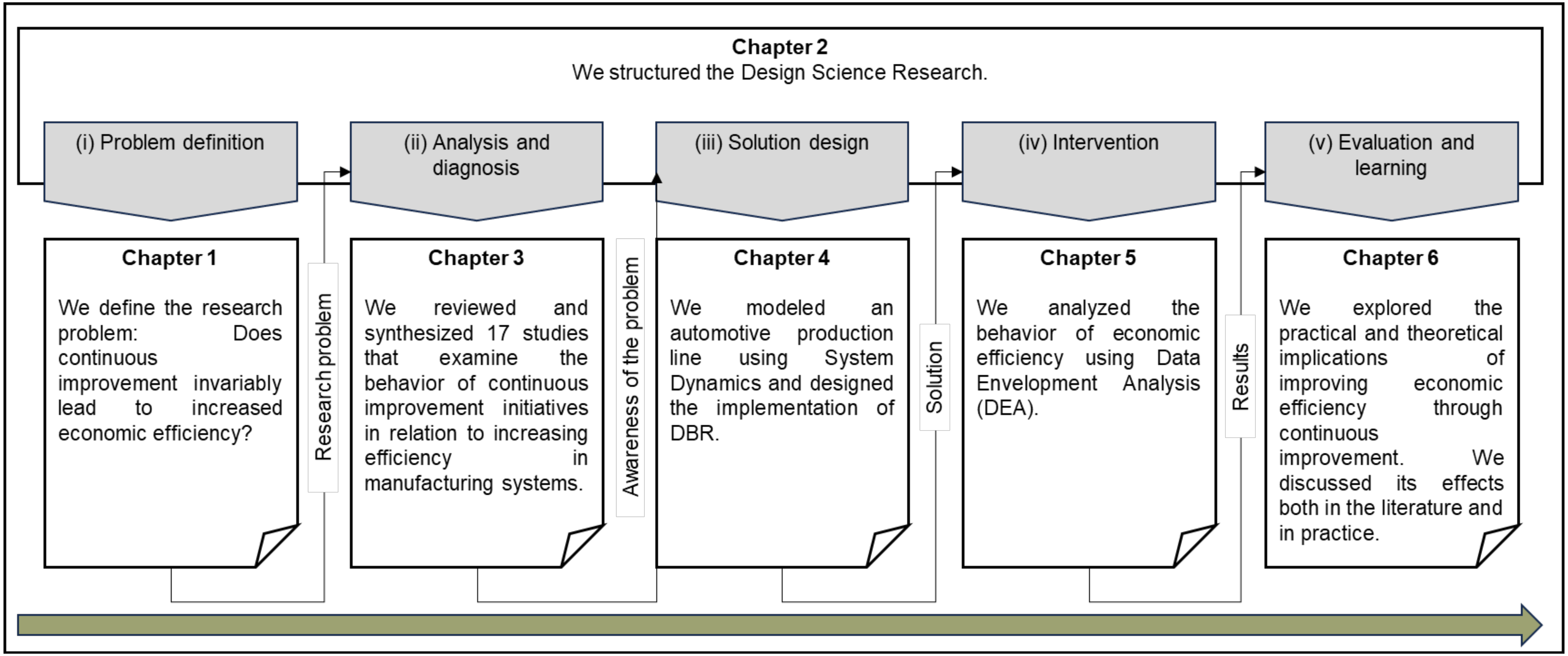
Beyond facilitating the implementation of solutions in real-world contexts, DSR plays a crucial role in advancing theoretical knowledge by integrating artifact creation with scientific foundations. This methodology not only addresses practical challenges but also enriches the existing body of knowledge, bridging the gap between academic research and professional practice. Its pragmatic and innovative nature makes DSR a valuable approach in fields such as information technology, engineering, and management, where the demand for effective and well-grounded solutions remains constant (Romme, 2003).

2.1 WORK METHOD

This study aims to generate both scientific and applied knowledge by integrating theoretical development with direct practical engagement. By adopting this approach, it not only advances the theoretical foundations of the field but also enhances the relevance and applicability of its findings in professional settings (van Aken, 2004; Romme, 2003).

The research follows the problem-solving cycle proposed by Van Strien (1997) and further developed by Van Aken e Berends (2018) for management science research. The problem-solving cycle consists of five key stages: (i) Problem definition; (ii) Analysis and diagnosis; (iii) Solution design; (iv) Intervention e (iv) Evaluation and learning. Each stage of the research aligns with a specific phase of the problem-solving cycle and corresponds to one or more chapters of this study. The sequential execution of these stages establishes a logical flow between the chapters, as illustrated in Figure 1.

Figure 1 - Work method



Source: Prepared by the author.

2.1.1 Problem Definition (Chapter 1)

Chapter 1 defines the research problem explored in this study, emphasizing the importance of efficiency and productivity—topics widely debated in academic, governmental, and business spheres. Their relevance is reinforced by their direct impact on the economic development of a region and, ultimately, a nation (Kerstens; Sadeghi; Van De Woestyne, 2019; Piran; Lacerda; Camargo, 2020).

The literature offers a diverse array of approaches designed to enhance efficiency in manufacturing systems. Among these, continuous improvement emerges as a key principle of Lean Manufacturing, widely regarded as one of the most effective strategies for boosting operational efficiency.

Against this backdrop, this section formulates the research problem, seeking to answer the following question: Does continuous improvement invariably lead to increased economic efficiency? With the problem definition established, the study moves to the next phase: analysis and diagnosis.

2.1.2 Analysis and Diagnosis (Chapter 3)

Chapter 3 outlines the analysis and diagnosis phase, following the approach proposed by (Ermel et al., 2021). This section reviews the existing literature on key aspects of the research question, drawing from 17 selected publications on continuous improvement and efficiency. The goal is to provide insights that contribute to addressing the investigated problem.

The literature review explores approaches and strategies aimed at enhancing continuous improvement and efficiency in manufacturing systems. A key objective of this study is to investigate whether technical efficiency translates into economic efficiency with the same intensity, while also analyzing the factors that influence this relationship.

2.1.3 Solution Design (Chapter 4)

The solution design, presented in Chapter 4, aims to conduct a comparative analysis of the application of Lean Manufacturing and Theory of Constraints (TOC) principles for production synchronization in an automotive assembly line. In this case, the manufacturing environment is highly favorable and well-suited for implementing

Lean Manufacturing, with no significant challenges related to component and material supply, demand variability, or product mix. The demand is stable and predictable, and the production line is designed to manufacture a single sales code.

Furthermore, the line was designed, implemented, and operated with strict adherence to Lean Manufacturing principles. All equipment is newly acquired and was specifically selected for this project, ensuring efficient operations free from obstacles that could compromise the effective implementation of Lean Manufacturing.

For comparative purposes, System Dynamics (SD) modeling was employed to develop scenario-based analyses. System Dynamics (SD) was selected for its ability to provide a macro-level perspective of systems, facilitating strategic decision-making (Law, 2014). The integration of TOC and SD as a tool for managing complex decision-making is also highlighted in the research of (Hilmola; Gupta, 2015).

2.1.4 Intervention (Chapter 5)

Chapter 5 examines the application of the Theory of Constraints (TOC) and Drum-Buffer-Rope (DBR) in manufacturing systems as an alternative approach to enhancing economic efficiency. While most studies focus on improving technical efficiency, research on economic efficiency remains scarce in the literature. Moreover, managers often prioritize information that considers economic factors in the decision-making process, as technical efficiency improvements do not always lead to economic gains (Piran et al., 2021).

Leveraging productive efficiency results, managers can set and quantify goals to enhance organizational performance, ensuring the long-term sustainability of the business. Furthermore, managers often prioritize information that integrates economic factors into the decision-making process (Hatami-Marbini; Arabmaldar, 2021).

Therefore, this study examines the impact of DBR implementation on the economic efficiency of the manufacturing process in an automotive production line. These effects were assessed over time through a longitudinal case study using Data Envelopment Analysis (DEA).

2.1.5 Evaluation and Learning (Chapter 6)

Finally, during the evaluation and learning phase, the conclusions from previous studies were synthesized, discussed, and presented in Chapter 6. This chapter delves into the theoretical and practical implications of the findings and offers guidelines for future research.

3 LEAN MANUFACTURING: A NECESSARY YET INSUFFICIENT PATH TO ECONOMIC EFFICIENCY?

Authors: Lúcio C. Noal a*, Daniel P. Lacerda a*

[a] *Post-Graduate Program in Production Engineering and System – PPGEPS/UNISINOS, Research Group on Modeling for Learning – GMAP / UNISINOS, Av. Unisinos, 950 – Bairro Cristo Rei, São Leopoldo, RS, 93.022-000,Brazil*

Abstract: The continuous improvement of production systems has been a key priority for decades. Productivity and efficiency remain central to economic development and are widely discussed across academia, business, and government. *Productivity isn't everything, but, in the long run, it is almost everything.* This well-known principle highlights the crucial role of long-term productivity as a primary driver of economic growth. To meet the ongoing demand for enhanced performance, manufacturing systems increasingly rely on continuous improvement practices as a fundamental strategy for operational optimization. Within this framework, Lean Manufacturing emerges as a structured approach to continuous improvement, emphasizing waste elimination and value creation for the customer. A widely accepted assumption within this methodology is that every improvement initiative inevitably results in economic benefits. However, research suggests that this relationship is not always linear or guaranteed. There are documented cases where the application of continuous improvement principles has led to unexpected or even counterproductive outcomes, challenging the conventional belief that operational efficiency gains automatically translate into economic benefits. This issue was already anticipated during the development of the Toyota Production System (TPS), which warned against the risks of a rigid, mechanistic implementation of Lean practices without proper adaptation to the organizational context. Despite this, the specific conditions under which productivity and technical efficiency gains from Lean Manufacturing translate into economic efficiency remain relatively underexplored. While a significant body of research highlights the benefits of Lean Manufacturing, many companies still struggle to sustain its implementation over time, pointing to gaps between theory and practice. Given this context, this study aims to examine the relationship between Lean Manufacturing and its impact on economic efficiency. The primary contribution of this research lies in questioning the causal link between technical efficiency, achieved through Lean Manufacturing, and its necessity for attaining economic efficiency. To explore this relationship, the Literature Grounded Theory (LGT) approach was applied, identifying 17 publications that examine the intersection between Lean Manufacturing and economic efficiency. Through content analysis, the study identified the conditions under which technical efficiency improvements can effectively translate into economic efficiency. The findings reveal that improvements in technical efficiency do not always lead to proportional economic gains. Lean Manufacturing, through its tools and methodologies, is predominantly geared toward enhancing technical efficiency, with a strong focus on waste reduction and process optimization. However, converting these technical improvements into sustainable economic outcomes requires a more comprehensive approach one that considers additional factors and the complex interactions that define production systems. These insights underscore the need for a strategic perspective in Lean Manufacturing implementation, ensuring that its practices align not only with operational efficiency but also with the broader economic and long-term objectives of organizations.

Keywords: Lean Manufacturing; Continuous Improvement; Economic Efficiency; Systematic Literature Review; Strategic Perspective.

3.1 INTRODUCTION

Intensifying global competition, coupled with rapid technological advancements, has significantly heightened consumer expectations regarding key attributes such as high quality, shorter lead times, lower costs, and increased product innovation (COSTA; VAREJÃO; GASPAR, 2024; GUPTA et al., 2022b). For-profit organizations primarily aim to generate profit in both the short and long term (Stefano et al., 2022; Goldratt; Cox, 2014). To achieve this objective, these organizations must operate efficient production systems capable of converting diverse resources such as materials, labor, and energy into products or services that effectively meet market demands (IKEZIRI et al., 2023a). To enhance operational excellence, companies have adopted various strategies, with continuous improvement (GUPTA et al., 2022a), innovation, and process and product optimization emerging as key practices (FOUND et al., 2018). These efforts are designed to sustain and strengthen competitive advantages in an increasingly dynamic marketplace (DIAS; SILVA; TENERA, 2019).

One of the primary challenges in modern manufacturing is optimizing production processes to reduce costs while maintaining a competitive edge. Competitiveness is inherently tied to striking a balance between fair pricing and high-quality products and services. Therefore, implementing strategies that eliminate waste and maximize operational efficiency is crucial (ALZUBI et al., 2019). Moreover, organizations are increasingly adopting strategies to enhance their production capacity, improve operational efficiency, elevate product quality, and strengthen organizational resilience. These efforts are essential for ensuring long-term sustainability and maintaining a competitive position in the global market (Mohd Aripin et al., 2023).

Despite advancements in technology, improving production flow remains a significant challenge. While the need to accelerate production processes is widely acknowledged, many organizations lack structured approaches to effectively identify the root causes of disruptions, which can lead to undesired inventory buildup and reduced operational efficiency (LAND et al., 2021a). In response, managers often turn to well-established production management frameworks such as *Lean Manufacturing* (LM) rather than conducting a deeper analysis of the underlying causes of manufacturing system inefficiencies (LAND et al., 2021a). At its core, *Lean Manufacturing* prioritizes waste elimination as a fundamental principle (PUCHE et al., 2019a). Within manufacturing system management, LM employs tools like *Kanban*, particularly in production and distribution systems that follow the *Just-in-Time* (JIT) approach, where replenishment orders are issued based on demand (PUCHE et al., 2019a). However, efficiency improvements are only truly valuable when directly linked to cost reduction (Ohno, 1997).

The literature extensively highlights successful cases of *Lean* implementation across various industries and organizational contexts (Tortorella et al., 2015Elkhairi; Fedouaki; El Alami, 2019; Reponen et al., 2021). Among the key benefits of *Lean* adoption are shorter lead times, increased customer satisfaction, higher employee motivation, and improved supplier relationships (VEGA-ALVITES, 2022). However, these outcomes cannot be universally applied to all organizational settings (Marodin et al., 2019). Moreover, the majority of companies struggle to implement *Lean* successfully (ALBLIWI et al., 2014; SECCHI; CAMUFFO, 2019). A major challenge in *Lean* adoption is the absence of sustained economic benefits, which continues to be a significant barrier to its long-term success within organizations (Staudacher; Tantardini, 2007; Bhasin, 2012; Kumar; Kumar, 2014; Frankowska; Czerniachowicz, 2020; Schulze; Dallasega, 2023).

Lean Manufacturing exemplifies a continuous improvement approach focused on eliminating waste and creating value for the customer (Mohd Aripin et al., 2023; Narassima et al., 2023). A widely held assumption in this methodology is that every continuous improvement initiative will inevitably generate economic benefits. However, the literature suggests that this relationship is neither always linear nor guaranteed. Studies have documented cases where continuous improvement efforts have led to unexpected or even counterproductive outcomes (BHASIN, 2013). Taiichi Ohno had already anticipated this issue during the development of the Toyota Production System (TPS), cautioning against the risks of a rigid, mechanistic implementation of Lean practices without proper adaptation to the organizational context (OHNO, 1997).

The absence of economic benefits is directly linked to the economic efficiency of operations, which, in turn, depends on the technical efficiency of manufacturing systems. Koopmans (1957) introduced the concept of technical efficiency, defining it as a measure based on physical quantities recorded at the systemic level. Technical efficiency represents an organization's, process's, or system's ability to maximize output whether in the form of goods or services while minimizing resource consumption (Ayouba et al., 2019). *Lean* tools are explicitly designed to enhance technical efficiency in manufacturing systems by systematically reducing waste within processes (Galeazzo; Furlan, 2018; Ferrazzi et al., 2024; Psarommatis; Azamfirei, 2024) .

Economic efficiency, which encompasses costs, revenues, and profits, is commonly divided into technical efficiency and allocative efficiency. While technical efficiency measures a system's ability to maximize output or minimize input for a given level of resources or production, allocative efficiency evaluates how effectively the mix of inputs or products aligns with the optimal combination to minimize costs or maximize revenues and profits (OH et al., 2010; VENKATESH; KUSHWAHA, 2018). In the analysis of economic efficiency, Farrell's (1957) approach follows a two-step process. First, technical efficiency is assessed, indicating how close a company is to the efficient frontier. Next, allocative efficiency is determined by examining whether resources such as capital and labor are allocated in the ideal proportions to minimize costs or maximize returns (Aparicio et al., 2015; Cesaroni; Giovannola, 2015; Jradi; Bouzdine Chameeva; Aparicio, 2019). When it comes to efficiency, *Lean* primarily focuses on optimizing technical efficiency, viewing economic efficiency as a resulting outcome rather than the core objective of the process (Schulze; Dallasega, 2023).

In this context, evaluating efficiency solely based on technical factors, such as time and physical quantities, while overlooking economic considerations, restricts the information available for effective managerial decision-making. Many organizations measure efficiency by calculating the ratio of hours actually worked to the total available hours (De Souza et al., 2018). Alternatively, some companies rely on the Overall Equipment Effectiveness (OEE) indicator, originally developed for manufacturing and widely applied within the framework of Total Productive Maintenance (TPM). This metric assesses the performance of operating equipment, providing valuable insights for identifying technical improvement opportunities within the manufacturing system (DOBRA; JÓSVAI, 2022).

This study seeks to clarify the relationship between *Lean Manufacturing* and continuous improvement, emphasizing their contributions to technical efficiency and their impact on economic efficiency in production processes. A total of 272 studies were identified, and following a rigorous screening process, 17 scientific articles were selected for in-depth analysis. The findings reveal that while the link between *Lean Manufacturing* and technical efficiency is explicitly explored in the literature, its connection to economic efficiency is often only implied.

The primary theoretical contributions of this study lie in its holistic examination of the relationship between *Lean Manufacturing bundles*, technical efficiency, and economic efficiency, offering an integrated perspective on these elements within production systems. Furthermore, it investigates the correlation between moderating factors and technical efficiency, analyzing the extent to which these factors positively or negatively affect economic efficiency. Finally, this research provides a comprehensive evaluation of the impact of *Lean bundles* tools on key *Lean Manufacturing* indicators, presenting a structured framework to better understand their effectiveness and implications for production performance.

Additionally, this study challenges the assumption that technical efficiency directly translates into economic efficiency. The research was conducted using the *Literature Grounded Theory* (LGT) methodology. According to (Ermel, 2020), the primary objective of LGT is to generate knowledge through a comprehensive review, analysis, and synthesis of scientific and technological research. This article is structured as follows: the next section outlines the methodological procedures of the study; Section 3 presents the analysis of the results; Section 4 discusses the findings;

and finally, Section 5 provides the concluding remarks followed by references and appendices.

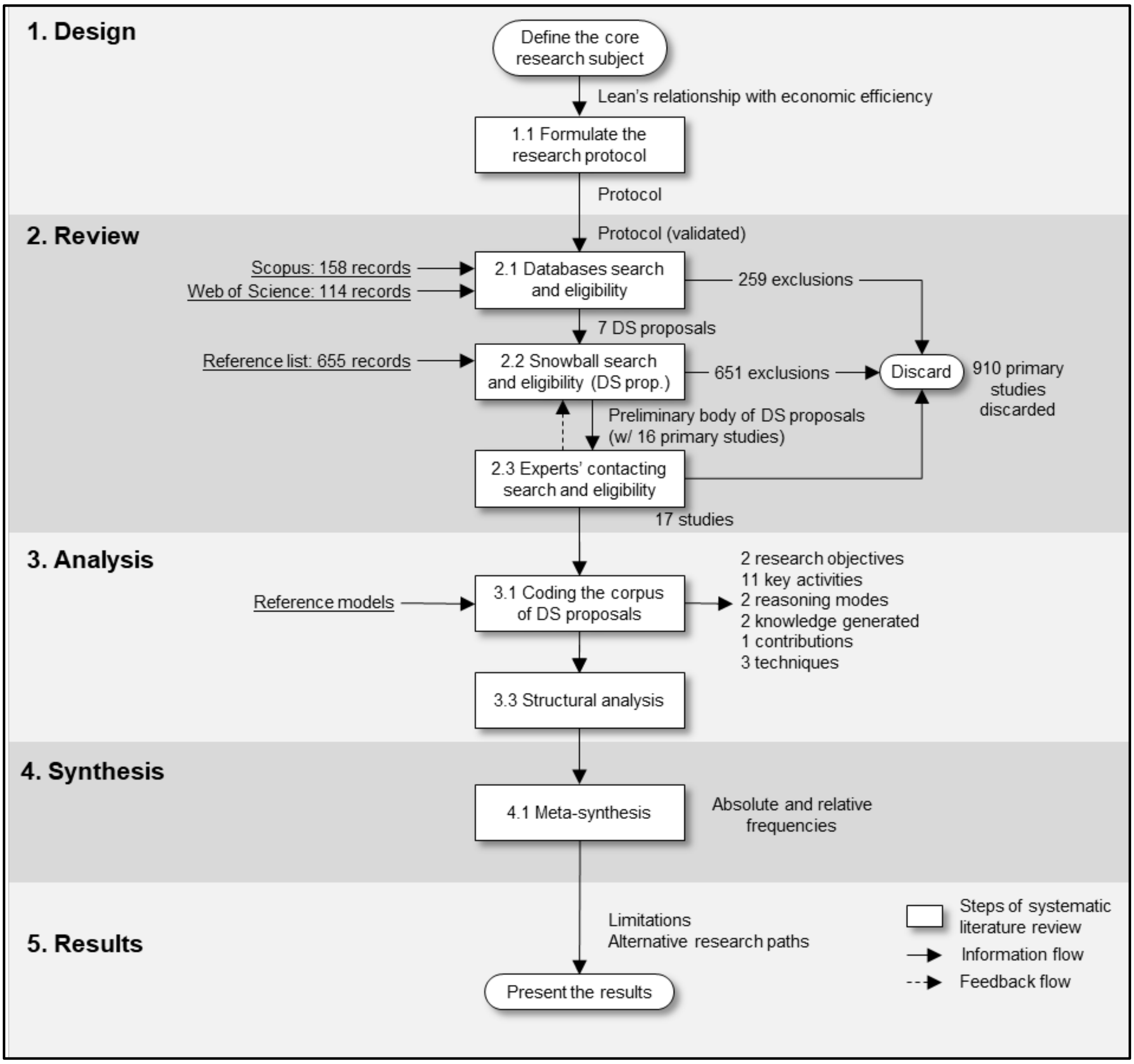
3.2 METHODOLOGICAL PROCEDURES

The literature review plays a vital role in establishing a strong foundation for advancing knowledge, fostering theoretical development, bridging gaps in well-explored research areas, and identifying topics that require further investigation (WEBSTER; WATSON, 2002). The findings from this systematic review offer fresh insights into the subject and contribute to the advancement of research in the field. This study employs the *Literature Grounded Theory* (LGT) method, which aims to generate knowledge through systematic review, analysis, and synthesis (Ermel, 2020).

In the sequence, a research protocol was developed, as outlined in Appendix A. The protocol formalizes the search strategy (MORANDI; CAMARGO, 2015), defining the research question, objectives, and scope in terms of breadth, extent, and depth, while adopting a broad and configurative perspective. It also establishes a conceptual framework that highlights the study's significance. Once the research protocol was finalized, the search strategies, search strings, time frame, and data sources were defined. After compiling the research database, duplicate articles were removed in the initial selection stage. In the second stage, titles, keywords, and abstracts were analyzed to ensure the inclusion of only articles relevant to the research objectives. Finally, the selected articles underwent a comprehensive full-text analysis.

The search and eligibility process presented in Figure 2 refers to the operationalization of the search strategy and the selection of studies that will form the corpus of analysis. Assessing the quality of the studies included in the *Systematic Literature Review* (SLR) is essential for any research aiming to map the literature. By evaluating the quality and relevance of the selected studies, researchers can ensure that only reliable and appropriate studies are used to support the review's findings (Ermel, 2020). In step 1.1, the research questions were formulated, "How has Lean Manufacturing related continuous improvement to efficiency in manufacturing and service processes?" and the protocol for the *Systematic Literature Review* (SLR) was established, following the guidelines proposed by (GAUSS et al., 2024).

Figure 2 - Search strategies



Source: Prepared by the author.

To conduct the literature review, two primary sources were utilized for identifying and selecting relevant studies: (i) academic databases and (ii) the snowballing strategy. The steps outlined in Sections 2.1, 2.2, and 2.3 were designed to identify studies that support the Lean perspective in relation to economic efficiency in manufacturing systems. In Step 2.1, a systematic search was performed in the Scopus and Web of Science databases, covering articles, books, and conference proceedings published up to 2024. A total of 272 publications were initially screened based on their titles and abstracts, with irrelevant or duplicate studies excluded according to the criteria established by Rojon, Okupe and McDowall (2021). Following this filtering process, the full texts of the remaining 29 studies were analyzed, resulting in the selection of 13 studies that met the eligibility and quality criteria defined in the research protocol. These selected studies then advanced to the snowballing stage.

In Step 2.2, which involved applying the snowballing technique, 655 studies were identified from the references and citations of the previously selected works. After reviewing their titles and abstracts, 17 studies were chosen for full-text analysis. Of these, four additional studies met the research protocol's criteria and were included in the final selection, bringing the total to 17 relevant studies, as listed in Appendix B.

For data analysis in Step 3.1, a coding scheme was implemented, combining predefined categorical codes from the literature (a priori) with emerging codes (a posteriori) identified during data interpretation (Ermel, 2020). This approach incorporated categories derived from prior research while integrating new categories developed through the coding process (Lacerda et al., 2013). To conclude the LGT stage, the coding phase, as outlined in Appendix C, enabled a comparative analysis of the study results. One of the primary functions of coding in LGT is to identify the characteristics of individual studies so that they can be synthesized later (Gough; Oliver; Thomas, 2012).

In addition to the coding presented in Appendix B, relationships of occurrence, co-occurrence, and frequency were analyzed. According to Bardin (2016), frequency is the most commonly used measure, as it reflects the importance of a registration unit based on how often it appears. In this study, frequency was determined by counting the number of times each code occurred within a unit of context, with each occurrence marked only once per unit. The co-occurrence measure considers the distribution and association of elements, extracting from the context the relationships between different message components.

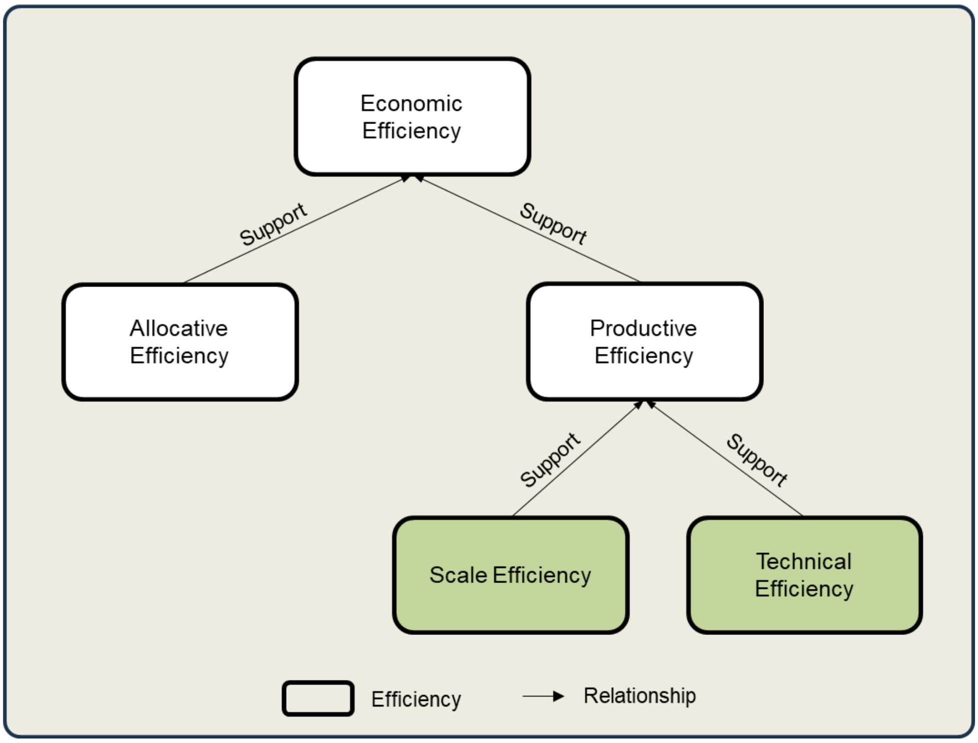
The codes were grouped into categories following rigorous methodological criteria, including mutual exclusivity, homogeneity, relevance, objectivity, and productivity (Bardin, 2016). This structured approach facilitated the synthesis of knowledge, enabling a broader and more theoretical understanding of the phenomenon under investigation. After completing this stage, the data analysis method was determined. The chosen approach prioritized scientific development and mapping, utilizing an aggregative review strategy, in which the results of primary studies are consolidated to generate findings and conduct a meta-synthesis.

This process involves a set of techniques used to synthesize findings from multiple qualitative studies, leading to a new interpretation of the phenomenon of interest (Ermel, 2020). The studies included in the review are presented in Appendix A. Finally, Step 5 aims to clarify the research findings by analyzing and synthesizing data in light of existing literature. This stage offers a comprehensive reflection on topics related to Lean Manufacturing and both technical and economic efficiency, fostering a deeper and more integrated understanding of these concepts.

3.3 ANALYSIS OF RESULTS

To gain a proper understanding of the topic, it is essential to present some fundamental concepts related to economic efficiency. Economic efficiency is the broadest concept of efficiency and can be divided into two main dimensions: productive efficiency and allocative efficiency (Piran; Lacerda; Camargo, 2018b, 2021b), as shown in Figure 3.

Figure 3 - Composition of Economic Efficiency



Source: Prepared by the author.

Allocative efficiency occurs when resources are distributed in a way that maximizes social welfare, ensuring that the production of goods and services aligns optimally with consumer preferences and needs. In other words, it guarantees that the right goods and services are produced in the correct quantities, preventing both shortages and waste (BARBERIO MARIANO, 2007; PIRAN; LACERDA; CAMARGO, 2018b). Conversely, productive efficiency refers to the ability to produce goods and services at the lowest possible cost by optimizing resource utilization and minimizing waste. This concept assumes that the economy operates at its production possibility frontier, meaning that increasing the output of one good is only possible by reducing the production of another (Barberio Mariano, 2007; Piran; Lacerda; Camargo, 2018).

Productive efficiency can be further divided into two key dimensions: technical efficiency and scale efficiency. Scale efficiency relates to the optimal use of production capacity, ensuring that a company operates at a level where long-term average costs are minimized, thereby enhancing competitiveness and economic sustainability. Technical efficiency, on the other hand, is defined as an organization's ability to maximize output while using the least amount of resources (inputs), such as labor, capital, raw materials, and time, eliminating waste and ensuring the best possible allocation of production factors (VENKATESH; KUSHWAHA, 2018).

Economic efficiency refers to an organization's ability to produce goods and services at the lowest possible cost while maximizing the value derived from available resources. This concept encompasses not only maximizing output but also minimizing operational costs, ensuring the organization's financial sustainability and competitiveness in the market (Aparicio; Ortiz; Pastor, 2017; Venkatesh; Kushwaha, 2018). Thus, the distinction between technical efficiency and economic efficiency lies in their scope: while technical efficiency focuses on the optimal use of inputs or maximizing production, economic efficiency incorporates the financial dimension, ensuring the best economic relationship—considering prices and quantities—between the resources used and the goods and services produced.

3.3.1 Relationships Between Lean Manufacturing, Continuous Improvement, and Efficiency

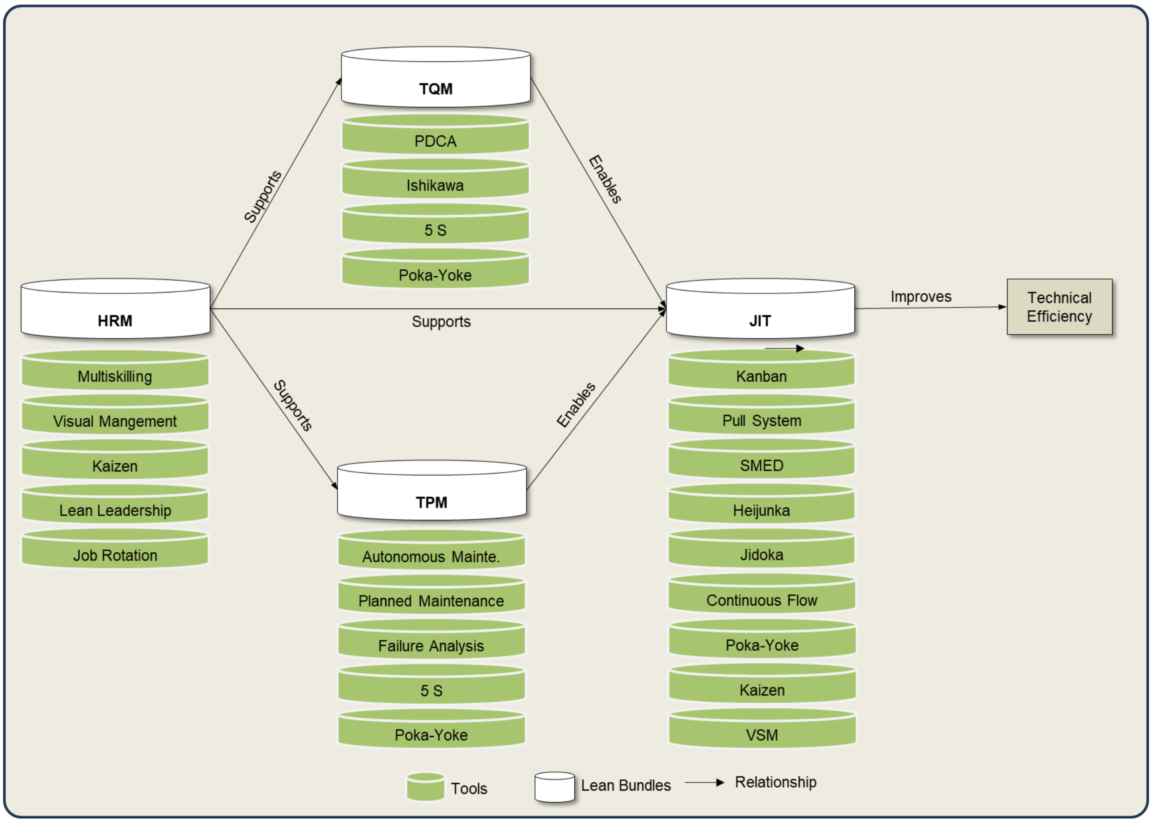
Lean Manufacturing (LM) is closely linked to continuous improvement and waste elimination in both manufacturing and service systems. This structured approach seeks to streamline processes, reduce costs, and enhance overall organizational efficiency (Costa; Varejão; Gaspar, 2024; Memari et al., 2022). Within *Lean Manufacturing*, four structured groups of practices, tools, and principles commonly known as Lean bundles stand out (FURLAN; VINELLI; PONT, 2011; PONT; FURLAN;

VINELLI, 2009). These bundles consist of complementary elements that operate in an integrated and synergistic manner to minimize waste, improve operational efficiency, and sustain continuous improvement in production systems.

Just-in-Time (JIT) Bundle, this bundle includes a set of practices designed to maintain a continuous and efficient production flow, reducing inventory levels and optimizing synchronization across manufacturing stages (PONT; FURLAN; VINELLI, 2009). Total Quality Management (TQM) Bundle, this bundle focuses on continuous improvement by ensuring high-quality products and processes, emphasizing customer satisfaction and defect reduction (NARASIMHAN; SWINK; KIM, 2006). Total Productive Maintenance (TPM) Bundle, this bundle incorporates strategies to optimize equipment performance and reliability through predictive and preventive maintenance, minimizing downtime and enhancing operational efficiency (Furlan; Vinelli; Pont, 2011). Human Resource Management (HRM) Bundle, this bundle encompasses practices aimed at fostering organizational development, promoting employee engagement, building specialized competencies, and ensuring strong top management support critical factors for the success of Lean initiatives(Galeazzo; Furlan, 2018).

Figure 4 summarizes the literature review on the relationship between Lean Manufacturing and technical efficiency in production systems. This relationship is based on minimizing waste in manufacturing processes, as highlighted by (Memari et al., 2022; Costa; Varejão; Gaspar, 2024; Rochman; Sudiarso; Herliansyah, 2024). To achieve this objective, the Lean methodology provides a set of tools organized into four Lean bundles, aimed at both improving essential activities and eliminating unproductive resources (Baptista; Abreu; Brito, 2021).

Figure 4 - Lean Manufacturing, continuous improvement and efficiency



Source: Prepared by the author.

The Human Resource Management (HRM) bundle plays a crucial role in supporting the effective implementation of Lean Manufacturing (LM) practices, as it is directly interconnected with the other three bundles within this framework. Specifically, the Total Quality Management (TQM) and Total Productive Maintenance (TPM) bundles serve as key enablers in the adoption of Just-in-Time (JIT), contributing to improved operational efficiency and greater stability in production processes. Together, these four bundles form an interdependent system, working synergistically to enhance the overall effectiveness of Lean Manufacturing while facilitating the use of various tools that drive technical efficiency in production. The Lean bundles' interdependence underscores how the optimization of one process directly influences the others within the production system. For instance, JIT relies on the reliability of equipment, which is ensured through TPM practices. Likewise, preventive and autonomous maintenance under TPM has a direct impact on production quality, reinforcing the principles of TQM. Additionally, the continuous improvement (Kaizen) philosophy is grounded in process standardization, promoting greater predictability and control over operations. As a result, Lean Bundles do not function in isolation; rather, their integrated application fosters stronger operational synergy, leading to a more efficient production system with reduced waste and continuous organizational improvement.

A review of the literature underscores *Lean Manufacturing*'s role in promoting continuous process improvement, with a strong emphasis on optimizing technical efficiency. Key benefits associated with this approach include reduced lead times, increased productivity, enhanced product quality, and higher customer satisfaction levels (Memari et al., 2022; Filipe; Pimentel, 2023). Technical efficiency refers to a system's or process's ability to maximize output while minimizing resource consumption, reducing waste, and optimizing productivity (DOGAN; KAYGISIZ; ALTINEL, 2018). It reflects an organization's capacity to make the most of available resources, achieving high productivity levels with minimal inefficiencies.

Table 2 maps *Lean* bundles to their respective tools, illustrating their impact on key indicators established by LM. The qualitative assessment of correlations is represented using symbols: (+++) indicates a strong interaction and connection, (○) denotes no immediate correlation, and (-) signifies a negative interaction.

Table 2 - Relationship between Lean bundles, tools, and Technical Efficiency

Bundles	Tools	How?	Technical Efficiency							
			OEE	Lead Time	Cycle Time	Takt Time	MTBF / MTTR	Cost of Non-Quality	Work-in-Process (WIP)	On-Time Delivery (OTD)
HRM	Multiskilling	Flexibility in the workflow.	+ +	○	○	+ +	+ +	+ +	○	+ +
	Visual Management	Quick identification of problems.	+	○	○	+ +	+	+	+ +	+ + +
	Kaizen	Innovation and problem solving.	+	+	+	+	+	+	+	+
	Lean Leadership	Autonomous teams	+ +	○	○	+	+ + +	+	○	+
	Job Rotation	Increases operational resilience.	-	○	○	-	○	+	○	+ +
TQM	PDCA (Plan, Do, Check, Act)	Continuous and systematic improvement.	+	+	○	○	+ +	+ + +	+	+ +
	Ishikawa	In-depth analysis and identification of problem roots.	+	+	○	○	+ +	+ + +	+	+ +
	5S	Improved productivity, safety and quality.	+	○	○	+ +	+	+ +	○	○
	Poka-Yoke	Reducing failures and increasing quality.	+	○	○	+ +	+	+ +	○	○
TPM	Autonomous Maintenance	Reduces unexpected stops and promotes a sense of responsibility.	+++	○	+	+++	+++	○	○	+++
	Planned Maintenance	Reduces failures and emergency costs.	-	○	-	+++	+++	○	○	+++
	Failure Analysis	Prevents the recurrence of failures.	-	○	○	++	+++	○	○	++
	5S	Reduces waste and improves safety.	○	○	○	○	○	○	○	○
	Poka-Yoke	Prevents accidents and operational failures.	○	○	○	○	+	○	○	○

Bundles	Tools	How?	Technical Efficiency							
			OEE	Lead Time	Cycle Time	Takt Time	MTBF / MTTR	Cost of Non-Quality	Work-in-Process (WIP)	On-Time Delivery (OTD)
JIT	Kanban	Reduces stocks and facilitates pull production.	++	○	+	+	○	○	++	++
	Pull System	Avoid overproduction and reduce stocks.	○	+	+	+	○	○	++	++
	Single Minute Exchange of Die (SMED)	Reduces cycle time and increases flexibility.	+++	+	○	+	○	○	○	++
	Heijunka	Reduces production peaks and intermediate stocks.	+++	+	++	++	○	○	++	+
	Jidoka	Reduces defects and improves quality.	+	○	○	+	○	+++	○	+
	Continuous Flow	Reduces waiting times and increases efficiency.	+++	++	+	+	-	○	+	+
	Poka-Yoke	Reduces errors and defects.	+	○	+	+	+	++	○	○
	Kaizen	Promotes innovation and efficiency.	++	++	++	++	++	++	++	++
	Value Stream Mapping (VSM)	Improve Cycle Time (Lead Time)	+	+++	+++	+++	○	○	+++	+++

Source: Prepared by the author.

Lean Bundles tools, such as Continuous Flow, Single Minute Exchange of Die (SMED), Heijunka, Planned Maintenance, and Autonomous Maintenance, have a direct relationship with the Overall Equipment Effectiveness (OEE) indicator. This metric is widely recognized as one of the key pillars for assessing the technical efficiency of a production system, encompassing three fundamental dimensions: availability, performance, and quality. The implementation of these methodologies significantly enhances equipment and process availability, as it enables the elimination or reduction of stoppages in the production flow. This optimization directly impacts operational performance and production stability, promoting greater efficiency in managing production resources and enhancing organizational competitiveness.

Conversely, tools such as Poka-Yoke, 5S, Failure Analysis, and Planned Maintenance have a less significant impact on indicators like Lead Time, Cycle Time, and Cost of Non-Quality. This distinction highlights that each tool serves a specific function, aligned with its intended objectives. However, evaluating these tools in isolation may, in some cases, limit the perception of their economic benefits. This is because they primarily focus on optimizing technical efficiency at a localized level, without necessarily driving a broader improvement in the economic efficiency of the production system as a whole.

3.3.2 Relationships between Technical Efficiency and Economic Efficiency

The analysis of the relationship between Lean Manufacturing and economic efficiency reveals a gap in the literature. This gap pertains to the challenges in converting the operational improvements achieved through Lean implementation into tangible economic gains, as originally anticipated (Frankowska; Czerniachowicz, 2020). While Lean is widely recognized for driving significant enhancements in manufacturing operations and systems, the correlation between these improvements and economic benefits is not always evident. This raises questions about its economic effectiveness across different organizational contexts (QURESHI et al., 2022).

The literature indicates that one of the main barriers to the successful implementation of Lean is the failure to achieve the expected economic returns. Table 3 presents examples of studies that have identified economic constraints as a challenge in Lean application, highlighting the gap between this methodology and economic efficiency. This scenario underscores that the lack of integration between the technical improvements enabled by Lean Manufacturing and concrete economic outcomes represents a significant obstacle to the adoption and long-term sustainability of the methodology within organizations.

Table 3 - Lean Economic Barriers

Authors	Title	Year	Objective
Schulze and Dallasega	Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions	2023	The study examines the barriers to Lean implementation in engineer-to-order (ETO) companies. Based on a systematic literature review, the barriers are grouped into four key categories: (i) economic; (ii) knowledge; (iii) management and (iv) culture. This classification offers a clearer and more structured understanding of the challenges encountered, helping to guide the development of strategies for more effective Lean implementation in the ETO sector.
Qureshi et al.	Exploring the Lean Implementation Barriers in Small and Medium-Sized Enterprises Using Interpretive Structure Modeling and Interpretive Ranking Process	2022	Research conducted on small and medium-sized manufacturing enterprises examines the challenges encountered when implementing the Lean methodology in their manufacturing systems. Among the primary barriers identified is the economic barrier, as implementations often fall short of achieving their initially projected economic goals. This study employs Interpretive Structural Modeling (ISM) to explore Lean barriers, analyze their interrelationships, and assess their impact on other obstacles to Lean implementation.
Leite, Radnor and Bateman	Meaningful inhibitors of the lean journey: a systematic review and categorisation of over 20 years of literature	2022	The article presents a systematic literature review on barriers to Lean implementation, encompassing over 20 years of research. The study identifies six primary barriers, categorized into two groups: behavioral and organizational (people-related) and technical (tool-related). Notably, a major technical barrier is the economic barrier, as Lean implementations often fall short of achieving the projected economic outcomes outlined in the project plan. Furthermore, the article proposes eight key insights, offering valuable contributions to the advancement of knowledge and best practices in Lean implementation.

Authors	Title	Year	Objective
Abu et al.	The implementation of lean manufacturing in the furniture industry: a review and analysis on the motives, barriers, challenges, and the applications	2019	This study explored the adoption of Lean manufacturing in the furniture industry within emerging economies, with a specific focus on Malaysia. The research began with a comprehensive literature review, followed by an analytical survey of 148 companies in the sector. The findings revealed that the primary barrier to Lean implementation is a lack of understanding of its economic benefits. Additionally, a notable discovery showed that 76% of furniture companies in the Klang Valley region had not adopted Lean practices. This study offers valuable insights into the challenges faced by the furniture industry in emerging economies, contributing to the development of strategies for more effective Lean implementation.
Zhang; Narkhede and Chaple	Evaluating lean manufacturing barriers: an interpretive process	2017	Since Lean barriers are dispersed across the literature and a variety of performance measures are used in practice, a comprehensive literature review was conducted to identify these barriers and metrics. A new classification technique, the Interpretive Ranking Process (IRP), was employed for the evaluation. In this IRP-based approach, a group discussion was conducted with five Indian Lean experts to determine the most critical barriers and performance measures. Several matrices were then developed to calculate the rankings of the selected Lean barriers. Following the validation of these rankings, an IRP-based Lean barrier evaluation model was proposed.
Dora, Kumar and Gellynck	Determinants and barriers to lean implementation in food-processing SMEs – a multiple case analysis	2016	This study examined the contextual factors and their impact on Lean manufacturing in small and medium-sized enterprises (SMEs) within the food processing sector. Using a multiple case study approach, it identified several barriers to Lean adoption, including quality requirements, short product shelf life, and demand and supply volatility. A key challenge highlighted was the lack of economic benefits from implementing the methodology. Furthermore, the inherent characteristics of SMEs, such as small factory size, inflexible layouts, and difficulty driving change, presented additional obstacles.

Source: Prepared by the author.

As illustrated in Figure 4, the literature review on economic efficiency within the context of Lean Manufacturing highlights a limited and indirect relationship between these two concepts. While Lean methodology, through its structured bundles and tools, establishes a direct connection with technical efficiency, this efficiency does not automatically translate into economic efficiency, revealing inherent constraints in their relationship. Economic efficiency is not a primary focus of Lean Manufacturing, which is primarily designed to optimize processes and eliminate operational waste. As a result, the financial gains derived from improvements in technical efficiency do not always translate proportionally into tangible economic benefits.

Several factors can hinder the conversion of these improvements into significant financial returns, including high initial implementation costs, external variables beyond the organization's control, and internal challenges related to management and cultural adaptation. This underscores the need for a more integrated and strategic approach one that not only enhances technical efficiency but also incorporates mechanisms to effectively translate these improvements into measurable economic gains (PIRAN; LACERDA; CAMARGO, 2021b).

In this context, Table 4 provides a summary of the impact of technical efficiency on economic efficiency. This analysis considers the most commonly used Lean Manufacturing indicators and evaluates their influence on economic efficiency. The table also highlights moderating factors that limit the direct conversion of technical efficiency into economic efficiency. Notably, no indicator fully demonstrated a direct impact of technical efficiency on economic efficiency. In all cases, key determinants were identified that, when combined, either facilitate or impede this transformation.

Table 4 - Influence of Technical Efficiency on Economic Efficiency

Technical Efficiency	**Economic Efficiency**			
	Revenue Efficiency		**Cost Efficiency**	
	Revenue	**Profitability**	**Inventory turnover**	**Unit cost**
OEE	*An increase in OEE does not directly translate into increased revenue.	* An increase in OEE does not directly translate into increased profitability.	* An increase in OEE does not directly translate into an increase in inventory turnover.	* An increase in OEE does not directly translate to a reduction in unit cost.
	Factors Moderators: - Demand;	Factors Moderators: - Demand; - Indirect costs;	Factors Moderators: - Organization barriers; - External variations; - Desalination of strategies;	Factors Moderators: - Demand; - Indirect costs;
Lead Time	* Reducing lead time does not directly translate into increased revenue.	* Reducing lead time does not directly translate into increased profitability.	* Reducing lead time is directly related to inventory turnover.	* Reducing lead time does not directly translate to a reduction in unit cost.
	Factors Moderators: - Demand; - Desalination of strategies; - Indirect costs;	Factors Moderators: - Demand; - Indirect costs; - Organization barriers;		Factors Moderators: - Demand; - Desalination of strategies; - Indirect costs; - Organization barriers; - External variations
Cycle Time	* Reducing cycle time does not directly translate into increased revenue.	* Reduction in cycle time does not directly translate into profitability gains.	*Reduction in cycle time has a direct relationship with inventory turnover.	* Reduction in cycle time does not directly translate into unit cost reduction.
	Factors Moderators: - Demand; - Indirect costs; - External variations	Factors Moderators: - Demand; - Indirect costs;		Factors Moderators: - Demand; - Indirect costs; - External variations
Takt Time	* Reducing takt time does not directly translate into increased revenue.	*Reducing takt time does not directly translate into increased profitability.	* Reducing takt time is directly related to inventory turnover.	* Reducing takt time does not directly translate into a reduction in unit cost.

Technical Efficiency	Economic Efficiency			
	Revenue Efficiency		Cost Efficiency	
	Revenue	Profitability	Inventory turnover	Unit cost
	Factors Moderators: - Demand; - Organization barriers; - External variations	Factors Moderators: - Demand; - Indirect costs;		Factors Moderators: - Demand; - Indirect costs; - Organization barriers; - External variations
MTBF/MTTR	Increase in MTBF and MTTR indicators does not directly translate into revenue gains.	* Increase in MTBF and MTTR indicators does not directly translate into profitability improvement.	* Increase in MTBF and MTTR indicators does not directly translate into improvement in inventory turnover.	* Increase in MTBF and MTTR indicators does not directly translate into unit cost reduction.
	Factors Moderators: - Demand; - Indirect costs;	Factors Moderators: - Demand; - Indirect costs; - Organization barriers;	Factors Moderators: - Demand; - Indirect costs; - Organization barriers; - External variations	Factors Moderators: - Demand; - Indirect costs; - Organization barriers; - External variations
Cost of Non-Quality	* Reduction in the cost of poor quality does not directly translate into revenue gain.	* Reduction in the cost of poor quality directly translates into increased profitability.	* Reduction in the cost of poor quality has no direct relationship with inventory turnover.	* Reduction in the cost of poor quality does not directly translate into unit cost reduction.
	Factors Moderators: - Demand; - Indirect costs;		Factors Moderators: - Demand; - Organization barriers; - External variations	Factors Moderators: - Indirect costs;
Work-in-Process (WIP)	* Reduction in WIP does not directly translate into revenue growth.	* Reduction in WIP does not directly translate into profitability gain.	* Reduction in WIP has a direct relationship with inventory turnover improvement.	* Reduction in WIP does not directly translate into unit cost reduction.
	Factors Moderators: - Demand; - Indirect costs;	Factors Moderators: - Demand; - Indirect costs; - Organization barriers;		Factors Moderators: - Demand; - Indirect costs; - Organization barriers; - External variations

<table>
<tr><th rowspan="3">Technical Efficiency</th><th colspan="4">Economic Efficiency</th></tr>
<tr><th colspan="2">Revenue Efficiency</th><th colspan="2">Cost Efficiency</th></tr>
<tr><th>Revenue</th><th>Profitability</th><th>Inventory turnover</th><th>Unit cost</th></tr>
<tr><td rowspan="2">On-Time Delivery (OTD)</td><td>* Improvement in OTD has no direct relationship with revenue growth.</td><td>* Improvement in OTD has no direct relationship with profitability.</td><td>* Improvement in OTD has no direct relationship with inventory turnover gain.</td><td>* Improvement in OTD has no direct relationship with unit cost improvement.</td></tr>
<tr><td>Factors Moderators:
- Demand;
- External variations</td><td>Factors Moderators:
- Demand;
- Organization barriers;</td><td>Factors Moderators:
- Organization barriers;
- External variations</td><td>Factors Moderators:
- Demand;
- Indirect costs;</td></tr>
</table>

Source: Prepared by the author.

The analysis of Table 4 indicates that an increase in technical efficiency, measured by Overall Equipment Effectiveness (OEE), contributes to economic efficiency through two key dimensions: revenue efficiency (revenue and profitability) and cost efficiency (inventory turnover and unit cost). However, an isolated increase in OEE is not directly linked to economic efficiency across all scenarios. The impact depends on the presence of moderating factors that influence the transformation of technical efficiency into economic gains. Specifically, an increase in OEE enhances revenue efficiency only when there is corresponding demand for the product or service. Without this alignment, the benefits remain limited to technical efficiency, with no direct effect on economic performance.

Similarly, reducing Lead Time as a result of improved technical efficiency has a direct correlation with inventory turnover. However, when examining its relationship with revenue efficiency, the influence of moderating factors—such as demand, indirect costs, organizational barriers, and strategic misalignment—becomes apparent. Therefore, Lead Time reduction alone does not automatically generate economic efficiency gains. Instead, achieving such gains requires the alignment of moderating factors alongside Lead Time improvements.

The lack of integration between economic efficiency and Lean Manufacturing advancements can limit the overall impact of technical efficiency improvements, even when significant progress is made. While continuous improvement and waste elimination are core principles of Lean Manufacturing, they do not necessarily result in direct economic benefits. Factors such as market fluctuations, indirect costs associated with Lean implementation and maintenance, and organizational barriers frequently hinder the conversion of technical gains into measurable economic results (QURESHI et al., 2022). This scenario underscores the need for a broader and more strategic perspective that incorporates both operational and economic factors, ensuring that Lean initiatives translate into long-term financial sustainability within organizations.

3.4 DISCUSSION

Despite the well-documented potential of Lean Manufacturing to enhance operational performance, the lack of integration between technical improvements and economic outcomes limits its ability to fully meet organizations' strategic objectives

(JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE, 2014a; RAMADAS; SATISH, 2021). While Lean is effective in boosting technical efficiency, translating these gains into economic efficiency depends on broader contextual factors, many of which extend beyond the methodology's scope (Memari et al., 2022). As a result, managers who perceive their operations as technically efficient may overlook additional initiatives that could generate significant economic benefits.

A detailed analysis of technical and allocative efficiency often reveals cases where organizations achieve high technical efficiency but struggle with lower allocative efficiency, underscoring the disconnect between these two performance dimensions (DAS; PATEL, 2014). For example, Chizari and Fehresti-Sani (2018) examined economic efficiency in vegetable oil supply chains in Iran, identifying instances where supply chains achieved 100% technical efficiency but had allocative efficiency levels of 71% and 54%. Similarly, Dogan, Kaygisiz and Altinel (2018) analyzed 39 egg production farms in Turkey, reporting an average technical efficiency of 98%, while allocative efficiency averaged 88%. Additionally, Das and Patel (2014) investigated cost efficiency in 24 pharmaceutical companies in India, identifying firms with 100% technical efficiency but allocative efficiency levels of 63% and 80%. These findings further emphasize the gap between technical and economic efficiency, reinforcing the need for a holistic approach that ensures Lean improvements lead to long-term financial sustainability.

These findings underscore the importance of considering allocative efficiency alongside technical efficiency for a more comprehensive assessment of economic performance. They emphasize that technical improvements do not always directly translate into economic gains, as their effectiveness is highly dependent on the specific context in which they are implemented (Marodin; Saurin, 2015; Schulze; Dallasega, 2023).

In contrast, economic efficiency provides a more comprehensive perspective, encompassing not only technical efficiency but also the optimal utilization of resources to minimize costs and maximize revenue and profitability (APARICIO et al., 2013b). While research indicates that Lean can reduce costs through waste elimination and enhanced technical efficiency (Leite; Radnor; Bateman, 2022; Qureshi et al., 2022; Schulze; Dallasega, 2023), it is important to recognize that cost reduction and economic efficiency are not interchangeable concepts. Cost reduction represents only one dimension of economic efficiency, which requires a broader assessment of financial performance and long-term organizational sustainability. However, this cost reduction does not always occur in a simple or immediate manner, as it often requires significant initial investments. This phenomenon, known as the **"cost to reduce cost"**, represents a paradox in which expenses must be incurred to achieve future savings.

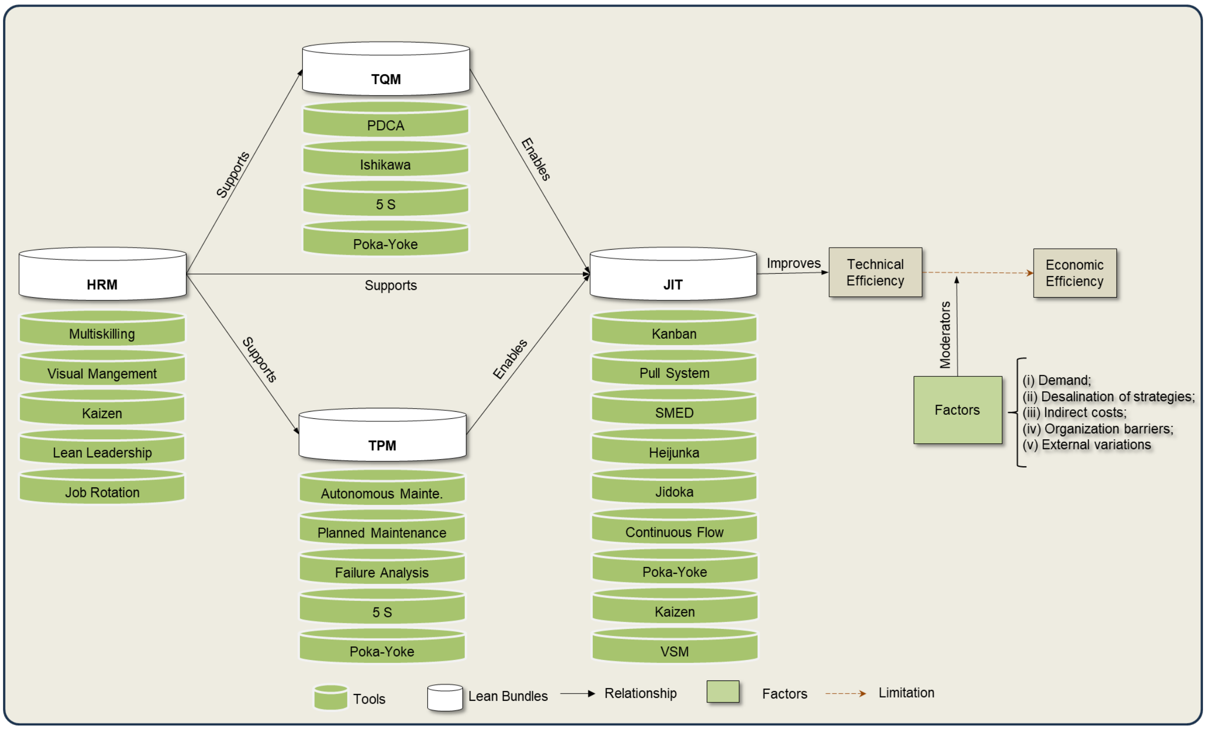
This perspective underscores the importance of recognizing economic efficiency as a core element of Lean Manufacturing, rather than merely a secondary benefit. Without this broader view, organizations may struggle to fully adopt Lean and risk limiting its impact on competitiveness and return on investment. To maximize Lean's potential across different organizational contexts, it is essential to strategically integrate technical improvements with economic outcomes.

Addressing the first research question, which examines the relationship between Lean methodology, continuous improvement, and economic efficiency, requires a solid understanding of the principles that underpin this approach. A fundamental pillar of Lean is continuous improvement, a concept that applies to both manufacturing and service systems (González Aleu; Garza-Reyes, 2020; Pervaz et al., 2024). In this framework, operational efficiency is deeply connected to technical efficiency in production processes, reinforcing the need for ongoing optimization. To achieve these goals, Lean offers a structured set of tools designed to identify and eliminate waste, thereby improving technical efficiency through process simplification and optimized resource utilization (Thürer; Tomašević; Stevenson, 2017; Baptista; Abreu; Brito, 2021; Memari et al., 2022; Filipe; Pimentel, 2023). These tools are specifically developed to sustain continuous improvement, a fundamental principle of Lean that seeks to enhance organizational performance by minimizing variability and inefficiencies.

Thus, Lean Manufacturing is explicitly designed to enhance technical efficiency, establishing itself as a methodology that integrates continuous optimization practices with the systematic elimination of waste. However, while the focus on technical efficiency is clear, the relationship between these improvements and economic outcomes can vary depending on the organizational context and external factors that influence the conversion of these gains into tangible economic benefits. The second research question seeks to investigate whether gains in technical efficiency are fully translated into economic efficiency in manufacturing and service systems. A review of the literature indicates that gains in technical efficiency are not proportionally converted into economic efficiency. While there is a relationship between these concepts, they are not equivalent, and the transformation of one into the other depends on various contextual and organizational factors.

Some of these factors include: (i) Market factors – Technical efficiency can increase production capacity, but if market demand is insufficient to absorb this additional capacity, technical gains will not translate into economic gains; (ii) Strategic misalignment – Emphasizing technical efficiency without integrating an economic analysis may lead to decisions that enhance productivity but do not necessarily reduce costs or increase revenue; (iii) Indirect costs – Technical improvements may require high initial investments, which can compromise short-term economic efficiency; (iv) Organizational barriers – Cultural resistance and lack of process integration can limit an organization's ability to convert technical improvements into economic benefits and (v) External variables – Fluctuations in input prices, regulations, and broader economic conditions can significantly influence economic viability. Figure 5 illustrates the correlations between Lean bundles and improvements in technical efficiency, while also highlighting the limitations in converting technical efficiency into economic efficiency due to the previously discussed factors.

Figure 5 - Lean, technical efficiency and conversion factors into economic efficiency



Source: Prepared by the author.

Expanding the understanding of economic efficiency reveals that it emerges from the interplay between technical efficiency and the influence of moderating factors.

These factors are just as critical as technical efficiency gains within the production process, as they shape the transformation of these gains into tangible economic benefits. A key consideration is the clear definition of manufacturing system objectives. Aligning these objectives with moderating factors allows for a more structured and cohesive approach when implementing strategies to enhance technical efficiency. Therefore, maximizing production outcomes should be approached holistically, ensuring that implemented actions contribute to broader system-wide improvements.

Additionally, any initiative within the production system must be aligned with three key indicators: profitability, inventory levels, and operating expenses. These metrics provide a comprehensive assessment of system performance, ensuring that efforts to enhance technical efficiency remain sustainable and aligned with economic efficiency principles. The assumption that technical efficiency automatically translates into economic efficiency is overly simplistic. While technical efficiency is a vital component of organizational performance, it alone does not guarantee the maximization of economic outcomes, which remains the primary objective of organizations. In this regard, economic analysis offers a broader perspective on organizational efficiency, helping identify strategies that may initially appear contradictory from a technical standpoint but, when assessed through an economic lens, prove to be strategically advantageous. Therefore, the integration of technical and economic analyses is essential for developing sustainable economic outcomes that align with organizational strategic goals.

For instance, reducing waste in internal processes may not result in higher revenue if market demand is insufficient to absorb the increased production capacity. Consequently, while technical efficiency is crucial, it does not automatically ensure proportional economic efficiency gains (NG CORRALES et al., 2022) . A key challenge frequently highlighted in the literature is the misalignment between increased production capacity and market demand. Even when processes are optimized for greater efficiency, a lack of additional demand to absorb higher production levels can lead to the underutilization of excess capacity (Ahmed; Sobuz, 2020; Memari et al., 2022; Almashaqbeh; Hernandez, 2024; Laroca et al., 2024a;).

In this scenario, investments in technical improvements may not always yield the expected financial returns, ultimately compromising the economic efficiency of such initiatives. Research highlights cases where waste reduction was successfully implemented, yet the lack of additional demand prevented the realization of the anticipated economic benefits. These findings emphasize that economic efficiency cannot be achieved solely through waste reduction and technical optimization. Instead, it requires strategic alignment with external demand to ensure that continuous improvement efforts generate sustainable and effective economic returns (Schulze; Dallasega, 2023).

In practice, while technical efficiency analysis is essential, it alone is insufficient to address organizational needs. Managers typically require broader insights that incorporate economic aspects, which are crucial for strategic decision-making aligned with the organization's financial objectives (Susaeta et al., 2016). Financial data, particularly when expressed in monetary terms, is highly valuable, as it enables organizations to evaluate whether continuous improvement initiatives are producing positive or negative economic impacts. Moreover, economic efficiency offers a more holistic approach, encompassing not only technical efficiency but also the optimal allocation of inputs and outputs to minimize costs or maximize revenue and profits (Aparicio et al., 2013).

An illustrative example is presented by (PIRAN et al., 2020), who investigated the steel sheet cutting process. In this study, efficiency was measured exclusively in terms of time units. To increase production volume, the company implemented practices that led to poorer material utilization, ultimately compromising economic efficiency.

Although these actions were perceived as technical improvements, they actually worsened the organization's economic outcomes. This example underscores the importance of integrating economic efficiency into operational decision-making, ensuring that implemented improvements align with the company’s financial objectives. The overemphasis on technical efficiency can limit the full potential of Lean Manufacturing. This limitation arises because other improvement opportunities, particularly those related to economic efficiency, are often overlooked (Piran; Lacerda; Camargo, 2020). The lack of an integrated economic perspective can weaken the financial impact of improvements, making it more difficult to achieve meaningful overall results.

Focusing exclusively on technical efficiency may lead managers to adopt a narrow view of the evaluated system, neglecting cost reduction opportunities identified through economic analysis (PIRAN et al., 2020). In many cases, managers who perceive their operations as technically efficient may mistakenly assume that this efficiency automatically translates into economic efficiency. This assumption can result in overlooking improvement initiatives that could enhance the organization's financial performance. Thus, while improving technical efficiency is crucial, it is not enough to achieve the ultimate goal of businesses: sustainable economic performance.

Conversely, economic analysis provides a broader perspective on efficiency, often uncovering counterintuitive strategies from a technical standpoint. For instance, it may be more economically advantageous for an organization to increase the use of lower-cost inputs while reducing reliance on more expensive resources (Venkatesh; Kushwaha, 2018). This type of approach would not typically be identified in an isolated technical efficiency analysis. Studies on public transportation companies in India demonstrated that adjusting the input mix increasing the use of some resources while reducing others led to lower operational costs. This logic also applies to production systems, where, for example, reducing the use of indirect labor resources can be offset by increasing direct labor, ultimately resulting in overall cost reductions (Das; Patel, 2014).

Thus, expanding the scope of Lean Manufacturing to include an approach that considers the economic impact of initiatives is crucial. Integrating technical and economic efficiency can enhance overall manufacturing performance, creating a more sustainable balance between operational effectiveness and financial returns. Adopting this broader perspective allows for a more strategic and holistic application of Lean Manufacturing, ensuring it aligns with organizations' long-term objectives.

3.5 CONCLUSION

After reviewing the available literature and analyzing publications that explore the relationship between Lean and efficiency, this study identifies key theoretical and practical contributions. From an initial set of 272 publications, the application of eligibility criteria, as previously detailed, refined the final analysis sample to 17 studies. These 17 reviewed publications examined Lean Manufacturing in relation to efficiency-focused topics. The analysis of Lean applications, with an emphasis on efficiency, reveals that the methodology is primarily associated with technical efficiency, as demonstrated by its toolset and implementation strategies.

From a theoretical standpoint, this study challenges the Lean Manufacturing approach in relation to economic efficiency in manufacturing systems. A review of the literature suggests that Lean Manufacturing addresses this aspect indirectly, considering it a byproduct of technical improvements and waste reduction rather than explicitly focusing on the conversion of these gains into sustainable economic outcomes. Several factors may constrain the anticipated economic benefits, including high implementation and maintenance costs, diminishing marginal returns on improvements over time, an excessive emphasis on technical efficiency at the expense of financial considerations, market demand fluctuations, and potential quality trade-offs.

Certain organizational factors, such as low maturity in continuous improvement, market volatility, strategic misalignment, technological limitations, and resistance to change, can obstruct the seamless transition from technical efficiency to economic efficiency. To ensure that continuous improvement initiatives yield sustainable financial benefits, they must be strategically aligned with both organizational goals and market dynamics. This study underscores the necessity of a broader, more integrated approach—one that extends beyond technical optimization to encompass financial, structural, and market-driven considerations in the planning and implementation of Lean Manufacturing.

As previously discussed, this perspective reveals a gap in opportunities, as incorporating a stronger focus on economic efficiency could generate more substantial benefits for manufacturing systems. Furthermore, a second major contribution is the recognition that not all technical efficiency improvements directly translate into economic efficiency gains. This finding underscores the importance of adopting a broader perspective, ensuring that improvements in technical efficiency align with long-term economic sustainability.

From a practical perspective, this research highlights the need for a more comprehensive approach in the implementation of Lean Manufacturing, placing economic efficiency at the core of its strategy. It is evident that managers often prioritize initiatives that demonstrate clear economic benefits, given that economic efficiency plays a crucial role in decision-making and organizational strategy development. In this regard, integrating an economic perspective into Lean has the potential to enhance its strategic relevance and increase its adoption within organizations. This shift could lead to more impactful and sustainable outcomes, reinforcing Lean as a valuable methodology not only for process optimization but also for financial performance improvements.

The insights generated by this study can raise awareness about the importance of economic efficiency in organizational settings. This approach promotes the development of a more holistic view of production processes, guiding strategic decision-making in the selection and implementation of methodologies. Failing to adopt this broader perspective hinders the full integration of Lean, thereby limiting its impact on organizational competitiveness and return on investment. Therefore, the strategic alignment of technical improvements with economic outcomes is crucial to maximizing Lean's potential across various corporate environments.

REFERENCES

ABDELOUAHED, B. et al. Influence of Lean and Lean Six Sigma on Social Factors in the Moroccan Industry - Case Study. **International Journal of Performability Engineering**, v. 19, n. 8, p. 516, 2023.

ABREU-LEDÓN, R. et al. A meta-analytic study of the impact of Lean Production on business performance. **International Journal of Production Economics**, v. 200, p. 83–102, 2018.

ABU, F. et al. The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications. **Journal of Cleaner Production**, v. 234, p. 660–680, 2019.

AHMED, A.; OLSEN, J.; PAGE, J. Integration of Six Sigma and simulations in real production factory to improve performance – a case study analysis. **International Journal of Lean Six Sigma**, v. 14, n. 2, p. 451–482, 28 fev. 2023.

AHMED, S.; SOBUZ, M. H. R. Challenges of implementing lean construction in the construction industry in Bangladesh. **Smart and Sustainable Built Environment**, v. 9, n. 2, p. 174–207, 2020.

ALBLIWI, S. et al. Critical failure factors of lean Six Sigma: A systematic literature review. **International Journal of Quality and Reliability Management**, v. 31, n. 9, p. 1012–1030, 30 set. 2014.

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALMASHAQBEH, S.; HERNANDEZ, E. M. EVALUATION AND IMPROVEMENT OF A PLASTIC PRODUCTION SYSTEM USING INTEGRATED OEE METHODOLOGY: A CASE STUDY. **Management Systems in Production Engineering**, v. 32, n. 3, p. 450–463, 1 ago. 2024.

ALMEIDA, M. R. Princípios Básicos Para Uma Proposta De Ensino Sobre. p. 37–50, 2006.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015a.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015b.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015c.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015d.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. Lean production as promoter of thinkers to achieve companies' agility. **Learning Organization**, v. 19, p. 219–237, 2012a.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. **Lean production as promoter of thinkers to achieve companies' agility**. **Learning Organization**, abr. 2012b.

ALZUBI, E. et al. Hybrid integrations of value stream mapping, theory of constraints and simulation: Application to wooden furniture industry. **Processes**, v. 7, n. 11, 2019.

ANDERSSON, C.; BELLGRAN, M. On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity. **Journal of Manufacturing Systems**, v. 35, p. 144–154, 2015.

ANFAVEA. **Anuário da indústria automobilística brasileira**. [s.l: s.n.].

ANFAVEA, A. N. DOS F. DE V. A. **Anuário Estatístico da Indústria Automobilística Brasileira**.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013a.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013b.

APARICIO, J. et al. Measuring and decomposing firm's revenue and cost efficiency: The Russell measures revisited. **International Journal of Production Economics**, v. 165, p. 19–28, 1 jul. 2015.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017a.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017b.

AYOUBA, K. et al. A measure of price advantage and its decomposition into output- and input-specific effects. **European Journal of Operational Research**, v. 276, n. 2, p. 688–698, 16 jul. 2019.

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAKER, P. Why is lean so far off? v. 55, p. 26–29, 2002.

BANKES, S. **Exploratory Modeling for Policy AnalysisOperations Research**. [s.l: s.n.].

BANKES, S.; WALKER, W.; KWAKKEL, J. **Exploratory Modeling and Analysis**. [s.l: s.n.].

BAPTISTA, A.; ABREU, L.; BRITO, E. APPLICATION OF LEAN TOOLS CASE STUDY IN A TEXTILE COMPANY. **Proceedings on Engineering Sciences**, v. 3, n. 1, p. 93–102, 2021.

BARBERIO MARIANO, E. Conceitos Básicos de Análise de Eficiência produtiva. 2007.

BARBOSA, L. M. et al. Exploratory analysis of the variables prevailing on the effects of product modularization on production volume and efficiency. **International Journal of Production Economics**, v. 193, p. 677–690, 2017.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016a.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016b.

BARRATT, M.; CHOI, T. Y.; LI, M. Qualitative case studies in operations management: Trends, research outcomes, and future research implications. **Journal of Operations Management**, v. 29, n. 4, p. 329–342, 2011.

BBC. **Entenda por que a produtividade no Brasil não cresce**. Disponível em: <https://www.bbc.com/portuguese/noticias/2014/05/140519_produtividade_porque_ru>. Acesso em: 29 abr. 2023.

BBC. **Ford: afinal, por que a montadora decidiu encerrar a produção de veículos no Brasil?** Disponível em: <https://www.bbc.com/portuguese/internacional-55640907>. Acesso em: 7 maio. 2023.

BERGENWALL, A. L.; CHEN, C.; WHITE, R. E. TPSs process design in American automotive plants and its effects on the triple bottom line and sustainability. **International Journal of Production Economics**, v. 140, n. 1, p. 374–384, nov. 2012.

BETTERTON, C. E.; COX, J. F. Espoused drum-buffer-rope flow control in serial lines: A comparative study of simulation models. **International Journal of Production Economics**, v. 117, n. 1, p. 66–79, 2009.

BHASIN, S. An appropriate change strategy for lean success. **Management Decision**, v. 50, n. 3, p. 439–458, 2012.

BHASIN, S. Impact of corporate culture on the adoption of the lean principles. **International Journal of Lean Six Sigma**, v. 4, n. 2, p. 118–140, 2013.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002a.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002b.

BLANCHARD, D. Census of U.S. Manufactures: Lean Green and Low Cost. **Industry Week**, v. October, 2007.

BORTOLOTTI, T.; BOSCARI, S.; DANESE, P. Successful lean implementation: Organizational culture and soft lean practices. **International Journal of Production Economics**, v. 160, p. 182–201, 2015.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015a.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015b.

CAMANHO et al. A literature review of economic efficiency assessments using Data Envelopment Analysis. **European Journal of Operational Research**, 2023.

CAMANHO, A. S.; DYSON, R. G. Cost efficiency measurement with price uncertainty: A DEA application to bank branch assessments. **European Journal of Operational Research**, v. 161, n. 2, p. 432–446, 2005.

CARDOSO ERMEL, A. P. et al. **Literature Reviews**. Cham: Springer International Publishing, 2021.

CESARONI, G.; GIOVANNOLA, D. Average-cost efficiency and optimal scale sizes in non-parametric analysis. **European Journal of Operational Research**, v. 242, n. 1, p. 121–133, 1 abr. 2015.

CHAKRAVORTY, S. S.; ATWATER, J. B. The impact of free goods on the performance of drumbuffer-rope scheduling systems. **International Journal of Production Economics**, v. 95, n. 3, p. 347–357, 2005.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016a.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016b.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018a.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018b.

CHARNES, A.; COOPER, W. W.; RHODES, E. Measuring the efficiency of decision making units. **European Journal of Operational Research**, v. 2, n. 6, p. 429–444, 1978.

CHIZARI, A. H.; FEHRESTI-SANI, M. Evaluation of the economic efficiency of vegetable oil supply chains. **Supply Chain Forum**, v. 19, n. 2, p. 132–141, 3 abr. 2018.

COOK, W. D.; TONE, K.; ZHU, J. Data envelopment analysis: Prior to choosing a model. **Omega (United Kingdom)**, v. 44, p. 1–4, 2014.

CORRALES, L. DEL C. N. et al. Overall equipment effectiveness: Systematic literature review and overview of different approaches. **Applied Sciences (Switzerland)**, v. 10, n. 18, 2020.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016a.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016b.

COSTA, B.; VAREJÃO, J.; GASPAR, P. D. Development of a Value Stream Map to Optimize the Production Process in a Luxury Metal Piece Manufacturing Company. **Processes**, v. 12, n. 8, 1 ago. 2024.

COSTA, F. et al. How to foster Sustainable Continuous Improvement: A cause-effect relations map of Lean soft practices. **Operations Research Perspectives**, v. 6, n. December, p. 100091, 2019.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010a.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010b.

COX III, J. F.; SCHLEIER JR, J. G. **Handbook da Teoria das Restrições.** Bookman ed. Porto Alegre: [s.n.].

COX, J. F. I. et al. The TOCICO dictionary. v. 2, p. 1–135, 2012.

COX, J.F. III; SCHLEIER, J.G., J. **Handbook Theory of Constraints**. [s.l.] Bookman, 2013.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021a.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021b.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015a.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015b.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015c.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015d.

DAS, S.; PATEL, G. N. Cost efficiency of pharmaceutical firms manufacturing drugs for specific diseases prevalent in India: A data envelopment analysis approach. **Journal of Medical Marketing**, v. 14, n. 1, p. 5–19, 1 fev. 2014.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018a.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018b.

DE TREVILLE, S. et al. Editorial: Toyota Production System practices as Fast-and-Frugal heuristics. **Journal of Operations Management**, v. 69, n. 4, p. 522–535, 2023.

DIAS, R. M. F.; SILVA, L. D.; TENERA, A. Application of a proposed TLS model in a Lean Productive System. **Independent Journal of Management & Production**, v. 10, n. 1, p. 076, 2019.

DOBRA, P.; JÓSVAI, J. Overall Equipment Effectiveness (OEE) Life Cycle at the Automotive Semi-Automatic Assembly Lines. **Acta Polytechnica Hungarica**, v. 19, n. 9, p. 141–155, 2022.

DOGAN, N.; KAYGISIZ, F.; ALTINEL, A. Technical and economic efficiency of laying hen farms in Konya, Turkey. **Revista Brasileira de Ciencia Avicola**, v. 20, n. 2, p. 263–272, 2018.

DORA, M.; KUMAR, M.; GELLYNCK, X. Determinants and barriers to lean implementation in food-processing SMEs - A multiple case analysis. **Production Planning and Control**, v. 27, n. 1, p. 1–23, 2 jan. 2016.

ELKHAIRI, A.; FEDOUAKI, F.; EL ALAMI, S. Barriers and critical success factors for implementing lean manufacturing in SMEs. **IFAC-PapersOnLine**, v. 52, n. 13, p. 565–570, 2019.

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011a.

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011b.

FERRAZZI, M. et al. Investigating the influence of lean manufacturing approach on environmental performance: A systematic literature review. **International Journal of Advanced Manufacturing Technology**, 1 fev. 2024.

FGV. **BRASILEIRO LEVA 1 HORA PARA PRODUZIR O QUE AMERICANO FAZ EM 15 MINUTOS**. Disponível em: <https://eesp.fgv.br/noticia/brasileiro-leva-1-hora-para-produzir-o-que-americano-faz-em-15-minutos>. Acesso em: 29 abr. 2023.

FILIPE, D.; PIMENTEL, C. Production and Internal Logistics Flow Improvements through the Application of Total Flow Management. **Logistics**, v. 7, n. 2, 1 jun. 2023.

FOUND, P. et al. Towards a theory of operational excellence. **Total Quality Management and Business Excellence**, v. 29, n. 9–10, p. 1012–1024, 29 jul. 2018.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020a.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020b.

FURLAN, A.; VINELLI, A.; PONT, G. D. Complementarity and lean manufacturing bundles: An empirical analysis. **International Journal of Operations and Production Management**, v. 31, n. 8, p. 835–850, 2011.

GALEAZZO, A.; FURLAN, A. Lean bundles and configurations: a fsQCA approach. **International Journal of Operations and Production Management**, v. 38, n. 2, p. 513–533, 2018.

GAUSS, L. et al. Design science in operations management: A review and synthesis of the literature. **International Journal of Management Reviews**, 5 dez. 2024.

GLOBO. **Mapa: todas as fábricas de carros, motos e caminhões estão paradas no Brasil por pandemia**. Disponível em: <https://autoesporte.globo.com/carros/noticia/2020/03/mapa-todas-fabricas-de-carros-motos-e-caminhoes-estao-paradas-no-brasil-por-pandemia.ghtml>.

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E. M. Computerized shop floor scheduling. 1988a.

GOLDRATT, E. M. Computerized shop floor scheduling. 1988b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009a.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009c.

GOLDRATT, E. M. & F. R. E. **The Race**. [s.l: s.n.].

GOLDRATT, E. M.; COX, J. **A Meta**. 3° ed. [s.l: s.n.].

GOLDRATT, E. M.; FOX, R. E. **The Race**. [s.l: s.n.].

GOLMOHAMMADI, D. A study of scheduling under the theory of constraints. **International Journal of Production Economics**, v. 165, p. 38–50, 2015.

GONZÁLEZ ALEU, F.; GARZA-REYES, J. A. **Leading continuous improvement projects: Lessons from successful, less successful, and unsuccessful continuous improvement case studies**. 2020.

GONZALEZ-R, P. L.; FRAMINAN, J. M.; RUIZ-USANO, R. A multi-objective comparison of dispatching rules in a drum-buffer-rope production control system. **International Journal of Computer Integrated Manufacturing**, v. 23, n. 2, p. 155–167, 2010.

GOSLING, J.; NAIM, M. M. Engineer-to-order supply chain management: A literature review and research agenda. **International journal of production economics**, v. 122(2), p. 741–754, 2009.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007a.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007b.

GUILLEN, K. et al. LEAN model for optimizing plastic bag production in small and medium sized companies in the plastics sector. **International Journal of Engineering Research and Technology**, v. 11, n. 11, p. 1713–1734, 2018.

GUPTA, A.; BHARDWAJ, A.; KANDA, A. Fundamental concepts of theory of constraints: An emerging philosophy. **World Academy of Science, Engineering and Technology**, v. 46, n. 10, p. 686–692, 2010.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022a.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022b.

GUPTA, S.; MODGIL, S.; GUNASEKARAN, A. Big data in lean six sigma: a review and further research directions. **International Journal of Production Research**, v. 58, n. 3, p. 947–969, 2020.

HARDCOPF, R.; LIU, G. (JASON); SHAH, R. Lean production and operational performance: The influence of organizational culture. **International Journal of Production Economics**, v. 235, n. March 2020, p. 108060, 2021.

HATAMI-MARBINI, A.; ARABMALDAR, A. Robustness of Farrell cost efficiency measurement under data perturbations: Evidence from a US manufacturing application. **European Journal of Operational Research**, v. 295, n. 2, p. 604–620, 2021.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015a.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015b.

HO, T. Q.; HOANG, V. N.; WILSON, C. Trade-off analysis of cost and nutrient efficiency of coffee farms in vietnam: A more generalised approach. **Journal of Environmental Management**, v. 279, n. August, p. 111601, 2021.

HOPP, W. J. Positive lean: merging the science of efficiency with the psychology of work. **International Journal of Production Research**, v. 56, n. 1–2, p. 398–413, 2018.

HOPP, W. J.; SPEARMAN, M. L. To pull or not to pull: What is the question? **Manufacturing and Service Operations Management**, v. 6, n. 2, p. 133–148, 2004.

HOPP, W. J.; SPEARMAN, M. S. The lenses of lean: Visioning the science and practice of efficiency. **Journal of Operations Management**, v. 67, n. 5, p. 610–626, 2021.

HÜTTMEIR, A. et al. Trading off between heijunka and just-in-sequence. **International Journal of Production Economics**, v. 118, n. 2, p. 501–507, abr. 2009.

IKEZIRI, L. M. et al. Theory of constraints: review and bibliometric analysis. **International Journal of Production Research**, v. 57, n. 15–16, p. 1–35, 2018.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023a.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023b.

INAN, G. G. ; et al. Operational performance improvement through continuous improvement initiatives in micro-enterprises of Turkey. **Asia-Pacific Journal of Business Administration,** v. 14, n. 3, p. 335–361, 2021.

IOANA, A. D.; MARIA, E. D.; CRISTINA, V. **Case study regarding the implementation of one-piece flow line in automotive company**. Procedia Manufacturing. **Anais**...Elsevier B.V., 2020.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014a.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014b.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014a.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014b.

JAIN, S.; TRIANTIS, K. P.; LIU, S. Manufacturing performance measurement and target setting: A data envelopment analysis approach. **European Journal of Operational Research**, v. 214, n. 3, p. 616–626, 2011.

JRADI, S.; BOUZDINE CHAMEEVA, T.; APARICIO, J. The measurement of revenue inefficiency over time: An additive perspective. **Omega (United Kingdom)**, v. 83, p. 167–180, 1 mar. 2019.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013a.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013b.

KERSTENS, K.; SADEGHI, J.; VAN DE WOESTYNE, I. Convex and nonconvex input-oriented technical and economic capacity measures: An empirical comparison. **European Journal of Operational Research**, v. 276, n. 2, p. 699–709, 2019.

KIM, J.; GERSHWIN, S. B. Integrated quality and quantity modeling of a production line. **Stochastic Modeling of Manufacturing Systems: Advances in Design, Performance Evaluation, and Control Issues**, p. 121–148, 2006.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010a.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010b.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, jan. 2010c.

KONOPKA, J. M. Capacity Utilization Bottleneck Efficiency System—CUBES. **IEEE Transactions on Components Packaging and Manufacturing Technology Part A**, v. 18, n. 3, p. 484–491, 1995.

KUMAR, R.; KUMAR, V. Barriers in implementation of lean manufacturing system in Indian industry: A survey. **International Journal of Latest Trends in Engineering & Technology**, v. 4, p. 243–251, 2014.

KWAKKEL, J. H.; PRUYT, E. Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. **Technological Forecasting and Social Change**, v. 80, n. 3, p. 419–431, 2013.

LACERDA, D. P. et al. Design Science Research: Método de pesquisa para a engenharia de produção. **Gestao e Producao**, v. 20, n. 4, p. 741–761, 26 nov. 2013.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021a.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021b.

LANZA, G. et al. Measuring global production effectiveness. **Procedia CIRP**, v. 7, p. 31–36, 2013.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024a.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024b.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024c.

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LEITE, H.; RADNOR, Z.; BATEMAN, N. Meaningful inhibitors of the lean journey: a systematic review and categorisation of over 20 years of literature. **Production Planning and Control**, v. 33, n. 5, p. 403–426, 2022.

LIKER, J.; ROTHER, M. Why Lean Programs Fail. **Lean Enterprise Institute**, p. 1–5, 2011.

LIM, A. S. S.; SABIL, S.; OTHMAN, A. E. B. A. the Mediating Role of Continuous Improvement on the Relationship Between Workplace Learning Dimensions and Sustainable Lean Manufacturing. **International Journal of Business and Society**, v. 23, n. 1, p. 260–278, 2022.

LIU, J. et al. A DEA-based approach for competitive environment analysis in global operations strategies. **International Journal of Production Economics**, v. 203, p. 110–123, 2018.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019a.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019b.

LUZ, G. P. et al. Proposition of a method for stochastic analysis of value streams. **Production Planning and Control**, v. 33, n. 8, p. 741–757, 2022.

MABIN, V. J.; BALDERSTONE, S. J. The performance of the theory of constraints methodology: Analysis and discussion of successful TOC applications. **International Journal of Operations and Production Management**, v. 23, n. 5–6, p. 568–595, 2003.

MAHJOOR, A. A. Technical, allocative and economic efficiencies of broiler farms in Fars Province, Iran: A Data Envelopment Analysis (DEA) approach. **World Applied Sciences Journal**, v. 21, n. 10, p. 1427–1435, 2013.

MANAVIZADEH, N. et al. A Simulated Annealing algorithm for a mixed model assembly U-line balancing type-I problem considering human efficiency and Just-In-Time approach. **Computers and Industrial Engineering**, v. 64, p. 669–685, 2013.

MARFATIA, H. et al. S earch and s urvey. n. February 2021, p. 10–17, 2020.

MARODIN, G. A. et al. Model of risk interactions hindering lean production implementation. **Gestao e Producao**, v. 25, n. 4, p. 696–712, 2018.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019a.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019b.

MARTINS, J. C. et al. Systems dynamic modeling to analyze the systemic viability of the combined use of regenerative converters and energy storage in a UPS manufacturer. **Journal of Cleaner Production**, v. 246, n. xxxx, p. 118950, 2020.

MEMARI, A. et al. The impact of lean production on operational performance: a case study. **Asia-Pacific Journal of Business Administration**, 2022.

MILLSTEIN, M. A.; MARTINICH, J. S. Takt Time Grouping: Implementing kanban-flow manufacturing in an unbalanced, high variation cycle-time process with moving constraints. **International Journal of Production Research**, v. 52, n. 23, p. 6863–6877, 2014.

MOHANAVELU, T.; KRISHNASWAMY, R.; MARIMUTHU, P. Simulation modelling and development of analytic hierarchy process-based priority dispatching rule for a dynamic press shop. **nternational Journal of Industrial and Systems Engineering**, v. 27(3), p. 340–364, 2017.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023a.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023b.

MOHD AZHAR SAHWAN; MOHD NIZAM AB RAHMAN; BABA MD DEROS. Barriers to Implement Lean Manufacturing in Malaysian Automotive Industry. **Jurnal Teknologi (Sciences and Engineering)**, v. 59, p. 107–110, 2012.

MORANDI, M. I. W. M. et al. Foreseeing Iron Ore Prices Using System Thinking and Scenario Planning. **Systemic Practice and Action Research**, v. 27, n. 3, p. 287–306, 2014.

MORANDI, M. I. W. M.; CAMARGO, L. F. R. **Revisão sistemática da literatura. Design science research: Método de pesquisa para avanço da ciência e tecnologia**. [s.l.] Bookman, 2015.

MUCHIRI, P.; PINTELON, L. Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. **International Journal of Production Research**, v. 46, n. 13, p. 3517–3535, 2008.

MUTHIAH, K. M. N.; HUANG, S. H. Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection. **International Journal of Production Research**, v. 45, n. 20, p. 4753–4769, 2007.

NACIRI, L. et al. **Lean and industry 4.0: A leading harmony**. Procedia Computer Science. **Anais**...Elsevier B.V., 2022.

NANCI, L. C.; AZEREDO, S. M.; MELLO, J. C. C. B. S. DE. Estudo da eficiência de empresas distribuidoras de jornais usando análise envoltória de dados. **Produto & Produção**, v. 7, n. 3, p. 27–35, 2006.

NARASIMHAN, R.; SWINK, M.; KIM, S. W. Disentangling leanness and agility: An empirical investigation. **Journal of Operations Management**, v. 24, n. 5, p. 440–457, 2006.

NARASSIMA, M. S. et al. Implementation of lean principles in the yarn manufacturing industry: a system dynamics approach. **Benchmarking**, 2023.

NEELY, A.; GREGORY, M.; PLATTS, K. A literature review and research agenda. **International Journal of Operations & Production Management**, v. 15, n. 4, p. 80–116, 2002.

NETLAND, T. H.; SCHLOETZER, J. D.; FERDOWS, K. Learning lean: rhythm of production and the pace of lean implementation. **International Journal of Operations and Production Management**, v. 41, n. 2, p. 131–156, 2021.

NG CORRALES, L. D. C. et al. Developing and Implementing a Lean Performance Indicator: Overall Process Effectiveness to Measure the Effectiveness in an Operation Process. **Machines**, v. 10, n. 2, 1 fev. 2022.

OECHSNER, R. et al. From overall equipment efficiency (OEE) to overall Fab effectiveness (OFE). **Materials Science in Semiconductor Processing**, v. 5, n. 4- 5 SPEC., p. 333–339, 2002.

OH, I. et al. Analysis of product efficiency in the Korean automobile market from a consumer's perspective. **Empirical Economics**, v. 38, n. 1, p. 119–137, fev. 2010.

OHNO, T. Toyota Production System: beyond large-scale production. **Oregon: Productivity Press**, 1988.

OHNO, T. **O Sistema Toyota de Produção Além da Produção em Larga Escala**. [s.l.] Bookman, 1997.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021a.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021b.

PACHECOA, D. A. DE J. Theory of Constraints, Lean Manufacturing and Six Sigma: Limits to and possibilities for integration. **Producao**, v. 24, n. 4, p. 940–956, 2014.

PARK, J.; LEE, D.; ZHU, J. An integrated approach for ship block manufacturing process performance evaluation: Case from a Korean shipbuilding company. **International Journal of Production Economics**, v. 156, p. 214–222, 2014.

PEARCE, A.; PONS, D.; NEITZERT, T. Implementing lean—Outcomes from SME case studies. **Operations Research Perspectives**, v. 5, p. 94–104, 2018.

PEREIRA, L.; TORTORELLA, G. Identification of the relationships between critical success factors, barriers and practices for lean implementation in a small company. **Brazilian Journal of Operations & Production Management**, v. 15, n. 2, p. 232–246, 1 jun. 2018.

PERVAZ, J. et al. SIMULATION-BASED ALGORITHM FOR CONTINUOUS IMPROVEMENT OF ENTERPRISES PERFORMANCE. **International Journal of Simulation Modelling**, v. 23, n. 2, p. 215–226, 1 jun. 2024.

PIRAN, F. A. S. et al. Product modularization and effects on efficiency: An analysis of a bus manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 182, p. 1–13, 2016.

PIRAN, F. A. S. et al. Overall Equipment Effectiveness: Required but not Enough—An Analysis Integrating Overall Equipment Effect and Data Envelopment Analysis. **Global Journal of Flexible Systems Management**, v. 21, n. 2, p. 191–206, 1 jun. 2020.

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, 2021a.

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, n. April, p. 108173, 2021b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020b.

PONT, G. D.; FURLAN, A.; VINELLI, A. Interrelationships among lean bundles and their effects on operational performance. **Operations Management Research**, v. 1, n. 2, p. 150–158, 2009.

PORTELA, M. C. A. S.; THANASSOULIS, E. Economic efficiency when prices are not fixed: Disentangling quantity and price efficiency. **Omega (United Kingdom)**, v. 47, p. 36–44, 2014.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019a.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019b.

PSAROMMATIS, F.; AZAMFIREI, V. **Zero Defect Manufacturing: A complete guide for advanced and sustainable quality management**. **Journal of Manufacturing Systems**Elsevier B.V., , 1 dez. 2024.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 2019a.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019b.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019c.

QAMAR, A. et al. Quality and flexibility performance trade-offs between lean and agile manufacturing firms in the automotive industry. **Production Planning and Control**, v. 31, n. 9, p. 723–738, 2020.

QURESHI, K. M. et al. Exploring the Lean Implementation Barriers in Small and Medium-Sized Enterprises Using Interpretive Structure Modeling and Interpretive Ranking Process. **Applied System Innovation**, v. 5, n. 4, p. 1–20, 2022.

RAMADAS, T.; SATISH, K. P. Identification and modeling of process barriers: Implementing lean manufacturing in small-and medium-size enterprises. **International Journal of Lean Six Sigma**, v. 12, n. 1, p. 61–77, 2021.

RAOUF, A. Improving capital productivity through maintenance. . **International Journal of Operations & Production Management**, v. 14 (7), p. 44–52, 1994.

REPONEN, E. et al. Benchmarking outcomes on multiple contextual levels in lean healthcare: a systematic review, development of a conceptual framework, and a research agenda. **BMC Health Services Research**, v. 21, n. 1, 1 dez. 2021.

ROCHMAN, Y. A.; SUDIARSO, A.; HERLIANSYAH, M. K. Development of Lean Implementation Framework for Indonesian Batik Small and Medium-Sized Enterprises. **International Journal of Engineering, Transactions B: Applications**, v. 37, n. 11, p. 2223–2238, 1 nov. 2024.

ROJON, C.; OKUPE, A.; MCDOWALL, A. Utilization and development of systematic reviews in management research: What do we know and where do we go from here? **International Journal of Management Reviews**, v. 23, n. 2, p. 191–223, 1 abr. 2021.

ROMERO, L. F. et al. A data envelope analysis to assess factors affecting technical and economic efficiency of individual broiler breeder hens. **Poultry Science**, v. 89, n. 8, p. 1769–1777, 2010.

SARTAL, A.; VAZQUEZ, X. H.; LOZANO-LOZANO, L. M. Organizational Tools and Cultural Change in the Success of Lean Transformations: Delving Into Sequence and Rhythm. **IEEE Transactions on Engineering Management**, v. 69, n. 5, p. 2205–2217, 1 out. 2022.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023a.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023b.

SCOTT, D.; PISA, R. Can overall factory effectiveness prolong Mooer's law? **Solid State Technology**, p. 75–81, 1998.

SECCHI, R.; CAMUFFO, A. Lean implementation failures: The role of organizational ambidexterity. **International Journal of Production Economics**, v. 210, p. 145–154, 1 abr. 2019.

SILVA, F.; MENEZES-FILHO, N.; KOMATSU, B. Evolução da produtividade no Brasil: comparações internacionais. **Insper Policy Paper**, n. 15, p. 30, 2016.

SOHRMANN, C. et al. Towards a Standardized Format for Automotive Mission Profiles State of the Art Use Cases for Mission Profiles Application of MPs in Verification and. **Proc. Automotive meets Electronics 10**, n. March, p. 39–44, 2021.

SPEAR, S.; BOWEN, H. K. Decoding the DNA of the Toyota Production System. **Harvard Business Review**, v. 77, n. 5, p. 96–106, 1999.

STAUDACHER, A. P.; TANTARDINI, M. **Lean production implementation: a survey in Italy**. XI Congreso de Ingeniería de Organizacion International Conference on Industrial Engineering and Industrial Management,. **Anais**...Madri: 2007.

STEELE, D. C. et al. Comparisons between drum-buffer-rope and material requirements planning: A case study. **International Journal of Production Research**, v. 43, n. 15, p. 3181–3208, 2005.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022a.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022b.

STRATTON, R.; WARBURTON, R. D. H. The strategic integration of agile and lean supply. **International Journal of Production Economics**, v. 85, n. 2, p. 183–198, 2003.

SUKWADI, R.; FELICIA, Y.; MUAFI. TOC, lean, and six sigma: An integrated model to increase the productivity of the textile industry. **Journal of Mechanical Engineering Research and Developments**, v. 44, n. 1, p. 327–336, 2021.

SUSAETA, A. et al. Technical, allocative, and total profit efficiency of loblolly pine forests under changing climatic conditions. **Forest Policy and Economics**, v. 72, p. 106–114, 1 nov. 2016.

SWEETSER, A. **A Comparison of System Dynamics (SD) and Discrete Event Simulation (DES)**. [s.l: s.n.].

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000a.

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, n. February, p. 107500, 2020a.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020c.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020d.

TELLES, E. S. et al. Drum-Buffer-Rope in an engineering-to-order productive system: a case study in a Brazilian aerospace company. **Journal of Manufacturing Technology Management**, v. 33, n. 6, p. 1190–1209, 6 set. 2022.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020a.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020b.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020c.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018a.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018b.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018c.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018d.

THÜRER, M.; TOMAŠEVIĆ, I.; STEVENSON, M. **On the meaning of 'Waste': review and definition**. **Production Planning and Control**Taylor and Francis Ltd., , 17 fev. 2017.

TOMA, S.; NARUO, S. Total Quality Management and Business Excellence: the Best Practices At Toyota Motor Corporation. 2017.

TORTORELLA, G. L. et al. The impact of contextual variables on learning organization in firms that are implementing lean: a study in Southern Brazil. **International Journal of Advanced Manufacturing Technology**, v. 78, n. 9–12, p. 1879–1892, 18 jun. 2015.

TORTORELLA, G. L. et al. Learning organisation and lean production: an empirical research on their relationship. **International Journal of Production Research**, v. 58, n. 12, p. 3650–3666, 2020.

VEGA-ALVITES, J. C. Q.-F. & M. L. Review Lean Manufacturing Model of Production Management Under the Preventive. **South African Journal of Industrial Engineering**, v. 33, n. 2, p. 143–156, 2022.

VENKATESH, A.; KUSHWAHA, S. Short and long-run cost efficiency in Indian public bus companies using Data Envelopment Analysis. **Socio-Economic Planning Sciences**, v. 61, p. 29–36, 1 mar. 2018.

VON GILSA, C. et al. Longitudinal evaluation of efficiency in a petrochemical company. **Benchmarking**, v. 24, n. 7, p. 1786–1813, 2017.

WAHAB, A. et al. Improvement on bill of materials formatting process by adopting lean and six sigma approaches-A case study in a semiconductor industry ilhammee. **International Journal of Integrated Engineering**, v. 11, n. 8, p. 81–90, 2019.

WAHLERS, J. L.; COX, J. F. Competitive factors and performance measurement: Applying the theory of constraints to meet customer needs. **International Journal of Production Economics**, v. 37, n. 2–3, p. 229–240, 1994.

WALLACE J. HOPP, M. L. S. **Factory Physics**. Third Edit ed. [s.l: s.n.].

WATSON, K. J.; BLACKSTONE, J. H.; GARDINER, S. C. The evolution of a management philosophy: The theory of constraints. **Journal of Operations Management**, v. 25, n. 2, p. 387–402, 2007.

WATSON, K. J.; PATTI, A. A comparison of JIT and TOC buffering philosophies on system performance with unplanned machine downtime. **International Journal of Production Research**, v. 46, n. 7, p. 1869–1885, 2008.

WEBSTER, J.; WATSON, R. MIS Quarterly. **Analyzing the Past To Prepare for the Future : Writing a Literature Review**, v. 26, n. 2, p. 13–23, 2002.

WONG, Y. C.; WONG, K. Y.; ALI, A. A study on Lean Manufacturingimplementation in the Malaysian electrical and electronics industry. **European Journal of Scientific Research**, v. Vol. 38, 2009.

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WU, H. H.; LIU, J. Y. A capacity available-to-promise model for drum-buffer-rope systems. **International Journal of Production Research**, v. 46, n. 8, p. 2255–2274, 2008.

WU, S.; WEE, H. M. Why the big three decline despite their lean management - A study based on the theory of constraints. **Global Perspective for Competitive Enterprise, Economy and Ecology - Proceedings of the 16th ISPE International Conference on Concurrent Engineering**, p. 691–699, 2009.

YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008a.

YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008b.

YENRADEE, P. Application of optimized production technology ina capacity constrained flow shop: a case study in a battery factory. **Comput. Ind. Eng.**, v. 27, p. 217–220, 1994.

ZHANG, L.; NARKHEDE, B. E.; CHAPLE, A. P. Evaluating lean manufacturing barriers: An interpretive process. **Journal of Manufacturing Technology Management**, v. 28, n. 8, p. 1086–1114, 2017.

APPENDIX A - PROTOCOL FOR SYSTEMATIC LITERATURE REVIEW

<table>
<tr><th colspan="3">Research Protocol</th></tr>
<tr><td colspan="3">Research Title: Path to Economic Efficiency supported by continuous improvement and Lean, an analysis through Systematic Literature Review</td></tr>
<tr><td colspan="3">Research Team: Noal, L. C., Gauss. L., and Lacerda, D. P.</td></tr>
<tr><td colspan="3">Interested Parties: Research Group on Modeling for Learning (GMAP | Unisinos)</td></tr>
<tr><td>Revision: 01</td><td>Date: 15/12/2024</td><td>Reviewed by: Gauss, L.; Lacerda, D. P.</td></tr>
<tr><td colspan="3">1. Research Question(s):</td></tr>
<tr><td colspan="3">How has Lean Manufacturing related continuous improvement to efficiency in manufacturing and service processes?</td></tr>
<tr><td colspan="3">2. Review Question(s):</td></tr>
<tr><td colspan="3">2.1. Does every improvement in technical efficiency turn into an improvement in economic efficiency?
2.2. How does the Lean Manufacturing methodology contribute to economic efficiency in production systems?</td></tr>
<tr><td colspan="3">3. Review Objective(s)</td></tr>
<tr><td colspan="3">3.1. Confront the gains in technical efficiency that may or may not be transformed into economic efficiency.
3.2. When implementing Lean and continuous improvement systems, is the gain in economic efficiency a relevant point?
3.3. Identify possible Lean gaps in the light of economic efficiency.</td></tr>
<tr><td colspan="3">4. Review Scope:</td></tr>
<tr><td>4.1. Amplitude:</td><td>☒ Narrow</td><td>☐ Broad</td></tr>
<tr><td>4.2. Deepness:</td><td>☐ Superficial</td><td>☒ Deep</td></tr>
<tr><td>4.3. Review Type:</td><td>☐ Aggregative</td><td>☒ Configurative</td></tr>
<tr><td colspan="3">5. Theoretical/Conceptual Framework:</td></tr>
<tr><td colspan="3">Efficiency and productivity are widely discussed across academic, governmental, and business sectors, given their intrinsic connection to the economic development of regions and, consequently, entire countries (Kerstens; Sadeghi; Van De Woestyne, 2019; Piran; Lacerda; Camargo, 2020). The primary objective of for-profit organizations is to generate sustainable profits, both in the short and long term (STEFANO et al., 2022a). To achieve this, organizations must operate production systems capable of transforming various resources—such as materials, labor, and energy—into products or services that effectively meet customer needs and market demands (IKEZIRI et al., 2023a). Globally, organizations have shown increasing interest in adopting the Lean methodology, initially within the industrial sector and, more recently, across service industries.
The implementation of Lean Manufacturing fosters process improvements by enhancing production efficiency, improving product quality, reducing operational costs, and creating a more conducive work environment for employees (Vega-alvites, 2022).
Despite its potential, many Lean implementations face significant challenges in fully realizing their efficiency objectives (HOPP, 2018). Moreover, the success rate of Lean adoption has proven to be notably low, underscoring the complexity of effectively integrating its principles into diverse operational contexts (HARDCOPF; LIU; SHAH, 2021). To achieve operational excellence, companies have embraced a variety of approaches, including continuous improvement initiatives (GUPTA et al., 2022a), innovation, and the refinement of processes and products, all aimed at sustaining competitive advantages (DIAS; SILVA; TENERA, 2019). In this context, strategies focused on waste elimination are crucial for maximizing operational efficiency (ALZUBI et al., 2019).
Consequently, organizations seek to adopt practices that enhance their productive capacity, operational performance, product quality, and organizational resilience (Mohd Aripin et al., 2023). For manufacturing industries in particular, integrating new operational approaches is vital to securing a competitive edge while boosting production capacity,</td></tr>
</table>

Research Protocol			
efficiency, quality, and resilience (Mohd Aripin et al., 2023). While the analysis of technical efficiency remains critical in practical applications, it often falls short of providing comprehensive insights, as managers typically require information that also addresses economic dimensions (Piran et al., 2021b). Recent studies have expanded efficiency analyses beyond traditional time-based metrics, incorporating variables related to physical quantities, such as raw material consumption (Barbosa et al., 2017; De Souza et al., 2018; Piran et al., 2016; Von Gilsa et al., 2017). However, these analyses have limitations, primarily because they do not account for economic factors. In contrast, evaluations that incorporate economic efficiency offer a broader perspective. They not only assess technical efficiency but also identify the optimal combination of inputs and outputs to minimize costs or maximize revenue and profit (Aparicio et al., 2013; Piran et al., 2021b). Relying solely on technical assessments can narrow a manager's perspective, potentially overlooking opportunities for cost reduction and operational improvements—gaps that are often highlighted through economic analyses.			
6. Time Horizon:			
Up to 2024.			
7. Search String:			
TITLE-ABS-KEY ("lean" , "efficiency" , "continuous improvement") AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI"))			
8. Search Sources:			
☒ Scopus	☒ Web of Science	☐ Science Direct	☐ Other:
9. Searching Approach:			
☒ Database searching	☐ Experts contacting	☒ Snowballing	☐ Other:
10. Eligibility Criteria:			
10.1. Inclusion criteria:	10.1.1. Documents that contain Lean, Continuous Improvement and Efficiency 10.1.2. Documents containing assessment of economic efficiency driven by Lean		
10.2. Exclusion criteria:	General: 10.2.1. Duplicate studies. 10.2.2. Content not available. 10.2.3. Not written in English. 10.2.4. Studies not related to Lean and Efficiency.		
11. Data Analysis:			
11.1. Scientometric analysis:	☐ Scientific development		
11.2. Bibliometric analysis:	☐ Research performance	☒ Scientific mapping	
11.3. Content analysis:	☐ Aggregative	☒ Thematic analysis	☒ Structural analysis
12. Data Synthesis:			
12.1. Aggregative synthesis:	☐ Quantitative meta-analysis	☐ Qualitative meta-analysis	
12.2. Configurative synthesis:	☒ Meta-synthesis	☐ Other:	

APPENDIX B – ANALYSIS CORPUS

	Title	Authors
D1	Simulation-Based Algorithm for Continuous Improvement of Enterprises Performance	(PERVAZ et al., 2024)
D2	Development of a Value Stream Map to Optimize the Production Process in a Luxury Metal Piece Manufacturing Company	(COSTA; VAREJÃO; GASPAR, 2024)
D3	Evaluation and Improvement of a Plastic Production System using Integrated OEE methodology: A case study	(ALMASHAQBEH; HERNANDEZ, 2024)
D4	Development of Lean Implementation Framework for Indonesian Batik Small and Medium-Sized Enterprises	(ROCHMAN; SUDIARSO; HERLIANSYAH, 2024)
D5	Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study	(LAROCA et al., 2024b)
D6	Integration of Six Sigma and simulations in real production factory to improve performance – a case study analysis	(AHMED; OLSEN; PAGE, 2023)
D7	Production and Internal Logistics Flow Improvements through the Application of Total Flow Management	(FILIPE; PIMENTEL, 2023)
D8	The impact of lean production on operational performance: a case study	(MEMARI et al., 2022)
D9	Organizational Tools and Cultural Change in the Success of Lean Transformations: Delving Into Sequence and Rhythm	(SARTAL; VAZQUEZ; LOZANO-LOZANO, 2022)
D10	Developing and Implementing a Lean Performance Indicator: Overall Process Effectiveness to Measure the Effectiveness in an Operation Process	(NG CORRALES et al., 2022)
D11	Operational performance improvement through continuous improvement initiatives in micro-enterprises of Turkey	(INAN et al., 2021)
D12	Application of Lean Tools case study in a textile company	(BAPTISTA; ABREU; BRITO, 2021)
D13	Learning organisation and lean production: an empirical research on their relationship	(TORTORELLA et al., 2020)
D14	Improvement on bill of materials formatting process by adopting lean and six sigma approaches-A case study in a semiconductor industry ilhammee	(WAHAB et al., 2019)
D15	Lean production and operational performance in the Brazilian automotive supply chain	(Marodin et al., 2019)
D16	Identification of the Relationships between critical success factors, barriers and practices for Lean implementation in a small company	(PEREIRA; TORTORELLA, 2018)
D17	On the meaning of 'Waste': review and definition	(THÜRER; TOMAŠEVIĆ; STEVENSON, 2017)

Source: Prepared by the author

APPENDIX C – CODIFICATION

	● Buffer - Waste Gr=12	● Does not present financial gains Gr=4	● Lean Gr=78	○ Lean - Culture Gr=18	● Lean - Economic Efficiency Gr=8	○ Lean - Reduction Variability Gr=8	○ Lean implementation failure Gr=18	● Lean Reduction Waste Gr=60	● Lean Tools - Technical Efficiency Gr=82	○ Reduction Costs Gr=8	○ Reduction Waste - Technical Efficiency Gr=12	○ WIP Inventory - Waste Gr=7
● **Buffer - Waste** Gr=12	0	0	2	0	0	0	0	0	1	0	1	3
● **Does not present financial gains** Gr=4	0	0	0	1	1	0	4	0	1	0	0	0
● **Lean** Gr=78	2	0	0	4	3	3	0	20	24	2	3	1
○ **Lean - Culture** Gr=18	0	1	4	0	0	1	4	2	5	0	1	0
● **Lean - Economic Efficiency** Gr=8	0	1	3	0	0	0	1	2	3	1	0	0
○ **Lean - Reduction Variability** Gr=8	0	0	3	1	0	0	0	5	3	1	0	0
○ **Lean implementation failure** Gr=18	0	4	0	4	1	0	0	0	2	0	1	0
● **Lean Reduction Waste** Gr=60	0	0	20	2	2	5	0	0	22	5	2	1
● **Lean Tools - Technical Efficiency** Gr=82	1	1	24	5	3	3	2	22	0	3	5	1
○ **Reduction Costs** Gr=8	0	0	2	0	1	1	0	5	3	0	0	0
○ **Reduction Waste - Technical Efficiency** Gr=12	1	0	3	1	0	0	1	2	5	0	0	1
○ **WIP Inventory - Waste** Gr=7	3	0	1	0	0	0	0	1	1	0	1	0

Source: Prepared by the author.

4 WHEN INVENTORIES ARE NOT FINANCIAL LOSSES: A COMPARATIVE ANALYSIS BETWEEN LEAN AND THEORY OF CONSTRAINTS CONCEPTS FOR PRODUCTION SYNCHRONIZATION

Authors: Lúcio C. Noal a*, Daniel P. Lacerda a*, Bruna Chaves a*, Maria Isabel Morandi a*, Fabio Piran a*

[a] Post-Graduate Program in Production Engineering and System – PPGEPS/UNISINOS, Research Group on Modeling for Learning – GMAP / UNISINOS, Av. Unisinos, 950 – Bairro Cristo Rei, São Leopoldo, RS, 93.022-000,Brazil

Abstract: Studies involving the combination of Lean and the Theory of Constraints (TOC) are scarce. Some possibilities may justify this scarcity, such as the different concepts and orientations of Lean and TOC regarding buffer and synchronization issues. This study aims to conduct a comparative analysis regarding the use of Lean and TOC concepts for production synchronization on an automotive assembly line. System Dynamics (SD) modeling was utilized to develop comparative scenarios. The simulated scenarios were compared with the empirical data. From the computational model analysis, Drum-Buffer-Rope (DBR) was implemented, and empirical intervention data was observed. Potential competing factors were isolated to increase the reliability of the empirical evidence. The economic results highlight that implementation of DBR-TOC synchronization can provide a 14% reduction in labor cost, a 17.8% reduction in overall production cost, and a 48% increase in production volume. In addition, the production system may enjoy benefits such as flexibility, increased reliability and quality that would improve the company's competitiveness.

Keywords: Lean; Synchronization; System Dynamics Modeling; Theory of Constraints.

4.1 INTRODUCTION

The automobile industry is significant in the Brazilian economy. In 2022, (Anfavea, 2022) estimated that this sector represented 3% of the GDP, generated a revenue of US$ 39 billion per year, and employed 119 thousand. The scenario, both globally and in Brazil, is one of fierce competition among these companies

(Piran et al., 2020). This scenario demands flexibility from them, for example, the response time to market changes must be fast, which forces companies to be agile and lean to develop a specific product and produce it efficiently and effectively (Gosling; Naim 2009; Piran et al., 2021).

Thus, there is a need to seek improvement in operational performance to ensure a profit favorable to the consolidation of the business (IKEZIRI et al., 2023b). Furthermore, customer behavior must be considered, which is often challenging to predict. This is because both demand and manufacture are influenced by several sources of variability, including customer preferences, setups, and machine failures (HOPP; SPEARMAN, 2021).

The implementation of Lean Manufacturing concepts can benefit manufacturers in general, and the automotive industry in particular (LAROCA et al., 2024c; WONG; WONG; ALI, 2009). These advantages can arise via different paths, such as developing a culture of continuous improvement (Gupta et al. 2022; Jagdish R. Jadhav; Shankar S. Mantha; Santosh B. Rane, 2014), the application of just-in-time practices, supplier delivery, kanban, reduced setup time, Electronic Data Interchange (EDI) communication, among others (DE TREVILLE et al., 2023). In addition, benefits can be obtained by applying Value Stream Mapping (VSM) in production processes; with the transformation from mass production thinking to Lean thinking (DE TREVILLE et al., 2023).

Lean Manufacturing postulates inventory as a loss, as each process must be supplied with the necessary items, in the necessary quantity, at the right time (Just-In-Time), without generating inventory. This implies incessant search for best practices, aiming to manufacture products with the appropriate quality, in the right quantity, at the right time, and at the lowest possible cost (NACIRI et al., 2022). On a production line, fluctuations in the product flow cause loss. This occurs because equipment, operators, inventory, and other elements required for production are not always in perfect synchronization, thus causing interruptions in the flow, and consequently reducing productivity (IKEZIRI et al., 2023a).

In industrial practice, the term synchronization in manufacturing systems is closely related to the Lean just-in-time philosophy and means the supply of the right components to the subsequent operations at the right time. In this sense, synchronization is usually assumed to contribute to improvement in the logistical performance of manufacturing systems, seen as the key to competitiveness and survival (CHANKOV; HÜTT; BENDUL, 2018a).

It is observed that the benefits of Lean are significant and thus are widely mentioned in research papers. However, there are barriers companies face in achieving these benefits. The barriers may be the difficulty in managing change, organizational issues (leadership, culture, finance, resources, among others), organizational systems (forecasting, infrastructure facilities, logistics, support), and technology (HARDCOPF; LIU; SHAH, 2021; SCHULZE; DALLASEGA, 2023a). In addition, other barriers could be lower demand, highly fluctuating customer orders (ESWARAMOORTHI et al., 2011a), lack of resources, lack of senior management involvement, worker resistance, among other factors (Marodin; Saurin 2015; Jagdish R. Jadhav; Shankar S. Mantha; Santosh B. Rane, 2014; Ramadas; Satish 2021). Conditions in terms of supplier, operation and market variability are explored by Goldratt (2009) as influences on the optimal functioning of lean manufacturing.

The Theory of Constraints (TOC) is another concept that can provide benefits for companies. However, unlike Lean, TOC postulates that seeking to minimize resource utilization to reduce production costs is not always the best way to improve overall results (Goldratt, 2009; Cox III; Schleier Jr, 2010). TOC points out that increasing production efficiency makes sense primarily with constrained resources, since local improvements in unconstrained resources would not generate increased earnings, because they do not increase sales (COX III; SCHLEIER JR, 2010a). In addition, such local improvements may increase in-process inventory build-up, impact lead times, and not stimulate production to perform better overall.

Drum-Buffer-Rope (DBR) is the Theory of Constraints approach to manufacturing synchronization. The inventories in DBR are based on the capacity of the constrained operation (Darlington et al. 2015; Kim; Cox; Mabin, 2010; Telles et al. 2020). The concept of inventory within the process amplifies the divergence of thought between DBR and Lean, since DBR conditions the protection of the constraint (bottleneck) through inventories (overproduction by anticipation), unlike Lean that seeks elimination of inventories. Thus, inventories are not considered a financial loss. Lean demands high-capacity utilization combined with reduced inventories, requiring that the variability (supply, operation and market) of the system be minimized (ALVES; DINIS-CARVALHO; SOUSA, 2012b; BERGENWALL; CHEN; WHITE, 2012).

The objective of this paper is to perform a critical, comparative evaluation of the implementation of Lean and TOC for production synchronization on an automotive assembly line that considers the manufacturing of a single product without variability and with resources presenting balanced operation times, as proposed by Lean. Furthermore, the contributions of TOC to solve a Lean-supported implementation, where the objectives not achieved are explored. Initially, a comparative analysis was performed, supported by System Dynamics (SD) modeling. The simulated scenarios were evaluated, and found to suggest statistically significant advantages of the DBR-TOC implementation. From these results, the potential improvements identified in the model were empirically implemented and observed over a 40-week period. The results pointed out a significant improvement in terms of productivity and costs, corroborating the model's results.

The theoretical contributions lie in the utilization of DBR combined with system dynamics, leading to devising scenarios that comparatively evaluate Lean and TOC, and their results in a specific case. Another contribution lies in the importance of evaluating whether the variabilities of the production system allow Lean implementation completely. Eliminating variabilities in the system is not cost-effective, and it is better to insert a buffer in the constraint to protect the system (LUZ et al., 2022). In the field of managerial contributions, the research allows understanding of the production synchronization approach suitable to improve results in the organization's context.

Finally, it is imperative to provide evidence supporting the need to avoid adopting lean solely as a managerial trend. Instead, a careful assessment of its suitability for the organization’s internal and external environments must be conducted.

4.2 THEORETICAL BACKGROUND

4.2.1 The Lean System

The pillars of Lean are Just-in-time (JIT) and Autonomation (TOMA; NARUO, 2017). The JIT strategy was developed by Taiichi Ohno at Toyota Motors, whose core concept was to make the right part available to the assembly line at the right time (TOMA; NARUO, 2017). JIT can offer flexibility to the organization (Alves; Dinis-Carvalho; Sousa, 2012; Bergenwall; Chen; White, 2012). This flexibility contributes to integrated problem-solving management to improve quality and facilitate on-time delivery, production and distribution (JADHAV; MANTHA; RANE, 2014a). It was also identified that the JIT concept was based on the "zero concept": zero defects, zero queues, zero breakage, zero inventories and so on (MANAVIZADEH et al., 2013).

Lean demands high-capacity utilization combined with reduced inventories, requiring that system variability be minimized. The concept of Heijunka - controlling the variability of the process sequence to enable higher capacity utilization - plays an integral role in Lean production. However, in situations where the customer defines the delivery sequence, scheduling production to maximize utilization becomes more challenging and requires subsequent reordering (Gupta et al. 2022; Land et al. 2021). An alternative approach, known as just-in-sequence scheduling (JIS), has begun to play an increasing role in Lean production, although production lines that operate JIS are clearly less lean than those that operate according to Heijunka (HÜTTMEIR et al., 2009). The choice between Heijunka and JIS scheduling illustrates the tension between lean and agile that must increasingly be relieved for manufacturing to be competitive (HÜTTMEIR et al., 2009).

A second aspect of the stability required by Lean is that of demand over time. Most companies cannot impose such conditions on their customers, as this is a necessary stability beyond the reach of production (Goldratt, 2009; Land et al. 2021). For environments different from the Toyota context, one should not expect to obtain the same magnitude of results. However, Lean techniques and tools can be implemented in isolation and achieve partially positive results (Goldratt, 2009).

Adherence to the concept of continuous flow requires abolition of local efficiency. Ohno addressed this issue, emphasizing that it makes no sense to encourage people to produce if the products are not needed in the short term (OHNO, 1988). This emphasis is probably the reason why, outside Toyota, Lean has become known as just-in-time production. However, in the literature, there is no explicit emphasis on the fact that Lean requires the aforementioned abolition (Goldratt, 2009). In order to achieve this production time, some conditions must be met: the operators must be qualified to perform all the steps of the process, the cycle time of which has to be short, and the variations and inconsistencies among the production cells that make up the production line must be eliminated, and, in the case of some known situations, certain machines**,** the decision-making for which has to be assumed at management level (IOANA; MARIA; CRISTINA, 2020).

4.2.2 Theory of Constraints and Drum-Buffer-Rope Approach

TOC proposes a set of rules designed to comprehensively manage an organization. These rules control production based on the capacity of constrained resources and facilitate strategy development. The goal of business organizations is to make money today and, in the future (Stefano et al. 2022). Its main premise is that every system has a constraint that limits its performance. This constraint is taken as the basis for managing and improving system performance (GOLDRATT; COX, 2005a). According to Goldratt and Cox (2005), a constraint (bottleneck) is anything that limits a system, preventing it from achieving superior performance relative to its goal.

The TOC decision-making process consists of five steps (GOLDRATT; COX, 2005a): (i) identify system constraints: addresses the need to identify possible constraints that might prevent the company from fulfilling a goal; (ii) explore system constraints: explore, as best as possible, the previously identified constraint(s), without, at this point, seeking greater investment towards their total elimination; (iii) subordinate everything restricted: the activities of the entire system should be subordinated to the constraint found in the first step; (iv) raise the system's constraints: at this stage, it is necessary to concentrate efforts with the intention of increasing the constraint's capacity to generate output; and (v) if, in the previous steps, a constraint is eliminated, it is necessary to restart the process by identifying which resource is, at this point, still restricting the system (Kendall, 2013).

Since the implementation of TOC, many companies have decreased lead times, improved performance, decreased inventories, increased production capacity and revenue (Guillen et al., 2018; Pearce; Pons; Neitzert, 2018; Elkhairi; Fedouaki; El Alami, 2019). Table 5 presents a summary of papers related to the topics described and the results obtained in each.

Table 5 - Summary of TOC papers

Title	Author and Year	Objective	Results
Drum-Buffer-Rope in an engineering-to-order productive system: a case study in a Brazilian aerospace company	Telles et al. (2022)	Evaluate the implementation of DBR in an ETO productive system, critically analyzing the necessary adaptations for its utilization.	Compared the DBR theoretical proposals and Simplified Drum-Buffer-Rope (S-DBR) methods.
The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting	Stefano et al. (2022)	Research proposes the Theory of Constraints (TOC) throughput accounting (TA) as an alternative managerial control mechanism in an international transfer pricing scenario.	Improved transfer pricing efficiency
The Theory of Constraints Case Study in the Make-to-Order Environment	Orue et al. (2021)	Case study to analyze MTO to identify the factors that influence the execution of the third stage of TOC.	Increased service level by 20%, lead time reduction 10%, inventory reduction 20%.
Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation	Thürer, Fernandes, and Stevenson (2020a)	Comparative analysis among Kanban, MRP, DBR and DDMRP within a simulation scenario for performance evaluation of each methodology.	Better performance in the utilization of Kanban and DDMRP when compared to MRP
Drum-Buffer-Rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA)	Telles et al. (2020)	Study to analyze the effects of DBR implementation on the efficiency of three ETO production lines of an aerospace manufacturer.	19% increase in efficiency
Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation	Thürer, Fernandes, and Stevenson (2020)	Evaluate performance of the 4 production planning and control systems under different levels of bottleneck severity and due date.	No big gains in service level, big gains in finished product inventory and little worsening in working inventory
The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective	Puche et al. (2019)	Comparative study between Kanban and DBR in four production scenarios. Proposed method for using each methodology.	8.47% profit increase
Enfoque estratégico para la identificación de cuellos de botella en entornos de fabricación	Lizarralde, Apaolaza, and Mediavilla (2019)	Presentation of a systematic process for implementing the first two steps of TOC in a production system.	21% improved service level, 35% lead time reduction, 30% inventory reduction

Title	Author and Year	Objective	Results
contra pedido y plantas tipo V: estudio de caso de DBR.			
Bottleneck Reduction on The Shoes Production Line using the Theory of Constraints Approach	Prasetyaningsih, Deferinanda, and Amaranti (2019)	The main objective of this research is the implementation of the Theory of Constraints concepts to reduce the imbalance problem at bottleneck workstations.	14% reduction in overtime
An OEE Improvement Method Based on TOC	Bai et al. (2018)	Interlinking the OEE analysis method with TOC/DBR in order to increase the productivity of equipment and processes.	Increased OEE ++
Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation	Thürer and Stevenson (2018a)	Research on the impact of bottleneck change on management decisions.	Change of bottleneck and DBR, reduction of backlog
On the beat of the Drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism	Thürer and Stevenson (2018b)	Research into the potential of using different combinations of rules for sequencing to improve DBR performance.	Backlog reduction
Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry	Aldás et al. (2018)	Comparative study among production control methodologies, Kanban, Conwip and DBR on operational mechanisms.	78.9% WIP reduction
Improving labor relations performance using a Simplified Drum-Buffer-Rope (S-DBR) technique	Chakravorty and Hales (2016)	Describe the implementation of DBR in service operations.	37.5% lead time reduction. Number of service complaints fell by 22%
Diseño, implementación y análisis de una metodología para aplicar TOC a empresas metalmecánicas con restricciones físicas internas – caso de aplicación: Colombia	Cortabarria, Martinez, and Mendoza (2016)	To apply the TOC/DBR methodology, highlighting the bottlenecks in one of the processes of a metal-mechanical industry with internal constraints.	Throughput increase, lead time reduction, 12% efficiency increase
Design and implementation of a Drum-Buffer-Rope pull-system	Darlington et al. (2015)	Implementation of DBR in a panel plant, with shared resources for the automotive industry.	Lead time reduction 56%
Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates	Hilmola and Gupta (2015)	Proposal of a system dynamic (SD) based on a simulation model to investigate the product mix problem.	Inconclusive - "Future research should be directed toward developing an enabling hybrid

Title	Author and Year	Objective	Results
			expert simulation system underlying constraint theory."
Implementation of S-DBR in four manufacturing SMEs: a research case study	Buestán Benavides and van Landeghem (2015)	To explore the practical issues related to the implementation of the DBR in four small- to medium-sized companies in Ecuador.	24% throughput gain, 70% service level improvement
Real-time buffer management method for DBR scheduling	Woo, Park and Fujimura (2009)	Proposition of a real-time buffer management method aligned with DBR and TOC methodology.	Stock reduction +, delivery delay reduction ++
Determination of buffer sizes for Drum–Buffer–Rope (DBR)-controlled production systems	Ye and Han (2008)	Description of an analytical approach based on reliability analysis to determine the size of the constraint buffers and the assembly buffer in a DBR controlled system.	Buffer Size Analysis obtained
TOC/DBR-based production planning and control in a manufacturing system with multiple system bottlenecks	Guan et al. (2007)	Proposition of a TOC/DBR-based method for planning and controlling production when multiple bottlenecks exist.	Reducing delivery delay +

Source: Prepared by the author.

To manage production in a manufacturing environment, TOC proposes Drum-Buffer-Rope (DBR) (GOLDRATT; COX, 2005a). DBR starts its logic by locating the most restrictive element (equipment, operation, etc.) of the system, called constraint (bottleneck) reducing the sources of variation that cause delays in the flow of materials in the system (Goldratt, 1988).

The constraint is the Drum, that is, responsible for setting the pace of production and all other subordinate operations/processes. The Drum is the resource to be scheduled, allowing a realistic delivery date to be proposed to the customer (Chakravorty; Atwater 2005; Telles et al. 2020). The buffer is an inventory protection measured in terms of time or number of parts released so that they arrive at the bottleneck early, thus enabling protection against incidents derived from previous processes (LIZARRALDE; APAOLAZA; MEDIAVILLA, 2019a). Table 6 describes the buffer types explored in the DBR methodology.

Table 6 - Buffer Types

Buffer Type	Description
CCR	A bottleneck process stage is identified as CCR in a production system. This buffer is utilized to manage time processing from the first process stage to CCR, so that raw material or the partially manufactured product arrives at the bottleneck process stage with enough time tolerance
Shipping	A shipping buffer is utilized to manage time processing from CCR to the shipping process stage for the delivery due date
Assembly	An assembly buffer is utilized for assembling materials, whether they have already passed through CCR or not. An assembly buffer manages processing time from the first flow stage, which does not pass through CCR to the assembly stage

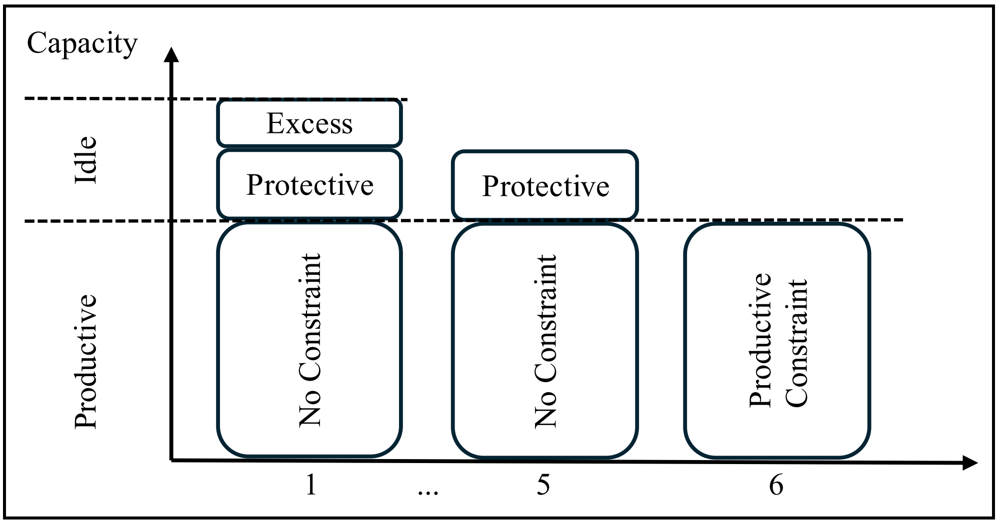
Source: Adapted fromWoo, Park and Fujimura (2009).

Inventories are only allowed in strategic locations, relative to the restrictive resources (TELLES et al., 2022). The sizing and management of the buffers must be dynamic in order to compensate for statistical fluctuations. The Rope is the communication mechanism that triggers the release of the material to the next step according to the rhythm determined by the constraint (COX III; SCHLEIER JR, 2010a). The Rope length is the time required to keep the buffer full, plus the processing time from the start until this time is reached (TELLES et al., 2022).

Generally, non-restrictive resources are not scheduled because each operation is governed by buffer consumption (GOLDRATT; COX, 2005a). The purpose of buffers is that, once parts have finished being processed in the constraint, they are processed as quickly as possible (Goldratt; Fox, 1986).

The variability of non-constraint resources can lead to disruption of the constraint. To address this, there are two methods illustrated in Figure 6. The first involves utilizing the capacity margin of unconstrained resources (protection capacity), while the second employs the WIP inventory positioned in front of the constraint (protection inventory) (Kim; Cox; Mabin, 2010).

Figure 6 - Productive and idle capacities



Source: Kim, Cox and Mabin (2010).

Productive capacity is defined as the maximum production capacity of a resource. Idle capacity, on the other hand, refers to the available capacity necessary to support the constraint. Idle capacity consists of two components: (i) protective capacity; and (ii) excess capacity (Kim; Cox; Mabin, 2010). Blackstone and Cox (2002) described protective capacity as that required in non-restrictive workstations to restore WIP (work-in-process) to its previous and subsequent locations relative to the restrictive workstation, thereby ensuring full utilization of the restrictive workstation. According to Caridi et al. (2006), protective capacity plays a significant role in determining productivity. Atwater and Chakravorty (2002) demonstrated that protective capacity at the second most utilized station can enhance system performance. Additionally, Lawrence and Buss (1994) found that higher levels of protective capacity reduce Drum oscillation.

It is difficult to determine the correct protective capacity, as the protection inventory has similar implications and definitions regarding the capacity

(BLACKSTONE; COX, 2002a). The protection inventory is defined as the amount of inventory required relative to the protection capacity in the system to achieve a specific throughput rate in the constraint. However, as Blackstone and Cox (2002) stated in their conclusions, there is no mathematical approach to defining protection inventory and protection capacity.

4.3 METHODOLOGICAL PROCEDURES

To develop the work, we initially utilized quantitative modeling. Research based on quantitative models stems from the construction of objective models that explain the behavior of operational processes (Stefano et al. 2022). We performed exploratory modeling (BANKES, 1993). Since there are some uncertainties in the company database utilized to simulate the scenarios, we utilized empirical distributions based on the historical data. Exploratory modeling and analysis (EMA) can be useful when there is sufficient information to be exploited by building models, but such information may not accurately describe the behavior of the system under consideration (BANKES; WALKER; KWAKKEL, 2013; KWAKKEL; PRUYT, 2013). To develop the quantitative model, we utilized System Dynamics (Forrester, 1961).

“System dynamics methodology is best suited to problems associated with continuous processes where feedback significantly affects the behavior of a system, producing dynamic changes in system behavior”. “Discrete-event simulation (DES) models, in contrast, are better at providing a detailed analysis of systems involving linear processes and modeling discrete changes in system behavior”. “There is certainly a large area of overlap between the two approaches. Many problems could be modeled with either approach and produce results that would look very similar. Both methods, utilized appropriately, can help provide increased understanding and serve as an aid to decision-making”.

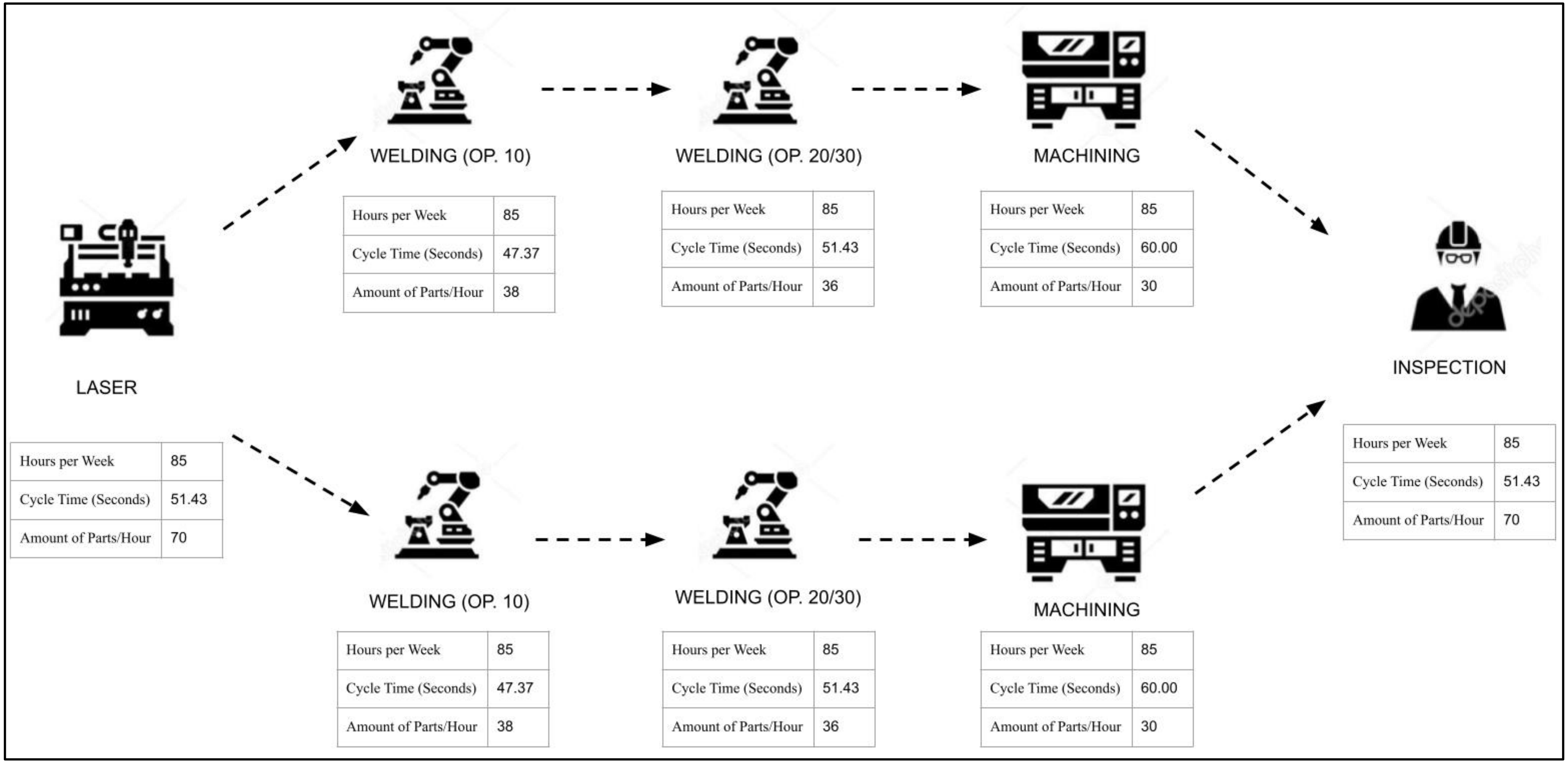
Deciding the simulation approach is important. Usually, system dynamics is associated with continuous processes, but, more importantly, it is useful to describe situations where feedback affects the behavior of a system (SWEETSER, 1999). In this study, the use of SDM was considered more appropriate due to the existence of a feedback loop in the calculation of the TOC dynamic buffer.

4.3.1 Definition of the context

The study is developed in a Brazilian company that operates in the automotive sector, and, over the past 5 years, has expanded its manufacturing park. As a result, the company has sought to increase the productivity and efficiency of its processes, initially implementing Lean concepts and, later, the Theory of Constraints (TOC). The company started the development of what would become its main product in the automotive sector, representing a turnover of U$ 12.5 million per year. In the company's production system guidelines, the production line was designed according to Lean concepts. Therefore, the processes have a capacity and time balance among the operations without the positioning of intermediate inventories. With the start of production on this line, the concept adopted (Lean) did not achieve the performance and adherence to the results planned at the time of development. The production output below demand generated side effects in terms of cost and unplanned manufacturing overheads.

The manufacturing process is composed of five operations: i) Laser cutting; ii) Welding OP.10; iii) Welding OP.20/30; iv) Machining; v) Inspection. Operations ii), iii) and iv) are performed on two lines with identical equipment, resources and specifications. Figure 7 illustrates the production line flow under study.

Figure 7 - Operations and production process



Source: Prepared by the author.

Operation 10 (OP.10) is performed on two identical pieces of equipment working in parallel. It is considered that the cycle time in these is equal. The volume of parts produced reported in Figure 7 corresponds to the production of each equipment separately. The same occurs for Operations 20/30 (OP.20/30) and Machining. The output according to design is 879 units in 17 hours, which already considers process losses. The total capacity without any loss is 1,020 units in 17 hours.

4.3.2 System Dynamics Modeling

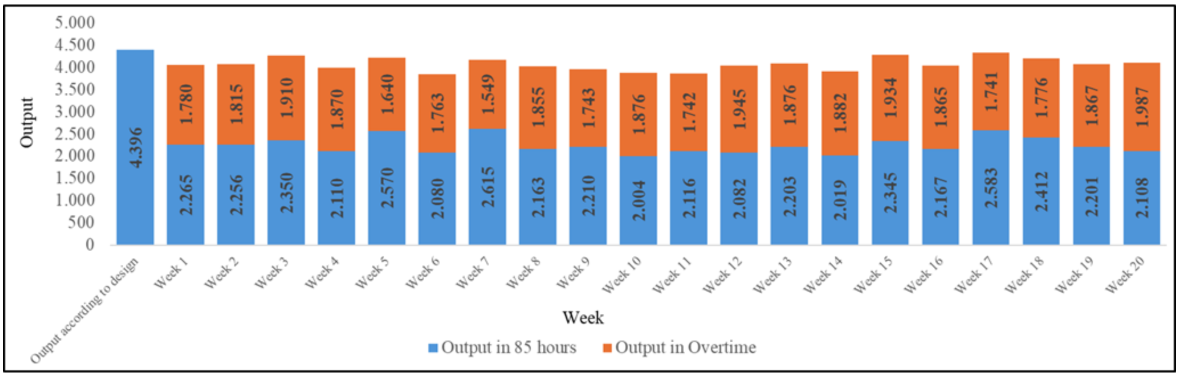
System dynamics was utilized because it makes it possible to observe systems from a macro level and enables strategic decision-making (LAW, 2014b). Hilmola and Gupta (2015), proposed a theoretical approach combining The Theory of Constraints (TOC) and System Dynamics (SD) for decision-making in complex situations. The research addresses issues regarding optimal inventory quantity and what the possible solutions to improve system performance are (MARTINS et al., 2020; MORANDI et al., 2014).

Forrester (1961) developed a theoretical model of the interactions among flows of resources, materials, and information in operational processes, which was able to explain the dynamic behavior of these processes. According to Law (2014), system dynamics models have three main components: a) inventories: the accumulations of resources, represented by a rectangle; b) flows: transfer resources among inventories are represented by double line arrows, and the direction of the arrow, which may be single or double, indicating the direction of the resource flows; and c) converter: utilized to declare system parameters, represented by circles.

4.4 DEVELOPMENT OF A MODEL TO REPRESENT THE DYNAMICS OF THE PRODUCTION SYSTEM

The inadequate performance obtained with the company's current production system provided a favorable environment to search for solutions. Figure 8 shows a comparison of the weekly output of the production line with the established target, and also the output carried out in additional work shifts to guarantee the delivery of the contracted demand. This shows the gap between planned output and realized output.

Figure 8 - Production Output (absolute volume of parts)

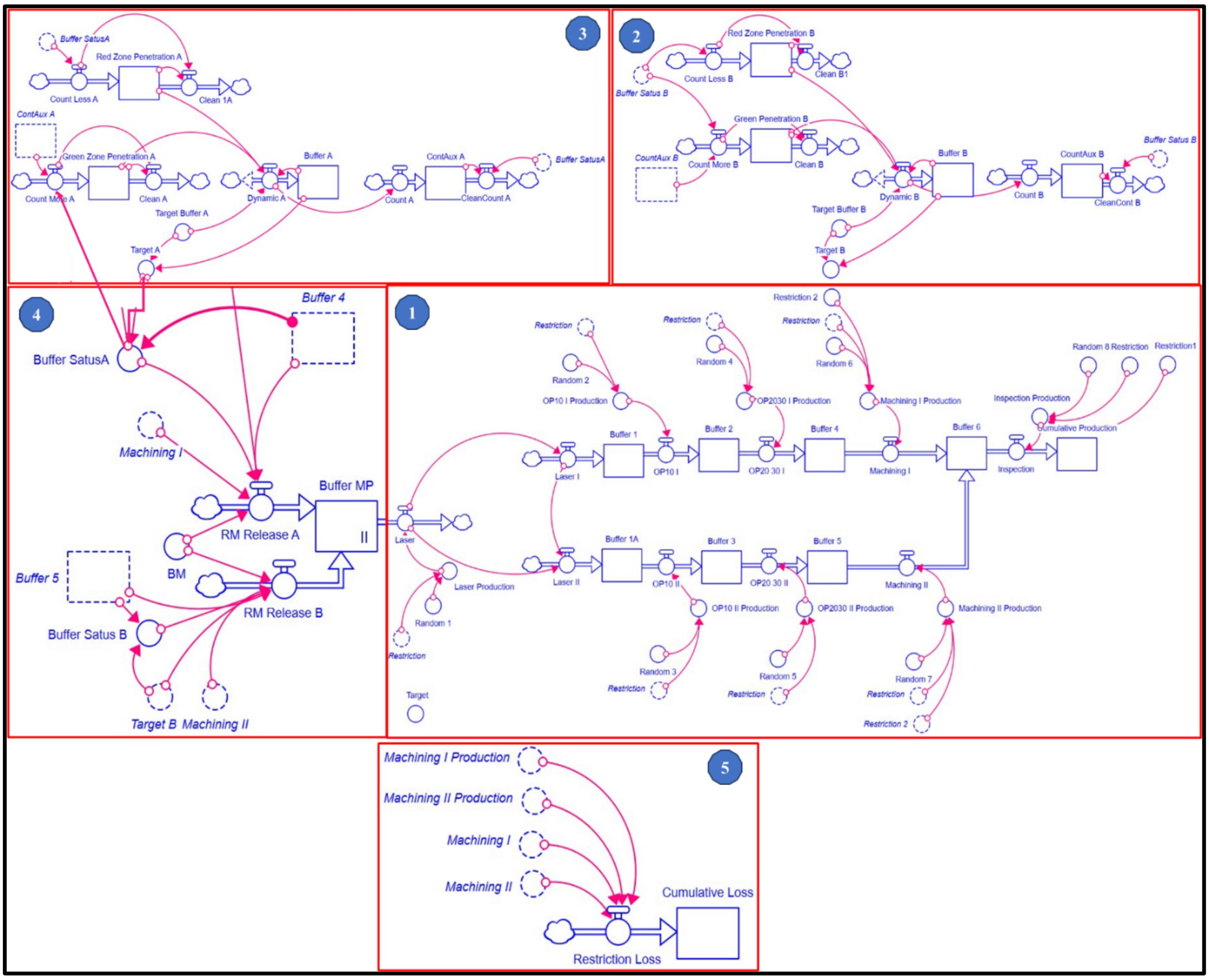


Source: Prepared by the author.

In this context of searching for a solution, the computational simulation model of system dynamics was built to understand the behavior of the current production system. Subsequently, potential contributions of the DBR were evaluated in different scenarios. To this end, the research was conducted using the TOC approach, contemplating each step of the targeting process.

Following the steps of the TOC decision-making, the constraint of the system studied was identified, this being the machining process. The constraint occurs due to the flow time of this operation being longer than the others, and consequently this point sets the pace of production. With this, the rest of the flow becomes subordinate to this constraint. Figure 9 presents an overview of the model, which is organized into five modules (Figure 10), numbered to facilitate understanding.

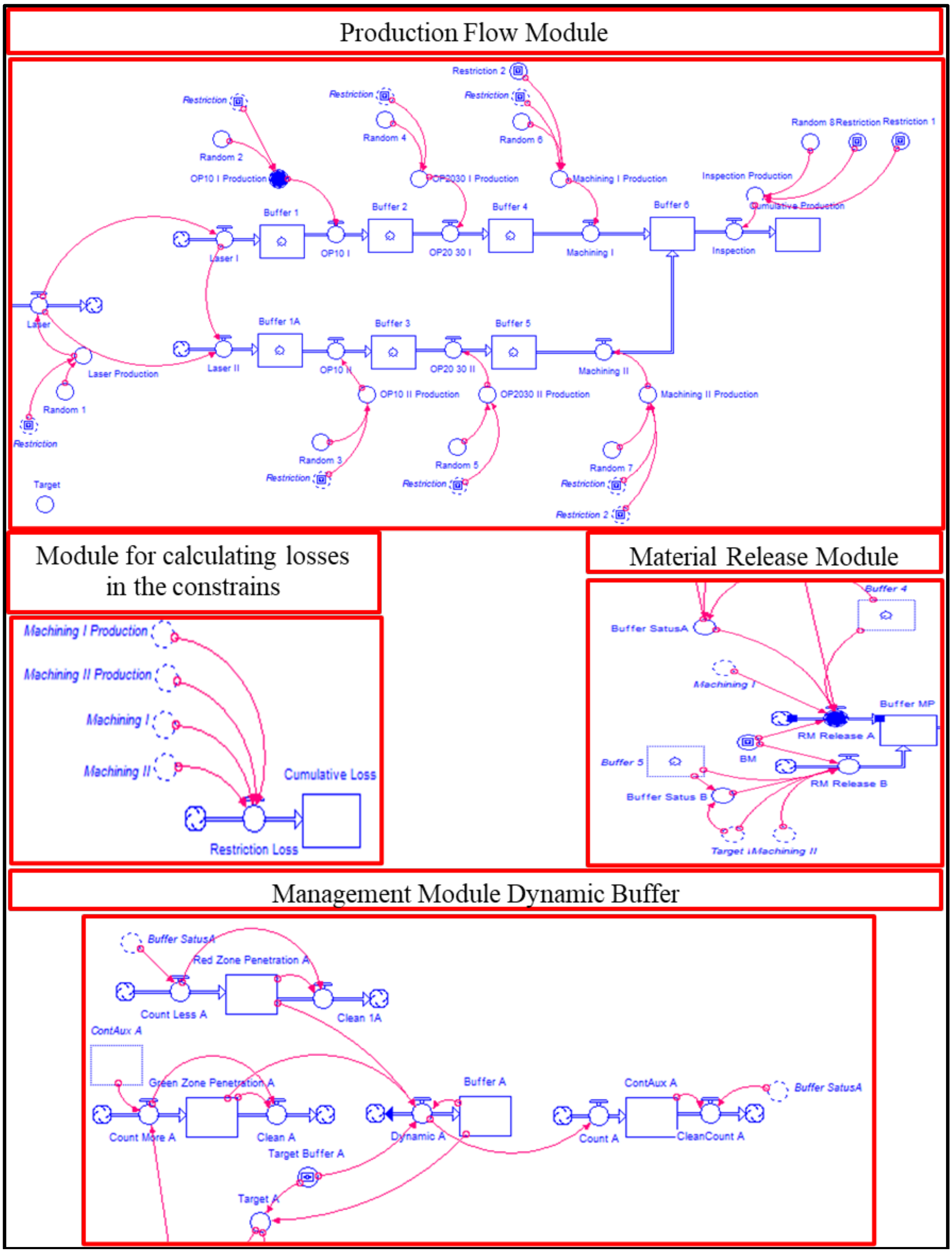
Figure 9 - Model Overview



Source: Prepared by the author.

The central module (Module 1) of the model represents the production flow of the company. Each flow represents the various operations, while the inventories indicate the amount of WIP. To define the quantity to be produced in each operation, empirical distribution functions, devised based on the information contained in the company's database, were utilized. Two sets of data were collected and utilized in the scenarios with and without constraint. The data utilized and the empirical distribution functions are presented in Appendix D, while the modules are presented in Figure 10.

Figure 10 - System Modules



Source: Prepared by the author.

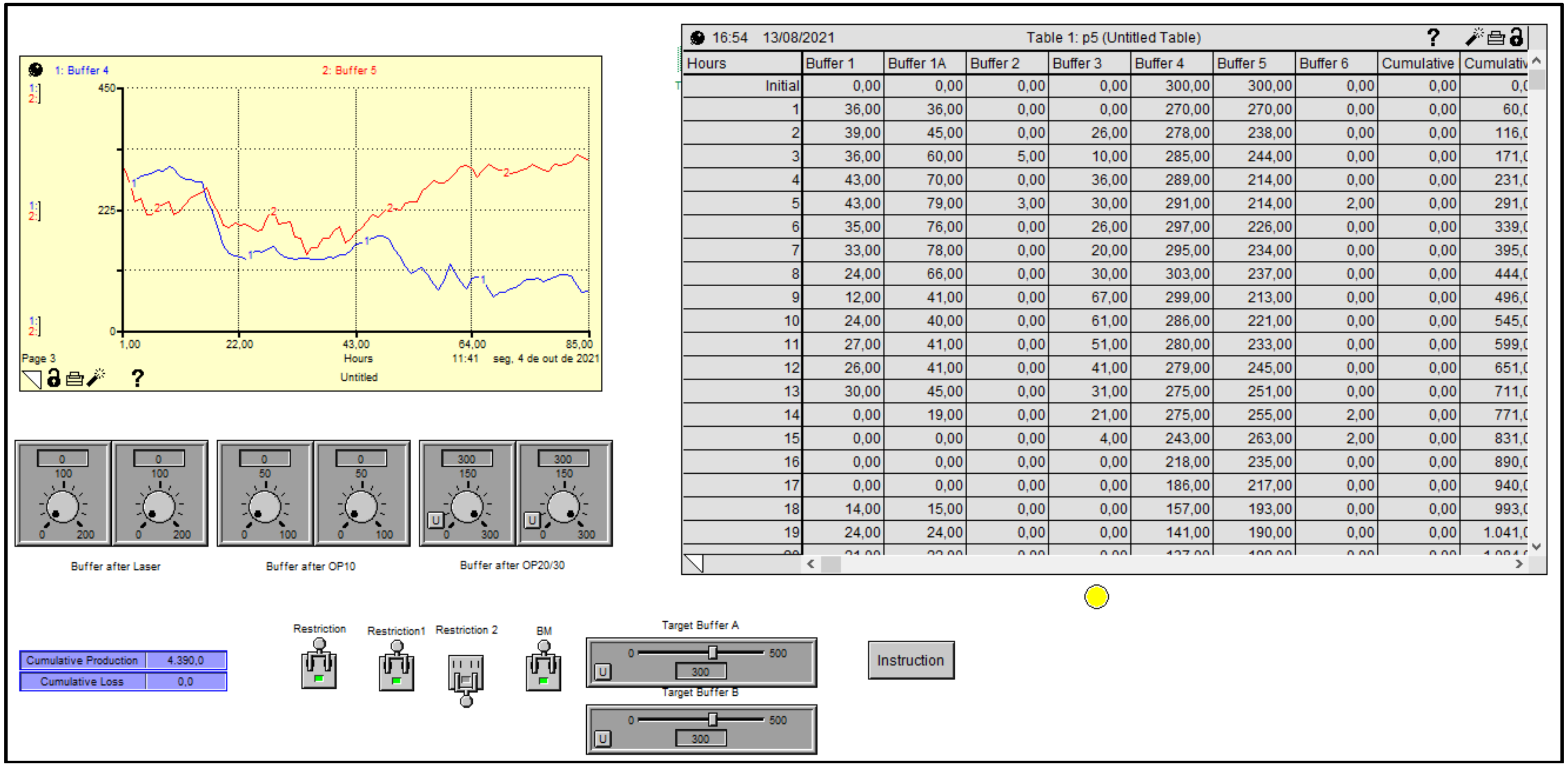
The material release module represents the raw material release mechanism, which follows the logic of pull production. In DBR scenarios, the amount of raw material to be released is calculated to maintain the desired buffer level before the constraint. The desired inventory level before the constraint can be calculated dynamically according to the rules of dynamic buffer management. Such calculation is performed in two identical modules that check the degree of buffer penetration in each of the constraints - Machining I and II - and adjust the target to be considered, as presented in the dynamic buffer management module.

Finally, the last module, called constraint loss calculation, aims to calculate the production loss in the constraint. This loss occurs when it is not possible to produce the quantity drawn in the empirical distribution, due to the lack of material to be processed. The model was parameterized so that each run would last 85 hours, equivalent to the company's weekly work regime, which considers 17 hours per day for five days, according to the production flow module. The details of the modules and the equations of the model can be found in Appendixes E and F, respectively.

4.4.1 Construction of the Experimental Scenarios

The model was built allowing simulation of the following experimental scenarios: (i) Lean Scenario; (ii) Scenario with empirical WIP; and (iii) DBR Scenario. The selection of parameters to configure each scenario was defined in the model interface (Figure 11).

Figure 11 - System Dynamics Model Interface



Hours	Buffer 1	Buffer 1A	Buffer 2	Buffer 3	Buffer 4	Buffer 5	Buffer 6	Cumulative	Cumulativ
Initial	0,00	0,00	0,00	0,00	300,00	300,00	0,00	0,00	0,(
1	36,00	36,00	0,00	0,00	270,00	270,00	0,00	0,00	60,(
2	39,00	45,00	0,00	26,00	278,00	238,00	0,00	0,00	116,(
3	36,00	60,00	5,00	10,00	285,00	244,00	0,00	0,00	171,(
4	43,00	70,00	0,00	36,00	289,00	214,00	0,00	0,00	231,(
5	43,00	79,00	3,00	30,00	291,00	214,00	2,00	0,00	291,(
6	35,00	76,00	0,00	26,00	297,00	226,00	0,00	0,00	339,(
7	33,00	78,00	0,00	20,00	295,00	234,00	0,00	0,00	395,(
8	24,00	66,00	0,00	30,00	303,00	237,00	0,00	0,00	444,(
9	12,00	41,00	0,00	67,00	299,00	213,00	0,00	0,00	496,(
10	24,00	40,00	0,00	61,00	286,00	221,00	0,00	0,00	545,(
11	27,00	41,00	0,00	51,00	280,00	233,00	0,00	0,00	599,(
12	26,00	41,00	0,00	41,00	279,00	245,00	0,00	0,00	651,(
13	30,00	45,00	0,00	31,00	275,00	251,00	0,00	0,00	711,(
14	0,00	19,00	0,00	21,00	275,00	255,00	2,00	0,00	771,(
15	0,00	0,00	0,00	4,00	243,00	263,00	2,00	0,00	831,(
16	0,00	0,00	0,00	0,00	218,00	235,00	0,00	0,00	890,(
17	0,00	0,00	0,00	0,00	186,00	217,00	0,00	0,00	940,(
18	14,00	15,00	0,00	0,00	157,00	193,00	0,00	0,00	993,(
19	24,00	24,00	0,00	0,00	141,00	190,00	0,00	0,00	1.041,(

Source: Prepared by the author.

The Lean Scenario represents the initial design state of the production line, assuming a continuous piece-by-piece flow and no buffer between consecutive operations. The parameterization for this scenario considers that there is no initial inventory among operations, and that the data to be utilized are those related to the process with constraint.

The Scenario with empirical WIP features a customization of the Lean scenario with the addition of inventory among operations in an empirical manner; such a procedure seeks to minimize the lack of parts at the workstations. The parameterization for this scenario considers the initial inventory level among the operations according to what was utilized in the company, and the activation of the constraint switch to consider the second set of data.

In the DBR Scenario, the operations, Machining I and Machining II, are the process constraints, that is, they are the Drum. The time buffer was transformed into a target inventory located before the constraint, and the Rope is the logic that determines the amount of raw material to be released so as to maintain the buffer at the desired level. In this scenario, the buffer strategy was modeled with two different approaches, whose parameters are described and represented in Table 7:

a) Fixed Buffer - considers a target inventory of 300 parts before each machining operation, considering a buffer time of 50% of the lead time. For this scenario, the logic adopted assumes a pull production, where the raw material is released according to what is processed in the constraint; if the buffer status is above 1, no raw material is released, and if the buffer status is below $^1/_3$, raw material is released to replenish the buffer.

b) Dynamic Buffer - considers an initial target inventory of 300 parts before each machining operation, considering a buffer time of 50% of the lead time. For this scenario, the logic adopted assumes a pull production, where raw material is released according to what is processed in the constraint. If the buffer status is above 1, no raw material is released, and if the buffer status is below $^1/_3$, raw material is released to replace the buffer. If the buffer stays in the green zone for more than 12 hours, the target buffer is decreased by one third, waits to return to the green zone, and only then does the time counting for downgrading resume. If the buffer remains in the red zone for more than 12 hours, the target buffer is increased by $^{1}/_{3}$.

Table 7 - System Parameterization

Parameterization	Local	Constraint	Buffer	Lowest	Largest	Unit
Scenario Lean	Buffer after laser	No	0	0	200	Parts
	Buffer after OP10		0	0	100	Parts
	Buffer after OP20/30		0	0	300	Parts
WIP Empirical	Buffer after laser	Yes – 1 constraint	120	0	200	Parts
	Buffer after OP10		60	0	100	Parts
	Buffer after OP20/30		60	0	300	Parts
Scenario DBR – Fixed Buffer	Buffer after laser	Yes – 2 constraints	0	0	200	Parts
	Buffer after OP10		0	0	100	Parts
	Buffer after OP20/30		300	0	300	Parts
Scenario DBR - Dynamic Buffer	Buffer after laser	Yes – 2 constraints	0	0	200	Parts
	Buffer after OP10		0	0	100	Parts
	Buffer after OP20/30		300	0	300	Parts

Source: Prepared by the author.

4.4.2 Performance measurement

As performance measurements, four indicators are adopted, organized into two categories: productivity analysis and financial analysis. For the productivity analysis, there is the output indicator (quantity of parts produced in 85 hours, referring to the initial design parameters of the production line, a daily operation of 17 hours, five days a week); for the financial analysis, there are the indicators: labor (cost), manufacturing overheads (cost), and inventory (quantity of parts and cost of inventories). These indicators are not generated by the model, but are comparison criteria for the scenario before and after the implementation of the work.

4.4.3 Validation of Results

To certify the reliability of the results generated by the model, the data reproduced by the theoretical Lean model was submitted against the real output data on the production line within 85 hours, as shown in Appendix G. To support this step, the ANOVA statistical test of variance was utilized, as shown in Appendix H. The statistical results of the test demonstrate that the model reflects the behavior of the system, and the hypothesis that there is no difference between the results generated by the model and those observed in production cannot be rejected.

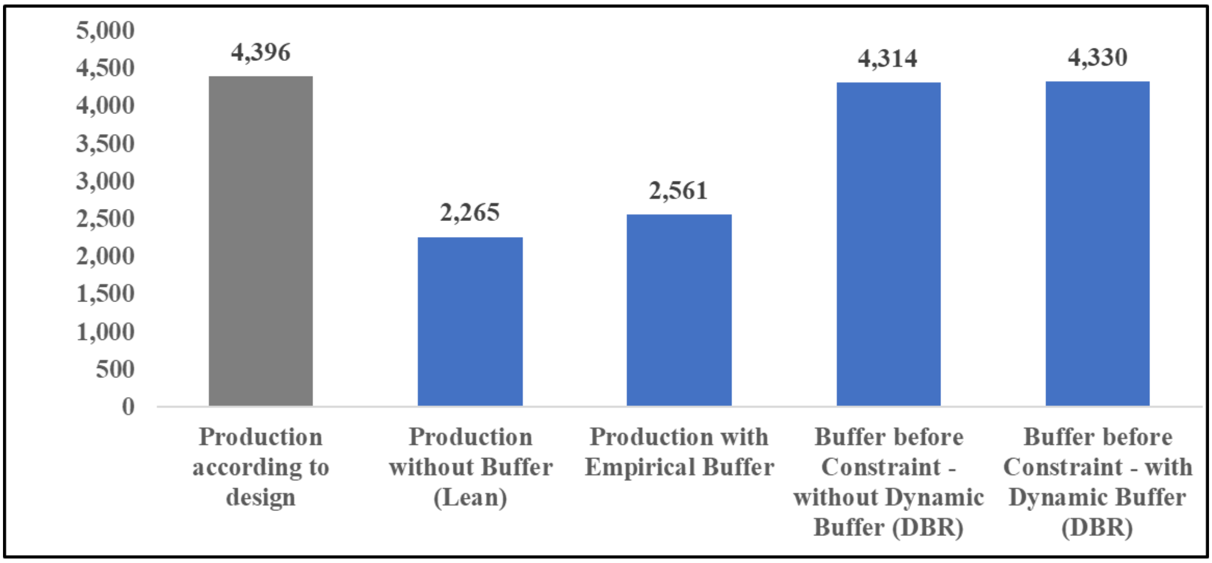
Subsequent to the model validation, the empirical results of the TOC scenario with a dynamic buffer were analyzed for ten weeks of 85 hours each, and compared to the output data generated by the model, the results being a P-value of 0.17351 and a critical F-value of 3.89741. Again, the results demonstrated that the model correctly emulates the system behavior, confirming the reliability of the model described in Appendix I.

4.5 ANALYSIS OF RESULTS

Figure 12 shows the production output in number of parts that have been constrained to the simulation environment. In the production scenario, according to the design, the possible output is 4,396 parts. Also in the design scenario, no buffer between consecutive operations was foreseen, and the initial assumption was to balance the capacity of the operations, ensuring continuous flow of material. This project environment was conceived through Lean concepts with the objective of guaranteeing the planned costs and efficiency.

Figure 12 shows the problem described, as well as the results obtained in each of the proposed scenarios. The scenario where the TOC approach was applied with the dynamic buffer is shown to outperform the other scenarios, reducing the gap between the maximum possible scenario and the one actually realized. The TOC scenario provides a 47% gain in output over the Lean environment during the 85 hours.

Figure 12 - Results of the System Dynamics Model output

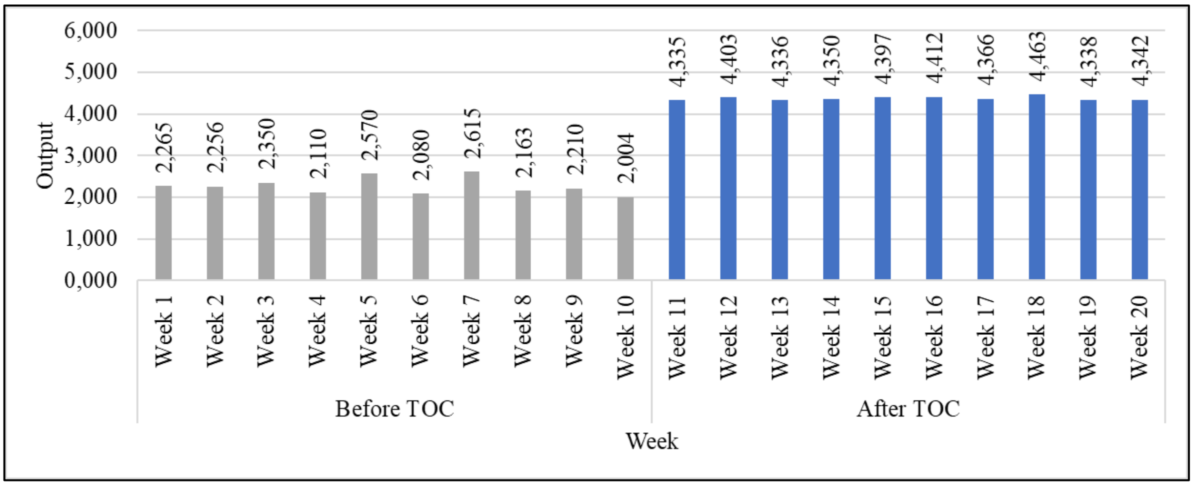


Source: Prepared by the author.

Figure 13 shows the resulting production output data before the TOC implementation work, and the output data after implementation. There is a marked increase in performance when comparing the two scenarios. Over the course of 10 weeks after the implementation of TOC, there was evidence of a 48% higher output than in the initial condition.

The working conditions were held constant as in the initial condition: operators, equipment, managers, working hours, daily target, manufacturing inputs and components. Therefore, it is possible to isolate the competing factors and identify the effect of the implementation performed.

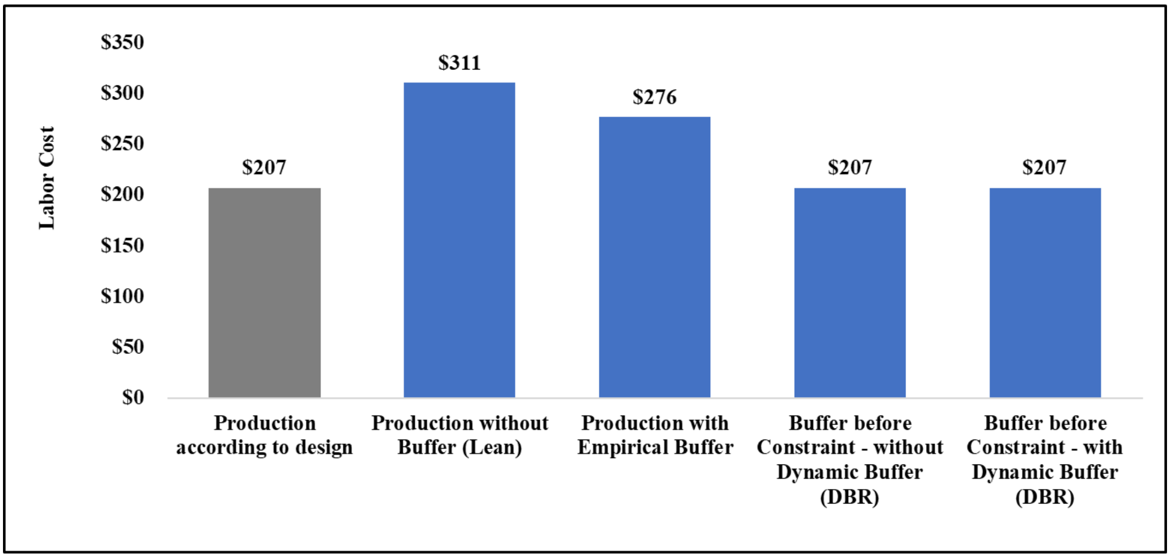
Figure 13 - Absolute volume of parts produced per week



Source: Prepared by the author.

After week 20, the results showed constancy, maintaining the performance level until today. Figures 14 and 15 present the data referring to labor costs and other production costs. In the labor cost evaluation, it is possible to identify that the TOC scenario presented a reduction 14% below that of Lean. In the TOC scenario (with and without the dynamic buffer), it was not possible to identify a gain in terms of labor cost. The production costs (Figure 15) had a proportionality with the volume of hours worked. It is recognized that the TOC scenario provides a 17.8% lower cost than that of Lean.

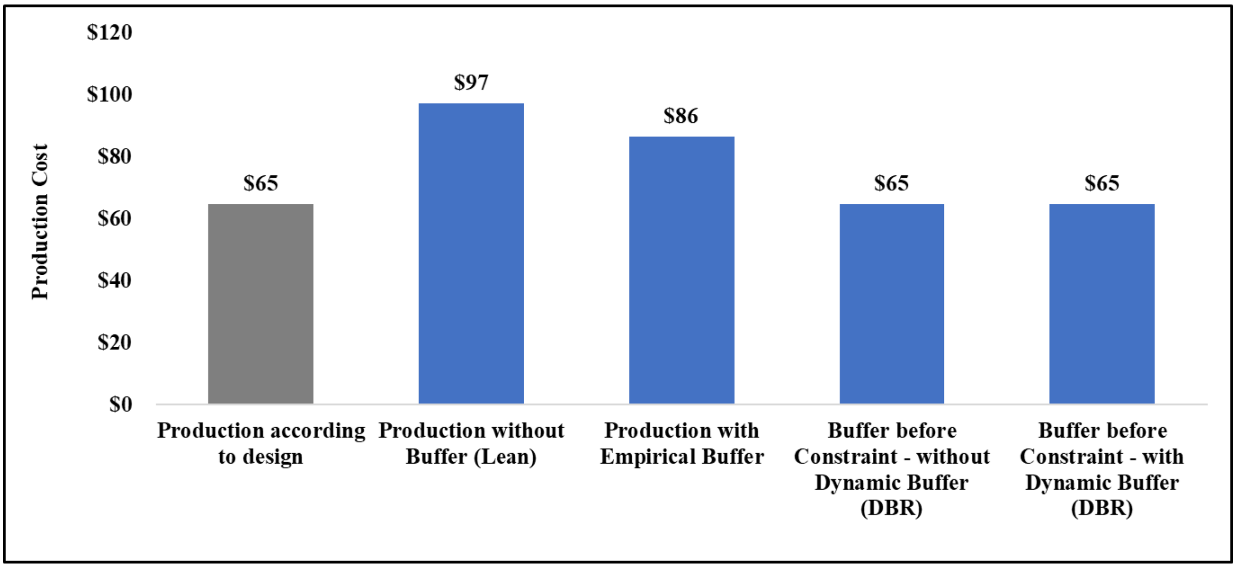
Figure 14 - Labor Cost



Source: Prepared by the author.

For a quantitative survey of economic results, the company's cost base was utilized. Labor costs consist of the average cost of operators working in this area, while production costs encompass the direct operational costs, consumables, and the costs of the equipment involved.

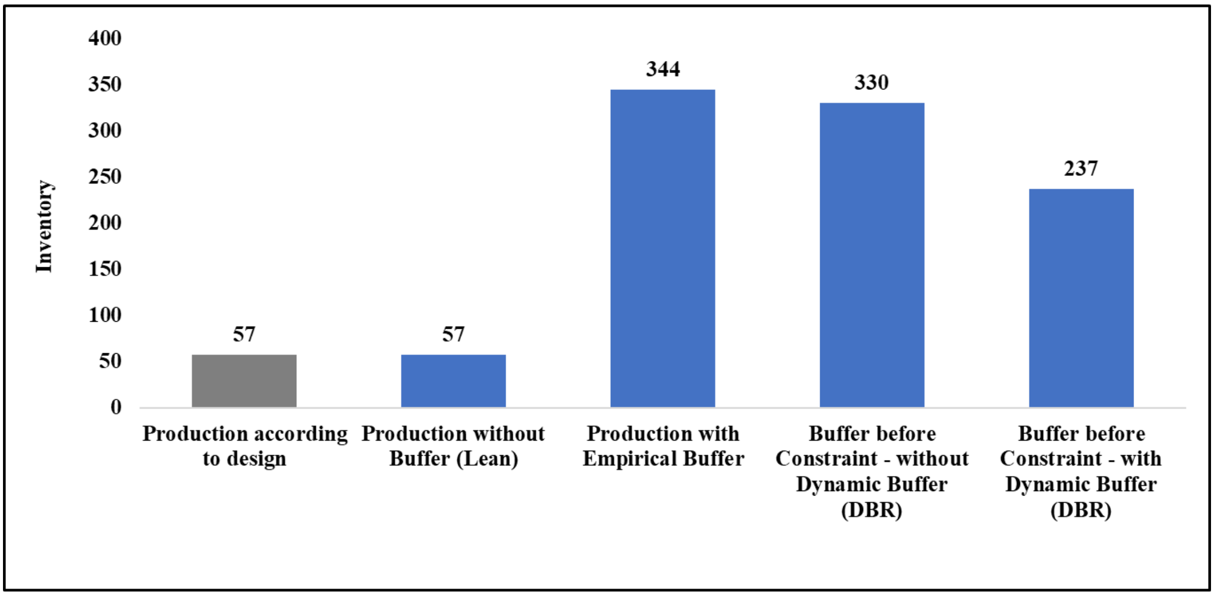
Figure 15 - Production Costs



Source: Prepared by the author.

Figure 16 enables analysis of the inventory in each scenario, in absolute volume of parts. Table 8 provides a comparative analysis of the scenarios in terms of total cost, thus confirming the best performance in the Buffer Before Constraint - With Dynamic Buffer scenario. Moreover, this scenario is the closest to the production and cost planned by the company (production according to design). For example, the production volume showed a variation of 1.5% and cost, 4.4% in relation to those projected.

Figure 16 - Inventory (Absolute Volume of Parts in Process)



Source: Prepared by the author.

Table 8 - Total Cost of Scenarios

Parameters	Output (parts)	WIP Cost ($)	Labor Cost ($)	Production Cost ($)	Total Cost ($)
Production according to design	4,396	1,710	88,000	27,500	117,210
Production without Buffer (Lean)	2,265	1,710	132,000	41,250	174,960
Production with Empirical Buffer	2,561	10,320	117,480	36,712	164,512
Buffer before Constraint - without Dynamic Buffer	4,314	9,900	88,000	27,500	125,400
Buffer before Constraint - with Dynamic Buffer	4,330	7,110	88,000	27,500	122,610

Source: Prepared by the author.

4.6 DISCUSSION OF RESULTS

This paper presents theoretical and practical contributions regarding the use of Lean and TOC by companies. The first theoretical contribution is to apply the DBR from the evaluation of system dynamics modeling to explore the scenarios that comparatively evaluate Lean and TOC. This allows understanding of the reasons why DBR-TOC showed better results when compared to Lean in the context studied. Although the production line was designed based on Lean, that is, to operate with balanced capacity, in practice, there was variability of resource capacity. Since there is no protection in the system, zero inventory, the system output is restricted to the lowest resource capacity. Thus, the system efficiency is the product of the individual efficiency. The insertion of strategically located inventories, as suggested by TOC, allows absorption of the capacity variability of the resources while keeping the restrictive resource supplied. In this case, the system is subject only to the capacity variability of the constrained resource.

The second theoretical contribution lies in the importance of evaluating whether the variability of the production system allows implementation of Lean in its entirety, that is, as suggested by the literature. The elimination of all variability in the system is not efficient in terms of cost, and it is better to insert a buffer in the constraint to protect the system (TAYLOR III, 2000a). In this sense, the results empirically evidence the importance of attention to the conditions necessary for the implementation of Lean, as Goldratt (2009) described. A third contribution consists of implementing the dynamic management of buffers. Using protection buffers without their recursive management may imply operating with protection levels above what would be necessary to guarantee the output rate. Therefore, once the buffers are defined, it is necessary to monitor and resize them to protect the throughput generation of the production system. System dynamics modeling contributes to the visualization and sizing of buffers prior to implementation. The expansion of the product mix can make even more important the contributions of system dynamics modeling, the evaluation of buffers, and the results derived from the implementation of the solution.

A fourth contribution lies in the empirical support that the research provided for the comparative analyses between Lean and the Theory of Constraints. In this sense, controlling for competing factors isolates the explanation of the results to intervention performed from the context of these theoretical models. The goal is not to sustain the superiority of TOC over Lean, but to expand reflection and research on the requirements necessary for the implementation of Lean concepts to achieve the expected results. Goldratt (2009, p. 33) stated "in Japan less than 20% of the manufacturers have implemented Lean". In this sense, this research provides empirical elements that contribute to the need to consider the necessary conditions for the implementation of Lean.

In this sense, we observed that the design decisions of the assembly line studied seem to have been influenced by certain assumptions underlying the implementation and support of Lean, for example, the assumption that prioritizes the reduction of variability as the main way to synchronize capacity with demand (DE TREVILLE et al., 2023). This study presents an alternative approach in which productivity is increased through the use of inventory buffers (Goldratt, 2009), allowing the system to operate close to capacity and synchronized with demand. In addition, there is the assumption that treats inventory and capacity buffers as equivalent in terms of cost (HOPP; SPEARMAN, 2004). However, this study empirically demonstrates different results, showing a reduction in costs when capacity buffers are replaced by stock buffers.

The set of studies presenting the benefits of TOC are widely portrayed in the literature. However, the fifth contribution consists of empirically evidencing comparative evaluation with external variables controlled and isolating the results generated by DBR-TOC and Lean, in particular Heinjunka's concept. Consequently, the empirical evidence generated increases the consistency of the expected results of both Lean and TOC. Finally, despite the use of automation in the production cells, the production concepts are shown to be central to achievement of the results. Therefore, the work suggests the need to subordinate the manufacturing technologies to the context, the conditions and the manufacturing concept the organization aims at. The manufacturing concepts adopted, considering the organization's context and conditions, can amplify or limit the results produced by the technology.

In terms of managerial contributions, the research allows understanding of the production synchronization approach suitable for the context of organizations to obtain better results. Thus, the work provides evidence that reinforces the need not to adopt Lean as a managerial fad, but to evaluate its suitability for the organization’s internal and external environment. Additionally, another managerial contribution of the research is linked to the benefits provided by SD. The positive results obtained with the model reduced resistance to testing the DBR approach in the factory, and allowed simulation of different scenarios before actual implementation. This research supports efficiency measurements and proves the benefits of implementing DBR on the production line, considering that the model developed can be replicated in other production lines where they have these same characteristics. This model enables a better decision-making process for managers to meet urgent orders, due to the stable condition of the production line output. Finally, the results of the implementation indicate a significant improvement in terms of productivity and costs, in conformity with the results of the model.

4.7 CONCLUSIONS

This research deals with the modeling of an automotive production line, focused on flow analysis, evaluating the behavior of the different concepts, Lean and TOC, modeled through system dynamics. The results allow us to state that, after the implementation of the Drum-Buffer-Rope (TOC), the efficiency of the line increased by an average of 48% in relation to the volume produced, and a reduction of 14% in labor cost, as well as 17.8% in production costs, when compared to the Lean scenario, which represents the current state of the line.

When analyzing the relationship between production and inventory, the TOC scenario, where dynamic buffering is utilized, shows the best result. It provides a 28% reduction in inventory volume when compared to the environment without dynamic buffering. The comparison of the TOC, Lean and Empirical WIP scenarios presents a distortion, since the latter two scenarios achieve lower production volumes and thus cause skewed results when compared to each other. The results point out that the automotive production line could reduce up to 29.9% of its total costs by applying TOC instead of Lean. These results were obtained with empirical data based on the company’s historical data, which may introduce uncertainty into the results. For this reason, it is suggested to continue the study with a new simulation model, using discrete event simulation, with probability distributions calculated from data collected by researchers. In future work, we suggest further research on buffer size, production line efficiency analysis, and combination of different buffers across processes. Moreover, we suggest that further comparative analyses between Lean and TOC implementation be conducted in different contexts.

REFERENCES

ABDELOUAHED, B. et al. Influence of Lean and Lean Six Sigma on Social Factors in the Moroccan Industry - Case Study. **International Journal of Performability Engineering**, v. 19, n. 8, p. 516, 2023.

ABREU-LEDÓN, R. et al. A meta-analytic study of the impact of Lean Production on business performance. **International Journal of Production Economics**, v. 200, p. 83–102, 2018.

ABU, F. et al. The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications. **Journal of Cleaner Production**, v. 234, p. 660–680, 2019.

AHMED, A.; OLSEN, J.; PAGE, J. Integration of Six Sigma and simulations in real production factory to improve performance – a case study analysis. **International Journal of Lean Six Sigma**, v. 14, n. 2, p. 451–482, 28 fev. 2023.

AHMED, S.; SOBUZ, M. H. R. Challenges of implementing lean construction in the construction industry in Bangladesh. **Smart and Sustainable Built Environment**, v. 9, n. 2, p. 174–207, 2020.

ALBLIWI, S. et al. Critical failure factors of lean Six Sigma: A systematic literature review. **International Journal of Quality and Reliability Management**, v. 31, n. 9, p. 1012–1030, 30 set. 2014.

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALMASHAQBEH, S.; HERNANDEZ, E. M. EVALUATION AND IMPROVEMENT OF A PLASTIC PRODUCTION SYSTEM USING INTEGRATED OEE METHODOLOGY: A CASE STUDY. **Management Systems in Production Engineering**, v. 32, n. 3, p. 450–463, 1 ago. 2024.

ALMEIDA, M. R. Princípios Básicos Para Uma Proposta De Ensino Sobre. p. 37–50, 2006.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015a.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015b.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015c.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015d.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. Lean production as promoter of thinkers to achieve companies' agility. **Learning Organization**, v. 19, p. 219–237, 2012a.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. **Lean production as promoter of thinkers to achieve companies' agility**. **Learning Organization**, abr. 2012b.

ALZUBI, E. et al. Hybrid integrations of value stream mapping, theory of constraints and simulation: Application to wooden furniture industry. **Processes**, v. 7, n. 11, 2019.

ANDERSSON, C.; BELLGRAN, M. On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity. **Journal of Manufacturing Systems**, v. 35, p. 144–154, 2015.

ANFAVEA. **Anuário da indústria automobilística brasileira**. [s.l: s.n.].

ANFAVEA, A. N. DOS F. DE V. A. **Anuário Estatístico da Indústria Automobilística Brasileira**.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013a.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013b.

APARICIO, J. et al. Measuring and decomposing firm's revenue and cost efficiency: The Russell measures revisited. **International Journal of Production Economics**, v. 165, p. 19–28, 1 jul. 2015.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017a.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017b.

AYOUBA, K. et al. A measure of price advantage and its decomposition into output- and input-specific effects. **European Journal of Operational Research**, v. 276, n. 2, p. 688–698, 16 jul. 2019.

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAKER, P. Why is lean so far off? v. 55, p. 26–29, 2002.

BANKES, S. **Exploratory Modeling for Policy AnalysisOperations Research**. [s.l: s.n.].

BANKES, S.; WALKER, W.; KWAKKEL, J. **Exploratory Modeling and Analysis**. [s.l: s.n.].

BAPTISTA, A.; ABREU, L.; BRITO, E. APPLICATION OF LEAN TOOLS CASE STUDY IN A TEXTILE COMPANY. **Proceedings on Engineering Sciences**, v. 3, n. 1, p. 93–102, 2021.

BARBERIO MARIANO, E. Conceitos Básicos de Análise de Eficiência produtiva. 2007.

BARBOSA, L. M. et al. Exploratory analysis of the variables prevailing on the effects of product modularization on production volume and efficiency. **International Journal of Production Economics**, v. 193, p. 677–690, 2017.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016a.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016b.

BARRATT, M.; CHOI, T. Y.; LI, M. Qualitative case studies in operations management: Trends, research outcomes, and future research implications. **Journal of Operations Management**, v. 29, n. 4, p. 329–342, 2011.

BBC. **Entenda por que a produtividade no Brasil não cresce**. Disponível em: <https://www.bbc.com/portuguese/noticias/2014/05/140519_produtividade_porque_ru>. Acesso em: 29 abr. 2023.

BBC. **Ford: afinal, por que a montadora decidiu encerrar a produção de veículos no Brasil?** Disponível em:

<https://www.bbc.com/portuguese/internacional-55640907>. Acesso em: 7 maio. 2023.

BERGENWALL, A. L.; CHEN, C.; WHITE, R. E. TPSs process design in American automotive plants and its effects on the triple bottom line and sustainability. **International Journal of Production Economics**, v. 140, n. 1, p. 374–384, nov. 2012.

BETTERTON, C. E.; COX, J. F. Espoused drum-buffer-rope flow control in serial lines: A comparative study of simulation models. **International Journal of Production Economics**, v. 117, n. 1, p. 66–79, 2009.

BHASIN, S. An appropriate change strategy for lean success. **Management Decision**, v. 50, n. 3, p. 439–458, 2012.

BHASIN, S. Impact of corporate culture on the adoption of the lean principles. **International Journal of Lean Six Sigma**, v. 4, n. 2, p. 118–140, 2013.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002a.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002b.

BLANCHARD, D. Census of U.S. Manufactures: Lean Green and Low Cost. **Industry Week**, v. October, 2007.

BORTOLOTTI, T.; BOSCARI, S.; DANESE, P. Successful lean implementation: Organizational culture and soft lean practices. **International Journal of Production Economics**, v. 160, p. 182–201, 2015.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015a.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015b.

CAMANHO et al. A literature review of economic efficiency assessments using Data Envelopment Analysis. **European Journal of Operational Research**, 2023.

CAMANHO, A. S.; DYSON, R. G. Cost efficiency measurement with price uncertainty: A DEA application to bank branch assessments. **European Journal of Operational Research**, v. 161, n. 2, p. 432–446, 2005.

CARDOSO ERMEL, A. P. et al. **Literature Reviews**. Cham: Springer International Publishing, 2021.

CESARONI, G.; GIOVANNOLA, D. Average-cost efficiency and optimal scale sizes in non-parametric analysis. **European Journal of Operational Research**, v. 242, n. 1, p. 121–133, 1 abr. 2015.

CHAKRAVORTY, S. S.; ATWATER, J. B. The impact of free goods on the performance of drumbuffer-rope scheduling systems. **International Journal of Production Economics**, v. 95, n. 3, p. 347–357, 2005.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016a.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016b.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018a.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018b.

CHARNES, A.; COOPER, W. W.; RHODES, E. Measuring the efficiency of decision making units. **European Journal of Operational Research**, v. 2, n. 6, p. 429–444, 1978.

CHIZARI, A. H.; FEHRESTI-SANI, M. Evaluation of the economic efficiency of vegetable oil supply chains. **Supply Chain Forum**, v. 19, n. 2, p. 132–141, 3 abr. 2018.

COOK, W. D.; TONE, K.; ZHU, J. Data envelopment analysis: Prior to choosing a model. **Omega (United Kingdom)**, v. 44, p. 1–4, 2014.

CORRALES, L. DEL C. N. et al. Overall equipment effectiveness: Systematic literature review and overview of different approaches. **Applied Sciences (Switzerland)**, v. 10, n. 18, 2020.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016a.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016b.

COSTA, B.; VAREJÃO, J.; GASPAR, P. D. Development of a Value Stream Map to Optimize the Production Process in a Luxury Metal Piece Manufacturing Company. **Processes**, v. 12, n. 8, 1 ago. 2024.

COSTA, F. et al. How to foster Sustainable Continuous Improvement: A cause-effect relations map of Lean soft practices. **Operations Research Perspectives**, v. 6, n. December, p. 100091, 2019.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010a.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010b.

COX III, J. F.; SCHLEIER JR, J. G. **Handbook da Teoria das Restrições.** Bookman ed. Porto Alegre: [s.n.].

COX, J. F. I. et al. The TOCICO dictionary. v. 2, p. 1–135, 2012.

COX, J.F. III; SCHLEIER, J.G., J. **Handbook Theory of Constraints**. [s.l.] Bookman, 2013.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021a.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021b.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015a.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015b.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015c.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015d.

DAS, S.; PATEL, G. N. Cost efficiency of pharmaceutical firms manufacturing drugs for specific diseases prevalent in India: A data envelopment analysis approach. **Journal of Medical Marketing**, v. 14, n. 1, p. 5–19, 1 fev. 2014.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018a.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018b.

DE TREVILLE, S. et al. Editorial: Toyota Production System practices as Fast-and-Frugal heuristics. **Journal of Operations Management**, v. 69, n. 4, p. 522–535, 2023.

DIAS, R. M. F.; SILVA, L. D.; TENERA, A. Application of a proposed TLS model in a Lean Productive System. **Independent Journal of Management & Production**, v. 10, n. 1, p. 076, 2019.

DOBRA, P.; JÓSVAI, J. Overall Equipment Effectiveness (OEE) Life Cycle at the Automotive Semi-Automatic Assembly Lines. **Acta Polytechnica Hungarica**, v. 19, n. 9, p. 141–155, 2022.

DOGAN, N.; KAYGISIZ, F.; ALTINEL, A. Technical and economic efficiency of laying hen farms in Konya, Turkey. **Revista Brasileira de Ciencia Avicola**, v. 20, n. 2, p. 263–272, 2018.

DORA, M.; KUMAR, M.; GELLYNCK, X. Determinants and barriers to lean implementation in food-processing SMEs - A multiple case analysis. **Production Planning and Control**, v. 27, n. 1, p. 1–23, 2 jan. 2016.

ELKHAIRI, A.; FEDOUAKI, F.; EL ALAMI, S. Barriers and critical success factors for implementing lean manufacturing in SMEs. **IFAC-PapersOnLine**, v. 52, n. 13, p. 565–570, 2019.

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011a.

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011b.

FGV. **BRASILEIRO LEVA 1 HORA PARA PRODUZIR O QUE AMERICANO FAZ EM 15 MINUTOS**. Disponível em: <https://eesp.fgv.br/noticia/brasileiro-leva-1-hora-para-produzir-o-que-americano-faz-em-15-minutos>. Acesso em: 29 abr. 2023.

FILIPE, D.; PIMENTEL, C. Production and Internal Logistics Flow Improvements through the Application of Total Flow Management. **Logistics**, v. 7, n. 2, 1 jun. 2023.

FOUND, P. et al. Towards a theory of operational excellence. **Total Quality Management and Business Excellence**, v. 29, n. 9–10, p. 1012–1024, 29 jul. 2018.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020a.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020b.

FURLAN, A.; VINELLI, A.; PONT, G. D. Complementarity and lean manufacturing bundles: An empirical analysis. **International Journal of Operations and Production Management**, v. 31, n. 8, p. 835–850, 2011.

GALEAZZO, A.; FURLAN, A. Lean bundles and configurations: a fsQCA approach. **International Journal of Operations and Production Management**, v. 38, n. 2, p. 513–533, 2018.

GAUSS, L. et al. Design science in operations management: A review and synthesis of the literature. **International Journal of Management Reviews**, 5 dez. 2024.

GLOBO. **Mapa: todas as fábricas de carros, motos e caminhões estão paradas no Brasil por pandemia**. Disponível em: <https://autoesporte.globo.com/carros/noticia/2020/03/mapa-todas-fabricas-de-carros-motos-e-caminhoes-estao-paradas-no-brasil-por-pandemia.ghtml>.

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E. M. Computerized shop floor scheduling. 1988a.

GOLDRATT, E. M. Computerized shop floor scheduling. 1988b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009a.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009c.

GOLDRATT, E. M. & F. R. E. **The Race**. [s.l: s.n.].

GOLDRATT, E. M.; COX, J. **A Meta**. 3° ed. [s.l: s.n.].

GOLDRATT, E. M.; FOX, R. E. **The Race**. [s.l: s.n.].

GOLMOHAMMADI, D. A study of scheduling under the theory of constraints. **International Journal of Production Economics**, v. 165, p. 38–50, 2015.

GONZALEZ-R, P. L.; FRAMINAN, J. M.; RUIZ-USANO, R. A multi-objective comparison of dispatching rules in a drum-buffer-rope production control system. **International Journal of Computer Integrated Manufacturing**, v. 23, n. 2, p. 155–167, 2010.

GOSLING, J.; NAIM, M. M. Engineer-to-order supply chain management: A literature review and research agenda. **International journal of production economics**, v. 122(2), p. 741–754, 2009.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007a.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007b.

GUILLEN, K. et al. LEAN model for optimizing plastic bag production in small and medium sized companies in the plastics sector. **International Journal of Engineering Research and Technology**, v. 11, n. 11, p. 1713–1734, 2018.

GUPTA, A.; BHARDWAJ, A.; KANDA, A. Fundamental concepts of theory of constraints: An emerging philosophy. **World Academy of Science, Engineering and Technology**, v. 46, n. 10, p. 686–692, 2010.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022a.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022b.

GUPTA, S.; MODGIL, S.; GUNASEKARAN, A. Big data in lean six sigma: a review and further research directions. **International Journal of Production Research**, v. 58, n. 3, p. 947–969, 2020.

HARDCOPF, R.; LIU, G. (JASON); SHAH, R. Lean production and operational performance: The influence of organizational culture. **International Journal of Production Economics**, v. 235, n. March 2020, p. 108060, 2021.

HATAMI-MARBINI, A.; ARABMALDAR, A. Robustness of Farrell cost efficiency measurement under data perturbations: Evidence from a US manufacturing application. **European Journal of Operational Research**, v. 295, n. 2, p. 604–620, 2021.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015a.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015b.

HO, T. Q.; HOANG, V. N.; WILSON, C. Trade-off analysis of cost and nutrient efficiency of coffee farms in vietnam: A more generalised approach. **Journal of Environmental Management**, v. 279, n. August, p. 111601, 2021.

HOPP, W. J. Positive lean: merging the science of efficiency with the psychology of work. **International Journal of Production Research**, v. 56, n. 1–2, p. 398–413, 2018.

HOPP, W. J.; SPEARMAN, M. L. To pull or not to pull: What is the question? **Manufacturing and Service Operations Management**, v. 6, n. 2, p. 133–148, 2004.

HOPP, W. J.; SPEARMAN, M. S. The lenses of lean: Visioning the science and practice of efficiency. **Journal of Operations Management**, v. 67, n. 5, p. 610–626, 2021.

HÜTTMEIR, A. et al. Trading off between heijunka and just-in-sequence. **International Journal of Production Economics**, v. 118, n. 2, p. 501–507, abr. 2009.

IKEZIRI, L. M. et al. Theory of constraints: review and bibliometric analysis. **International Journal of Production Research**, v. 57, n. 15–16, p. 1–35, 2018.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023a.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023b.

INAN, G. G. ; et al. Operational performance improvement through continuous improvement initiatives in micro-enterprises of Turkey. **Asia-Pacific Journal of Business Administration,** v. 14, n. 3, p. 335–361, 2021.

IOANA, A. D.; MARIA, E. D.; CRISTINA, V. **Case study regarding the implementation of one-piece flow line in automotive company**. Procedia Manufacturing. **Anais**...Elsevier B.V., 2020.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014a.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014b.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014a.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014b.

JAIN, S.; TRIANTIS, K. P.; LIU, S. Manufacturing performance measurement and target setting: A data envelopment analysis approach. **European Journal of Operational Research**, v. 214, n. 3, p. 616–626, 2011.

JRADI, S.; BOUZDINE CHAMEEVA, T.; APARICIO, J. The measurement of revenue inefficiency over time: An additive perspective. **Omega (United Kingdom)**, v. 83, p. 167–180, 1 mar. 2019.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013a.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013b.

KERSTENS, K.; SADEGHI, J.; VAN DE WOESTYNE, I. Convex and nonconvex input-oriented technical and economic capacity measures: An empirical comparison. **European Journal of Operational Research**, v. 276, n. 2, p. 699–709, 2019.

KIM, J.; GERSHWIN, S. B. Integrated quality and quantity modeling of a production line. **Stochastic Modeling of Manufacturing Systems: Advances in Design, Performance Evaluation, and Control Issues**, p. 121–148, 2006.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010a.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010b.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, jan. 2010c.

KONOPKA, J. M. Capacity Utilization Bottleneck Efficiency System—CUBES. **IEEE Transactions on Components Packaging and Manufacturing Technology Part A**, v. 18, n. 3, p. 484–491, 1995.

KUMAR, R.; KUMAR, V. Barriers in implementation of lean manufacturing system in Indian industry: A survey. **International Journal of Latest Trends in Engineering & Technology**, v. 4, p. 243–251, 2014.

KWAKKEL, J. H.; PRUYT, E. Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. **Technological Forecasting and Social Change**, v. 80, n. 3, p. 419–431, 2013.

LACERDA, D. P. et al. Design Science Research: Método de pesquisa para a engenharia de produção. **Gestao e Producao**, v. 20, n. 4, p. 741–761, 26 nov. 2013.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021a.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021b.

LANZA, G. et al. Measuring global production effectiveness. **Procedia CIRP**, v. 7, p. 31–36, 2013.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024a.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024b.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024c.

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LEITE, H.; RADNOR, Z.; BATEMAN, N. Meaningful inhibitors of the lean journey: a systematic review and categorisation of over 20 years of literature. **Production Planning and Control**, v. 33, n. 5, p. 403–426, 2022.

LIKER, J.; ROTHER, M. Why Lean Programs Fail. **Lean Enterprise Institute**, p. 1–5, 2011.

LIM, A. S. S.; SABIL, S.; OTHMAN, A. E. B. A. the Mediating Role of Continuous Improvement on the Relationship Between Workplace Learning Dimensions and Sustainable Lean Manufacturing. **International Journal of Business and Society**, v. 23, n. 1, p. 260–278, 2022.

LIU, J. et al. A DEA-based approach for competitive environment analysis in global operations strategies. **International Journal of Production Economics**, v. 203, p. 110–123, 2018.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019a.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019b.

LUZ, G. P. et al. Proposition of a method for stochastic analysis of value streams. **Production Planning and Control**, v. 33, n. 8, p. 741–757, 2022.

MABIN, V. J.; BALDERSTONE, S. J. The performance of the theory of constraints methodology: Analysis and discussion of successful TOC applications. **International Journal of Operations and Production Management**, v. 23, n. 5–6, p. 568–595, 2003.

MAHJOOR, A. A. Technical, allocative and economic efficiencies of broiler farms in Fars Province, Iran: A Data Envelopment Analysis (DEA) approach. **World Applied Sciences Journal**, v. 21, n. 10, p. 1427–1435, 2013.

MANAVIZADEH, N. et al. A Simulated Annealing algorithm for a mixed model assembly U-line balancing type-I problem considering human efficiency and Just-

In-Time approach. **Computers and Industrial Engineering**, v. 64, p. 669–685, 2013.

MARFATIA, H. et al. S earch and s urvey. n. February 2021, p. 10–17, 2020.

MARODIN, G. A. et al. Model of risk interactions hindering lean production implementation. **Gestao e Producao**, v. 25, n. 4, p. 696–712, 2018.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019a.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019b.

MARTINS, J. C. et al. Systems dynamic modeling to analyze the systemic viability of the combined use of regenerative converters and energy storage in a UPS manufacturer. **Journal of Cleaner Production**, v. 246, n. xxxx, p. 118950, 2020.

MEMARI, A. et al. The impact of lean production on operational performance: a case study. **Asia-Pacific Journal of Business Administration**, 2022.

MILLSTEIN, M. A.; MARTINICH, J. S. Takt Time Grouping: Implementing kanban-flow manufacturing in an unbalanced, high variation cycle-time process with moving constraints. **International Journal of Production Research**, v. 52, n. 23, p. 6863–6877, 2014.

MOHANAVELU, T.; KRISHNASWAMY, R.; MARIMUTHU, P. Simulation modelling and development of analytic hierarchy process-based priority dispatching rule for a dynamic press shop. **nternational Journal of Industrial and Systems Engineering**, v. 27(3), p. 340–364, 2017.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023a.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023b.

MOHD AZHAR SAHWAN; MOHD NIZAM AB RAHMAN; BABA MD DEROS. Barriers to Implement Lean Manufacturing in Malaysian Automotive Industry. **Jurnal Teknologi (Sciences and Engineering)**, v. 59, p. 107–110, 2012.

MORANDI, M. I. W. M. et al. Foreseeing Iron Ore Prices Using System Thinking and Scenario Planning. **Systemic Practice and Action Research**, v. 27, n. 3, p. 287–306, 2014.

MORANDI, M. I. W. M.; CAMARGO, L. F. R. **Revisão sistemática da literatura. Design science research: Método de pesquisa para avanço da ciência e tecnologia**. [s.l.] Bookman, 2015.

MUCHIRI, P.; PINTELON, L. Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. **International Journal of Production Research**, v. 46, n. 13, p. 3517–3535, 2008.

MUTHIAH, K. M. N.; HUANG, S. H. Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection. **International Journal of Production Research**, v. 45, n. 20, p. 4753–4769, 2007.

NACIRI, L. et al. **Lean and industry 4.0: A leading harmony**. Procedia Computer Science. **Anais**...Elsevier B.V., 2022.

NANCI, L. C.; AZEREDO, S. M.; MELLO, J. C. C. B. S. DE. Estudo da eficiência de empresas distribuidoras de jornais usando análise envoltória de dados. **Produto & Produção**, v. 7, n. 3, p. 27–35, 2006.

NARASIMHAN, R.; SWINK, M.; KIM, S. W. Disentangling leanness and agility: An empirical investigation. **Journal of Operations Management**, v. 24, n. 5, p. 440–457, 2006.

NARASSIMA, M. S. et al. Implementation of lean principles in the yarn manufacturing industry: a system dynamics approach. **Benchmarking**, 2023.

NEELY, A.; GREGORY, M.; PLATTS, K. A literature review and research agenda. **International Journal of Operations & Production Management**, v. 15, n. 4, p. 80–116, 2002.

NETLAND, T. H.; SCHLOETZER, J. D.; FERDOWS, K. Learning lean: rhythm of production and the pace of lean implementation. **International Journal of Operations and Production Management**, v. 41, n. 2, p. 131–156, 2021.

NG CORRALES, L. D. C. et al. Developing and Implementing a Lean Performance Indicator: Overall Process Effectiveness to Measure the Effectiveness in an Operation Process. **Machines**, v. 10, n. 2, 1 fev. 2022.

OECHSNER, R. et al. From overall equipment efficiency (OEE) to overall Fab effectiveness (OFE). **Materials Science in Semiconductor Processing**, v. 5, n. 4-5 SPEC., p. 333–339, 2002.

OH, I. et al. Analysis of product efficiency in the Korean automobile market from a consumer’s perspective. **Empirical Economics**, v. 38, n. 1, p. 119–137, fev. 2010.

OHNO, T. Toyota Production System: beyond large-scale production. **Oregon: Productivity Press**, 1988.

OHNO, T. **O Sistema Toyota de Produção Além da Produção em Larga Escala**. [s.l.] Bookman, 1997.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021a.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021b.

PACHECOA, D. A. DE J. Theory of Constraints, Lean Manufacturing and Six Sigma: Limits to and possibilities for integration. **Producao**, v. 24, n. 4, p. 940–956, 2014.

PARK, J.; LEE, D.; ZHU, J. An integrated approach for ship block manufacturing process performance evaluation: Case from a Korean shipbuilding company. **International Journal of Production Economics**, v. 156, p. 214–222, 2014.

PEARCE, A.; PONS, D.; NEITZERT, T. Implementing lean—Outcomes from SME case studies. **Operations Research Perspectives**, v. 5, p. 94–104, 2018.

PEREIRA, L.; TORTORELLA, G. Identification of the relationships between critical success factors, barriers and practices for lean implementation in a small company. **Brazilian Journal of Operations & Production Management**, v. 15, n. 2, p. 232–246, 1 jun. 2018.

PERVAZ, J. et al. SIMULATION-BASED ALGORITHM FOR CONTINUOUS IMPROVEMENT OF ENTERPRISES PERFORMANCE. **International Journal of Simulation Modelling**, v. 23, n. 2, p. 215–226, 1 jun. 2024.

PIRAN, F. A. S. et al. Product modularization and effects on efficiency: An analysis of a bus manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 182, p. 1–13, 2016.

PIRAN, F. A. S. et al. Overall Equipment Effectiveness: Required but not Enough—An Analysis Integrating Overall Equipment Effect and Data Envelopment Analysis. **Global Journal of Flexible Systems Management**, v. 21, n. 2, p. 191–206, 1 jun. 2020.

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, 2021a.

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, n. April, p. 108173, 2021b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and

Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020b.

PONT, G. D.; FURLAN, A.; VINELLI, A. Interrelationships among lean bundles and their effects on operational performance. **Operations Management Research**, v. 1, n. 2, p. 150–158, 2009.

PORTELA, M. C. A. S.; THANASSOULIS, E. Economic efficiency when prices are not fixed: Disentangling quantity and price efficiency. **Omega (United Kingdom)**, v. 47, p. 36–44, 2014.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019a.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019b.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 2019a.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019b.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019c.

QAMAR, A. et al. Quality and flexibility performance trade-offs between lean and agile manufacturing firms in the automotive industry. **Production Planning and Control**, v. 31, n. 9, p. 723–738, 2020.

QURESHI, K. M. et al. Exploring the Lean Implementation Barriers in Small and Medium-Sized Enterprises Using Interpretive Structure Modeling and Interpretive Ranking Process. **Applied System Innovation**, v. 5, n. 4, p. 1–20, 2022.

RAMADAS, T.; SATISH, K. P. Identification and modeling of process barriers: Implementing lean manufacturing in small-and medium-size enterprises. **International Journal of Lean Six Sigma**, v. 12, n. 1, p. 61–77, 2021.

RAOUF, A. Improving capital productivity through maintenance. . **International Journal of Operations & Production Management**, v. 14 (7), p. 44–52, 1994.

REPONEN, E. et al. Benchmarking outcomes on multiple contextual levels in lean healthcare: a systematic review, development of a conceptual framework, and a research agenda. **BMC Health Services Research**, v. 21, n. 1, 1 dez. 2021.

ROCHMAN, Y. A.; SUDIARSO, A.; HERLIANSYAH, M. K. Development of Lean Implementation Framework for Indonesian Batik Small and Medium-Sized Enterprises. **International Journal of Engineering, Transactions B: Applications**, v. 37, n. 11, p. 2223–2238, 1 nov. 2024.

ROJON, C.; OKUPE, A.; MCDOWALL, A. Utilization and development of systematic reviews in management research: What do we know and where do we go from here? **International Journal of Management Reviews**, v. 23, n. 2, p. 191–223, 1 abr. 2021.

ROMERO, L. F. et al. A data envelope analysis to assess factors affecting technical and economic efficiency of individual broiler breeder hens. **Poultry Science**, v. 89, n. 8, p. 1769–1777, 2010.

SARTAL, A.; VAZQUEZ, X. H.; LOZANO-LOZANO, L. M. Organizational Tools and Cultural Change in the Success of Lean Transformations: Delving Into Sequence and Rhythm. **IEEE Transactions on Engineering Management**, v. 69, n. 5, p. 2205–2217, 1 out. 2022.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023a.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023b.

SCOTT, D.; PISA, R. Can overall factory effectiveness prolong Mooer's law? **Solid State Technology**, p. 75–81, 1998.

SECCHI, R.; CAMUFFO, A. Lean implementation failures: The role of organizational ambidexterity. **International Journal of Production Economics**, v. 210, p. 145–154, 1 abr. 2019.

SILVA, F.; MENEZES-FILHO, N.; KOMATSU, B. Evolução da produtividade no Brasil: comparações internacionais. **Insper Policy Paper**, n. 15, p. 30, 2016.

SOHRMANN, C. et al. Towards a Standardized Format for Automotive Mission Profiles State of the Art Use Cases for Mission Profiles Application of MPs in Verification and. **Proc. Automotive meets Electronics 10**, n. March, p. 39–44, 2021.

SPEAR, S.; BOWEN, H. K. Decoding the DNA of the Toyota Production System. **Harvard Business Review**, v. 77, n. 5, p. 96–106, 1999.

STAUDACHER, A. P.; TANTARDINI, M. **Lean production implementation: a survey in Italy**. XI Congreso de Ingeniería de Organizacion International Conference on Industrial Engineering and Industrial Management,. **Anais**...Madri: 2007.

STEELE, D. C. et al. Comparisons between drum-buffer-rope and material requirements planning: A case study. **International Journal of Production Research**, v. 43, n. 15, p. 3181–3208, 2005.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022a.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022b.

STRATTON, R.; WARBURTON, R. D. H. The strategic integration of agile and lean supply. **International Journal of Production Economics**, v. 85, n. 2, p. 183–198, 2003.

SUKWADI, R.; FELICIA, Y.; MUAFI. TOC, lean, and six sigma: An integrated model to increase the productivity of the textile industry. **Journal of Mechanical Engineering Research and Developments**, v. 44, n. 1, p. 327–336, 2021.

SUSAETA, A. et al. Technical, allocative, and total profit efficiency of loblolly pine forests under changing climatic conditions. **Forest Policy and Economics**, v. 72, p. 106–114, 1 nov. 2016.

SWEETSER, A. **A Comparison of System Dynamics (SD) and Discrete Event Simulation (DES)**. [s.l: s.n.].

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000a.

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, n. February, p. 107500, 2020a.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020c.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020d.

TELLES, E. S. et al. Drum-Buffer-Rope in an engineering-to-order productive system: a case study in a Brazilian aerospace company. **Journal of Manufacturing Technology Management**, v. 33, n. 6, p. 1190–1209, 6 set. 2022.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020a.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020b.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020c.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018a.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018b.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018c.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018d.

THÜRER, M.; TOMAŠEVIĆ, I.; STEVENSON, M. **On the meaning of ‘Waste’: review and definition**. **Production Planning and Control**Taylor and Francis Ltd., , 17 fev. 2017.

TOMA, S.; NARUO, S. Total Quality Management and Business Excellence: the Best Practices At Toyota Motor Corporation. 2017.

TORTORELLA, G. L. et al. The impact of contextual variables on learning organization in firms that are implementing lean: a study in Southern Brazil. **International Journal of Advanced Manufacturing Technology**, v. 78, n. 9–12, p. 1879–1892, 18 jun. 2015.

TORTORELLA, G. L. et al. Learning organisation and lean production: an empirical research on their relationship. **International Journal of Production Research**, v. 58, n. 12, p. 3650–3666, 2020.

VEGA-ALVITES, J. C. Q.-F. & M. L. Review Lean Manufacturing Model of Production Management Under the Preventive. **South African Journal of Industrial Engineering**, v. 33, n. 2, p. 143–156, 2022.

VENKATESH, A.; KUSHWAHA, S. Short and long-run cost efficiency in Indian public bus companies using Data Envelopment Analysis. **Socio-Economic Planning Sciences**, v. 61, p. 29–36, 1 mar. 2018.

VON GILSA, C. et al. Longitudinal evaluation of efficiency in a petrochemical company. **Benchmarking**, v. 24, n. 7, p. 1786–1813, 2017.

WAHAB, A. et al. Improvement on bill of materials formatting process by adopting lean and six sigma approaches-A case study in a semiconductor industry ilhammee. **International Journal of Integrated Engineering**, v. 11, n. 8, p. 81–90, 2019.

WAHLERS, J. L.; COX, J. F. Competitive factors and performance measurement: Applying the theory of constraints to meet customer needs. **International Journal of Production Economics**, v. 37, n. 2–3, p. 229–240, 1994.

WALLACE J. HOPP, M. L. S. **Factory Physics**. Third Edit ed. [s.l: s.n.].

WATSON, K. J.; BLACKSTONE, J. H.; GARDINER, S. C. The evolution of a management philosophy: The theory of constraints. **Journal of Operations Management**, v. 25, n. 2, p. 387–402, 2007.

WATSON, K. J.; PATTI, A. A comparison of JIT and TOC buffering philosophies on system performance with unplanned machine downtime. **International Journal of Production Research**, v. 46, n. 7, p. 1869–1885, 2008.

WEBSTER, J.; WATSON, R. MIS Quarterly. **Analyzing the Past To Prepare for the Future : Writing a Literature Review**, v. 26, n. 2, p. 13–23, 2002.

WONG, Y. C.; WONG, K. Y.; ALI, A. A study on Lean Manufacturingimplementation in the Malaysian electrical and electronics industry. **European Journal of Scientific Research**, v. Vol. 38, 2009.

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WU, H. H.; LIU, J. Y. A capacity available-to-promise model for drum-buffer-rope systems. **International Journal of Production Research**, v. 46, n. 8, p. 2255–2274, 2008.

WU, S.; WEE, H. M. Why the big three decline despite their lean management - A study based on the theory of constraints. **Global Perspective for Competitive Enterprise, Economy and Ecology - Proceedings of the 16th ISPE International Conference on Concurrent Engineering**, p. 691–699, 2009.

YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008a.

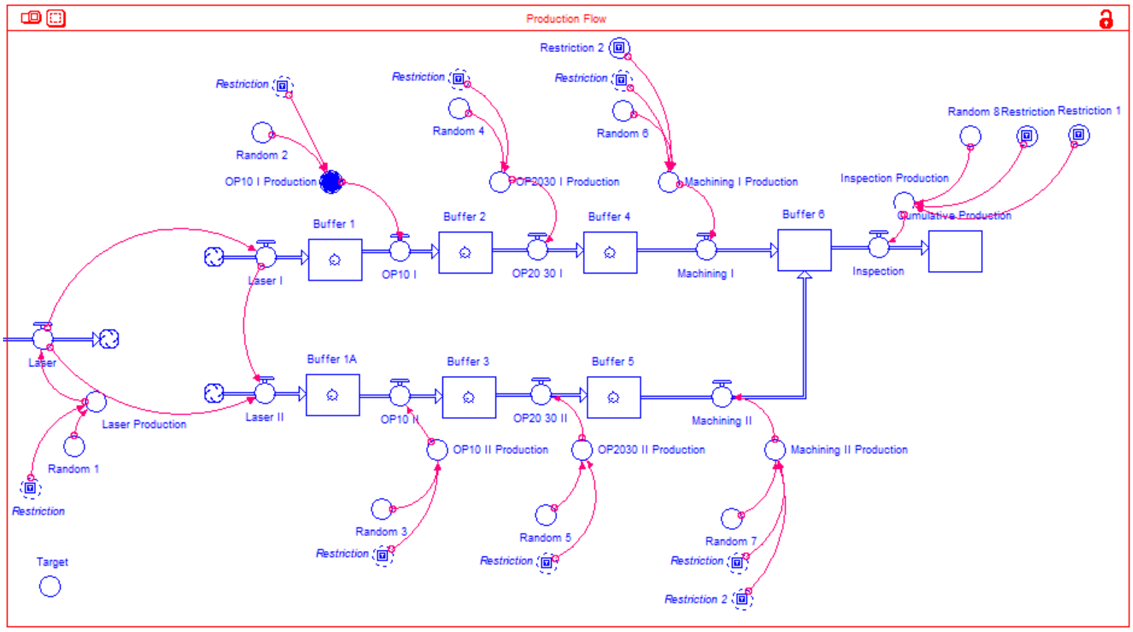
YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008b.

YENRADEE, P. Application of optimized production technology ina capacity constrained flow shop: a case study in a battery factory. **Comput. Ind. Eng.**, v. 27, p. 217–220, 1994.

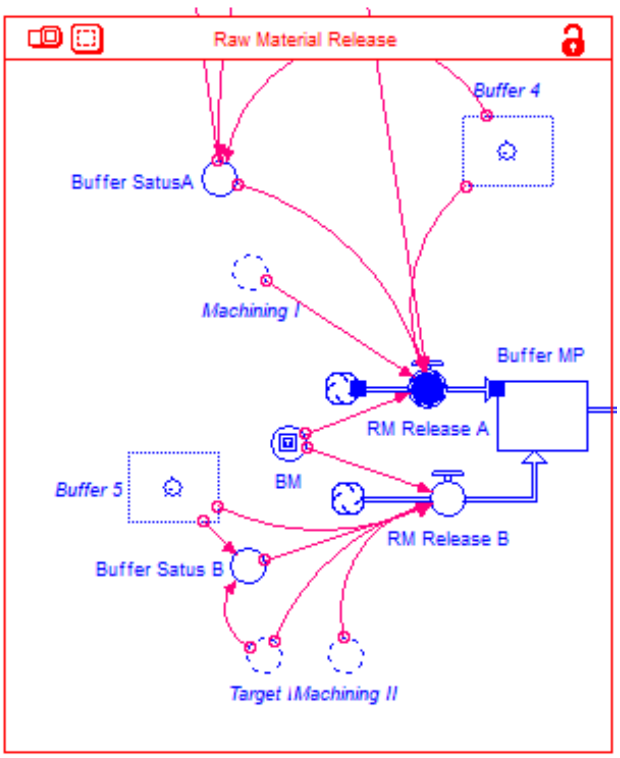
APPENDIX D – PRODUCTION OPERATIONS DATA

	With Constraint												DBR											
	Production without Buffer (Lean)						Production with Empirical Buffer						Buffer before Constraint - without Dynamic Buffer						Buffer before Constraint - with Dynamic Buffer					
			Average Inventory						Average Inventory						Average Inventory						Average Inventory			
	Production	**Loss**	**Laser**	**OP10**	**OP20/30**	**Machining**	**Production**	**Loss**	**Laser**	**OP10**	**OP20/30**	**Machining**	**Production**	**Loss**	**Laser**	**OP10**	**OP20/30**	**Machining**	**Production**	**Loss**	**Laser**	**OP10**	**OP20/30**	**Machining**
1	2,405	360	16	6	8	54	2,579	74	32	101	137	74	4,213	-	28	3	298	1	4,343	-	60	9	193	1
2	2,405	417	16	3	10	53	2,582	168	39	110	120	40	4,307	-	28	2	299	1	4,237	-	52	4	149	-
3	2,150	533	15	8	7	14	2,558	287	40	139	89	58	4,262	-	30	1	298	-	4,439	-	63	3	164	1
4	2,245	421	14	6	10	7	2,607	41	35	139	95	81	4,111	-	28	1	301	-	4,372	-	46	3	143	1
5	2,287	579	15	8	7	13	2,676	181	37	138	95	39	4,530	-	36	4	289	1	4,472	-	54	11	167	1
6	2,266	567	15	9	7	9	2,604	113	37	151	82	61	4,433	-	36	2	292	1	4,394	-	71	9	197	1
7	2,269	429	15	8	7	13	2,477	61	30	99	141	59	4,414	-	30	4	296	1	4,306	-	47	5	164	-
8	2,297	460	15	7	8	15	2,566	190	37	110	123	51	4,299	-	35	2	292	-	4,270	-	39	4	132	-
9	2,486	352	17	5	8	66	2,482	157	28	118	124	46	4,111	-	26	1	303	-	4,487	-	62	15	172	1
10	2,364	325	16	6	9	28	2,563	116	41	117	112	58	4,491	-	38	5	287	1	4,423	-	54	5	205	1
11	2,496	379	16	5	8	98	2,511	-	36	97	137	47	4,319	-	30	2	297	1	4,361	-	56	3	179	-
12	2,315	333	15	6	9	28	2,546	233	42	127	101	57	4,303	-	32	4	293	-	4,400	-	52	6	170	1
13	2,191	534	14	9	7	37	2,527	57	31	129	110	86	4,408	-	29	7	294	1	4,333	-	48	3	205	-
14	2,107	665	14	10	6	18	2,515	151	41	151	78	75	4,318	-	30	2	298	-	4,435	-	66	8	151	1
15	2,302	369	15	6	9	16	2,633	41	29	115	125	96	4,239	-	29	2	298	1	4,299	-	53	7	180	1
16	2,292	386	15	6	9	24	2,648	1	41	85	143	38	4,204	-	28	9	292	-	4,216	-	51	7	194	-
17	2,257	555	14	10	6	21	2,560	199	31	147	92	134	4,277	-	30	4	295	-	4,337	-	53	13	195	-
18	2,236	428	15	5	10	31	2,420	195	26	125	118	41	4,315	-	30	4	296	1	4,224	-	41	3	180	1
19	2,104	574	13	9	7	9	2,277	-	29	69	172	157	4,363	-	33	5	292	-	4,370	-	52	10	152	-
20	2,273	296	14	4	11	7	2,829	-	46	112	111	64	4,305	-	29	1	300	-	4,401	-	54	4	155	1
21	2,084	430	14	8	9	8	2,500	33	35	100	135	93	4,288	-	33	5	292	1	4,430	-	62	9	191	1
22	2,325	468	15	7	8	57	2,580	-	30	74	165	61	4,356	-	32	3	295	1	4,152	-	53	5	210	-
23	2,238	357	15	6	10	18	2,517	112	34	136	100	155	4,164	-	27	2	301	1	4,312	-	54	9	183	-
24	2,303	401	16	7	7	68	2,469	205	38	151	81	71	4,383	-	31	2	296	1	4,295	-	42	3	169	-
25	2,052	668	13	7	10	14	2,630	80	36	114	120	44	4,357	-	37	1	292	1	4,331	-	64	4	136	-
26	2,205	505	14	7	9	29	2,515	18	44	134	91	202	4,404	-	34	6	290	1	4,295	-	97	23	169	1
27	2,307	374	15	5	10	24	2,559	116	29	114	126	13	4,224	-	27	6	296	-	4,246	-	51	3	210	-
28	2,248	282	14	5	10	15	2,829	24	41	133	94	39	4,381	-	34	2	294	1	4,331	-	54	6	211	-
29	2,244	461	15	7	8	13	2,456	53	42	143	84	121	4,281	-	32	3	294	-	4,196	-	44	5	149	-
30	2,204	440	14	5	11	11	2,602	33	30	104	136	61	4,349	-	30	5	295	1	4,178	-	47	7	179	1
Average	2,265	445	15	7	9	27	2,561	98	36	119	114	74	4,314	-	31	3	295	1	4,330	-	55	7	175	1
Detour	104	100	1	2	1	22	105	80	5	22	24	41	97	-	3	2	4	-	87	-	11	4	22	-

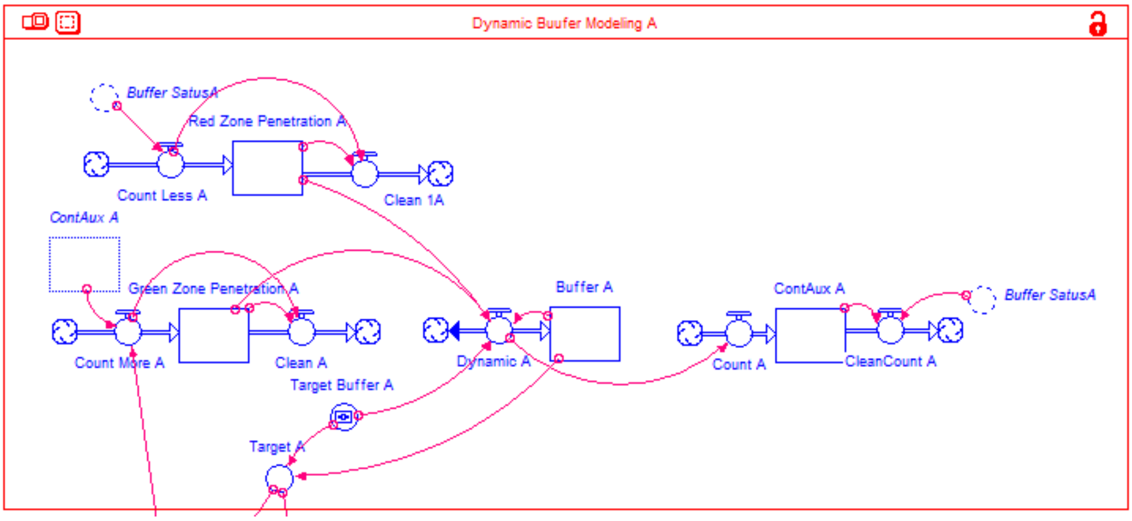
APPENDIX E - PRODUCTIVE FLOW MODULE



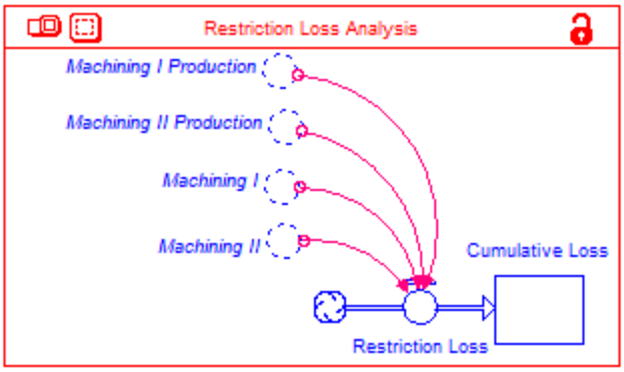
Material Release Module



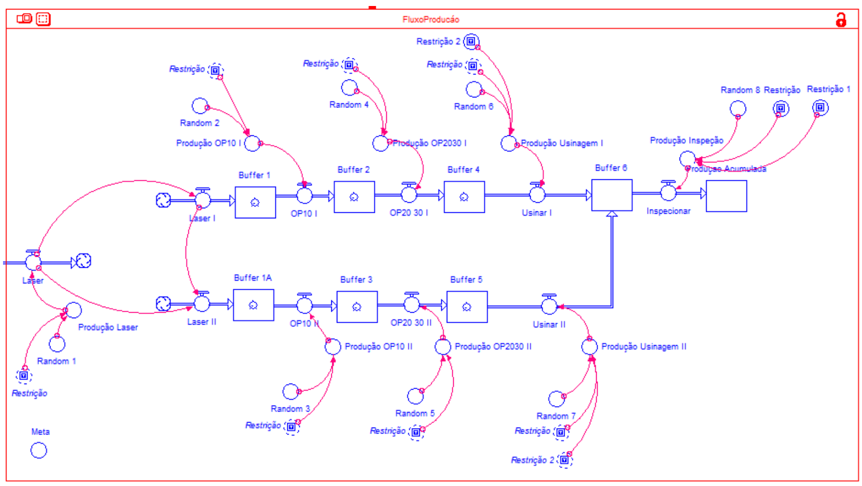
Dynamic Buffer Management Module



Constraint Losses Calculation Module



Productive Flow Module



APPENDIX F - MODEL EQUATIONS

Buffer_1(t) = Buffer_1(t - dt) + (Laser_I - OP10_I) * dt
INIT Buffer_1 = 0
INFLOWS:
Laser_I = INT(Laser/2)
OUTFLOWS:
OP10_I = OP10_I_Production
Buffer_1A(t) = Buffer_1A(t - dt) + (Laser_II - OP10_II) * dt
INIT Buffer_1A = 0
INFLOWS:
Laser_II = Laser-Laser_I
OUTFLOWS:
OP10_II = OP10_II_Production
Buffer_2(t) = Buffer_2(t - dt) + (OP10_I - OP20_30_I) * dt
INIT Buffer_2 = 0
INFLOWS:
OP10_I = OP10_I_Production
OUTFLOWS:
OP20_30_I = OP2030_I_Production
Buffer_3(t) = Buffer_3(t - dt) + (OP10_II - OP20_30_II) * dt
INIT Buffer_3 = 0
INFLOWS:
OP10_II = OP10_II_Production
OUTFLOWS:
OP20_30_II = OP2030_II_Production
Buffer_4(t) = Buffer_4(t - dt) + (OP20_30_I - Machining_I) * dt
INIT Buffer_4 = 0
INFLOWS:
OP20_30_I = OP2030_I_Production
OUTFLOWS:
Machining_I = Machining_I_Production
Buffer_5(t) = Buffer_5(t - dt) + (OP20_30_II - Machining_II) * dt
INIT Buffer_5 = 0
INFLOWS:
OP20_30_II = OP2030_II_Production
OUTFLOWS:
Machining_II = Machining_II_Production
Buffer_6(t) = Buffer_6(t - dt) + (Machining_I + Machining_II - Inspection) * dt
INIT Buffer_6 = 0
INFLOWS:
Machining_I = Machining_I_Production
Machining_II = Machining_II_Production
OUTFLOWS:
Inspection = Inspection_Production
Buffer_A(t) = Buffer_A(t - dt) + (Dynamic_A) * dt
INIT Buffer_A = 0
INFLOWS:
Dynamic_A = IF TIME=1 THEN Target_Buffer_A ELSE IF Red_Zone_Penetration_A>12 THEN (Buffer_A/3) ELSEIF Green_Zone_Penetration_A<12 THEN 0 ELSE (-Buffer_A/3)
Buffer_B(t) = Buffer_B(t - dt) + (Dynamic_B) * dt
INIT Buffer_B = 0
INFLOWS:
Dynamic_B = IF TIME=1 THEN Target_Buffer_B ELSE IF Red_Zone_Penetration_B>12 THEN (Buffer_B/3) ELSEIF Green_Penetration_B<12 THEN 0 ELSE (-Buffer_B/3)

Buffer_MP(t) = Buffer_MP(t - dt) + (RM_Release_A + RM_Release_B - Laser) * dt
INIT Buffer_MP = 60
INFLOWS:
RM_Release_A = IF BM=0 THEN Machining_I ELSEIF Buffer_SatusA>1 THEN 0 ELSEIF Buffer_SatusA<(2/3) THEN (Machining_I+ (Target_A-Buffer_4)) ELSE Machining_I
RM_Release_B = IF BM=0 THEN Machining_II ELSEIF Buffer_Satus_B>1 THEN 0 ELSEIF Buffer_Satus_B<(2/3) THEN (Machining_II+ (Target_B-Buffer_5)) ELSE Machining_II
OUTFLOWS:
Laser = Laser_Production
ContAux_A(t) = ContAux_A(t - dt) + (Count_A - CleanCount_A) * dt
INIT ContAux_A = 0
INFLOWS:
Count_A = IF TIME=1 THEN 0 ELSE IF Dynamic_A<0 THEN 1 ELSE 0
OUTFLOWS:
CleanCount_A = IF Buffer_SatusA<1 AND ContAux_A>0 THEN ContAux_A ELSE 0
CountAux_B(t) = CountAux_B(t - dt) + (Count_B - CleanCont_B) * dt
INIT CountAux_B = 0
INFLOWS:
Count_B = IF TIME=1 THEN 0 ELSE IF Dynamic_B<0 THEN 1 ELSE 0
OUTFLOWS:
CleanCont_B = IF Buffer_Satus_B<1 AND CountAux_B>0 THEN CountAux_B ELSE 0
Cumulative_Loss(t) = Cumulative_Loss(t - dt) + (Restriction_Loss) * dt
INIT Cumulative_Loss = 0
INFLOWS:
Restriction_Loss = (Machining_I_Production+Machining_II_Production)-(Machining_I+Machining_II)
Cumulative_Production(t) = Cumulative_Production(t - dt) + (Inspection) * dt
INIT Cumulative_Production = 0
INFLOWS:
Inspection = Inspection_Production
Green_Penetration_B(t) = Green_Penetration_B(t - dt) + (Count_More_B - Clean_B) * dt
INIT Green_Penetration_B = 0
INFLOWS:
Count_More_B = IF CountAux_B>0 AND Buffer_Satus_B>1 THEN 0 ELSEIF Buffer_Satus_B>(2/3) THEN 1 ELSE 0
OUTFLOWS:
Clean_B = IF Count_More_B=0 OR Green_Penetration_B=12 THEN Green_Penetration_B ELSE 0
Green_Zone_Penetration_A(t) = Green_Zone_Penetration_A(t - dt) + (Count_More_A - Clean_A) * dt
INIT Green_Zone_Penetration_A = 0
INFLOWS:
Count_More_A = IF ContAux_A>0 AND Buffer_SatusA>1 THEN 0 ELSEIF Buffer_SatusA>(2/3) THEN 1 ELSE 0
OUTFLOWS:
Clean_A = IF Count_More_A=0 OR Green_Zone_Penetration_A=12 THEN Green_Zone_Penetration_A ELSE 0
Red_Zone_Penetration_A(t) = Red_Zone_Penetration_A(t - dt) + (Count_Less_A - Clean_1A) * dt
INIT Red_Zone_Penetration_A = 0
INFLOWS:
Count_Less_A = IF Buffer_SatusA<(1/3) THEN 1 ELSE 0
OUTFLOWS:
Clean_1A = IF Count_Less_A=0 OR Red_Zone_Penetration_A=12 THEN Red_Zone_Penetration_A ELSE 0
Red_Zone_Penetration_B(t) = Red_Zone_Penetration_B(t - dt) + (Count_Less_B - Clean_B1) * dt
INIT Red_Zone_Penetration_B = 0
INFLOWS:
Count_Less_B = IF Buffer_Satus_B<(1/3) THEN 1 ELSE 0
OUTFLOWS:
Clean_B1 = IF Count_Less_B=0 OR Red_Zone_Penetration_B=12 THEN Red_Zone_Penetration_B ELSE 0

- BM = 0
- Buffer_SatusA = (Buffer_4)/Target_A
- Buffer_Satus_B = Buffer_5/Target_B
- Inspection_Production = IF Restriction1=1 THEN 60 ELSEIF Restriction=0 THEN(IF Random_8<0.03 THEN 8 ELSEIF Random_8<0.11 THEN 10 ELSEIF Random_8<0.20 THEN 14 ELSEIF Random_8<0.22 THEN 16 ELSEIF Random_8<0.26 THEN 20 ELSEIF Random_8<0.32 THEN 25 ELSEIF Random_8<0.41 THEN 28 ELSEIF Random_8<0.47 THEN 30 ELSEIF Random_8<0.49 THEN 32 ELSEIF Random_8<0.56 THEN 33 ELSEIF Random_8<0.61 THEN 38 ELSEIF Random_8<0.74 THEN 40 ELSEIF Random_8<0.76 THEN 42 ELSEIF Random_8<0.78 THEN 44 ELSEIF Random_8<0.84 THEN 48 ELSEIF Random_8<0.90 THEN 49 ELSE 54)ELSE (IF Random_8<0.04 THEN 23 ELSEIF Random_8<0.12 THEN 29 ELSEIF Random_8<0.16 THEN 30 ELSEIF Random_8<0.20 THEN 38 ELSEIF Random_8<0.28 THEN 40 ELSEIF Random_8<0.32 THEN 41 ELSEIF Random_8<0.44 THEN 50 ELSEIF Random_8<0.48 THEN 51 ELSEIF Random_8<0.52 THEN 53 ELSEIF Random_8<0.56 THEN 54 ELSE IF Random_8<0.60 THEN 55 ELSEIF Random_8<0.68 THEN 57 ELSEIF Random_8<0.72 THEN 59 ELSE 60)
- Laser_Production = IF Restriction=0 THEN (IF Random_1<0.14 THEN 38 ELSEIF Random_1<0.20 THEN 41 ELSEIF Random_1<0.22 THEN 42 ELSEIF Random_1<0.24 THEN 45 ELSEIF Random_1<0.25 THEN 48 ELSEIF Random_1<0.31 THEN 50 ELSEIF Random_1<0.34 THEN 52 ELSEIF Random_1<0.42 THEN 55 ELSEIF Random_1<0.48 THEN 58 ELSEIF Random_1<0.62 THEN 60 ELSEIF Random_1<0.81 THEN 62 ELSEIF Random_1<0.83 THEN 65 ELSEIF Random_1<0.92 THEN 70 ELSE 72)ELSE (IF Random_1<0.12 THEN 68 ELSEIF Random_1<0.16 THEN 69 ELSEIF Random_1<0.32 THEN 70 ELSE 72)
- Machining_II_Production = IF Restriction=0 AND Restriction_2=0 THEN (IF Random_7<0.1 THEN 4 ELSE IF Random_7<0.12 THEN 6 ELSEIF Random_7<0.18 THEN 9 ELSEIF Random_7<0.25 THEN 10 ELSEIF Random_7<0.30 THEN 11 ELSEIF Random_7<0.45 THEN 15 ELSEIF Random_7<0.47 THEN 16 ELSEIF Random_7<0.49 THEN 17 ELSEIF Random_7<0.55 THEN 18 ELSEIF Random_7<0.76 THEN 22 ELSEIF Random_7<0.78 THEN 23 ELSEIF Random_7<0.80 THEN 24 ELSEIF Random_7<0.90 THEN 25 ELSE 27)ELSE(IF Random_7<0.04 THEN 0 ELSEIF Random_7<0.08 THEN 15 ELSEIF Random_7<0.28 THEN 18 ELSEIF Random_7<0.48 THEN 24 ELSEIF Random_7<0.52 THEN 28 ELSEIF Random_7<0.76 THEN 30 ELSE 32)
- Machining_I_Production = IF Restriction=0 AND Restriction_2 = 0 THEN(IF Random_6<0.1 THEN 0 ELSE IF Random_6<0.13 THEN 4 ELSEIF Random_6<0.15 THEN 6 ELSEIF Random_6<0.26 THEN 9 ELSEIF Random_6<0.35 THEN 14 ELSEIF Random_6<0.43 THEN 15 ELSEIF Random_6<0.49 THEN 16 ELSEIF Random_6<0.55 THEN 17 ELSEIF Random_6<0.68 THEN 18 ELSEIF Random_6<0.75 THEN 20 ELSEIF Random_6<0.77 THEN 22 ELSEIF Random_6<0.81 THEN 23 ELSEIF Random_6<0.89 THEN 25 ELSEIF Random_6<0.90 THEN 26 ELSE 27)ELSE(IF Random_6<0.04 THEN 0 ELSEIF Random_6<0.08 THEN 13 ELSEIF Random_6<0.12 THEN 20 ELSEIF Random_6<0.20 THEN 24 ELSEIF Random_6<0.28 THEN 25 ELSEIF Random_6<0.48 THEN 28 ELSEIF Random_6<0.52 THEN 29 ELSEIF Random_6<0.84 THEN 30 ELSE 32)
- OP10_II_Production = IF Restriction=0 THEN (IF Random_3<0.14 THEN 11 ELSEIF Random_3<0.16 THEN 16 ELSEIF Random_3<0.24 THEN 17 ELSEIF Random_3<0.33 THEN 18 ELSEIF Random_3<0.35 THEN 19 ELSEIF Random_3<0.41 THEN 20 ELSEIF Random_3<0.47 THEN 21 ELSEIF Random_3<0.54 THEN 22 ELSEIF Random_3<0.65 THEN 23 ELSEIF Random_3<0.78 THEN 27 ELSEIF Random_3<0.98 THEN 28 ELSE 32)ELSE(IF Random_3<0.04 THEN 20 ELSEIF Random_3<0.8 THEN 26 ELSEIF Random_3<0.24 THEN 31 ELSEIF Random_3<0.32 THEN 32 ELSEIF Random_3<0.40 THEN 33 ELSEIF Random_3<0.44 THEN 35 ELSE 37)
- OP10_I_Production = IF Restriction=0 THEN (IF Random_2<0.05 THEN 13 ELSEIF Random_2<0.14 THEN 16 ELSEIF Random_2<0.25 THEN 17 ELSEIF Random_2<0.30 THEN 18 ELSEIF Random_2<0.32 THEN 20 ELSEIF Random_2<0.54 THEN 22 ELSEIF Random_2<0.64 THEN 24 ELSEIF Random_2<0.76 THEN 25 ELSEIF Random_2<0.82 THEN 26 ELSEIF Random_2<0.86 THEN 27 ELSEIF Random_2<0.89 THEN 28 ELSEIF Random_2<0.94 THEN 29 ELSE 32)ELSE(IF Random_2<0.04 THEN 23 ELSEIF Random_2<0.12 THEN 27 ELSEIF Random_2<0.20 THEN 29 ELSEIF Random_2<0.36 THEN 30 ELSEIF Random_2<0.44 THEN 31 ELSEIF Random_2<0.64 THEN 32 ELSEIF Random_2<0.72 THEN 33 ELSEIF Random_2<0.84 THEN 35 ELSE 37)
- OP2030_II_Production = IF Restriction=0 THEN(IF Random_5<0.2 THEN 0 ELSEIF Random_5<0.25 THEN 10 ELSEIF Random_5<0.35 THEN 14 ELSEIF Random_5<0.43 THEN 17 ELSEIF Random_5<0.54 THEN 19 ELSEIF Random_5<0.73 THEN 20 ELSEIF Random_5<0.80 THEN 21 ELSEIF Random_5<0.84 THEN 22 ELSEIF Random_5<0.88 THEN 23 ELSEIF Random_5<0.90 THEN 24 ELSE 26)ELSE(IF Random_5<0.04 THEN 0 ELSEIF Random_5<0.16 THEN 26 ELSEIF Random_5<0.20 THEN 27 ELSEIF Random_5<0.32 THEN 28 ELSEIF Random_5<0.44 THEN 30 ELSEIF Random_5<0.68 THEN 32 ELSEIF Random_5<0.72 THEN 35 ELSE 36)

- OP2030_I_Production = IF Restriction=0 THEN (IF Random_4<0.03 THEN 8 ELSEIF Random_4<0.08 THEN 10 ELSEIF Random_4<0.10 THEN 12 ELSEIF Random_4<0.19 THEN 13 ELSEIF Random_4<0.26 THEN 16 ELSEIF Random_4<0.28 THEN 17 ELSEIF Random_4<0.48 THEN 19 ELSEIF Random_4<0.68 THEN 20 ELSEIF Random_4<0.73 THEN 21 ELSEIF Random_4<0.75 THEN 23 ELSEIF Random_4<0.84 THEN 24 ELSEIF Random_4<0.85 THEN 25 ELSEIF Random_4<0.88 THEN 26 ELSEIF Random_4<0.90 THEN 27 ELSE 28)ELSE(IF Random_4<0.04 THEN 14 ELSEIF Random_4<0.08 THEN 22 ELSEIF Random_4<0.24 THEN 30 ELSEIF Random_4<0.56 THEN 32 ELSEIF Random_4<0.60 THEN 33 ELSEIF Random_4<0.84 THEN 34 ELSE 36)
- Random_1 = RANDOM(0,100)/100
- Random_2 = RANDOM(0,100)/100
- Random_3 = RANDOM(0,100)/100
- Random_4 = RANDOM(0,100)/100
- Random_5 = RANDOM(0,100)/100
- Random_6 = RANDOM(0,100)/100
- Random_7 = RANDOM(0,100)/100
- Random_8 = RANDOM(0,100)/100
- Restriction = 0
- Restriction1 = 0
- Restriction_2 = 0
- Target = 60
- Target_A = IF TIME=1 THEN Target_Buffer_A ELSE Buffer_A
- Target_B = IF TIME=1 THEN Target_Buffer_B ELSE Buffer_B
- Target_Buffer_A = 100
- Target_Buffer_B = 100

APPENDIX G - HOURLY OUTPUT DATA

Hours	Lean	Real Data	TOC with dynamic buffer	Real Data Week 1	Real Data Week 2	Real Data Week 3	Real Data Week 4	Real Data Week 5	Real Data Week 6	Real Data Week 7	Real Data Week 8	Real Data Week 9	Real Data Week 10
1	-	26	60	48	52	60	54	53	46	45	60	53	57
2	21	27	56	55	50	56	53	54	58	51	56	45	30
3	10	11	55	53	48	54	52	53	49	50	56	54	40
4	10	2	60	54	47	45	55	52	48	10	60	56	50
5	48	21	60	50	50	55	56	55	50	20	60	57	50
6	54	35	48	58	56	54	50	56	49	30	57	30	56
7	33	17	56	47	50	50	56	50	56	40	54	40	50
8	33	23	49	47	56	60	50	56	56	50	60	50	56
9	38	-	52	49	55	44	47	50	60	60	56	60	55
10	35	25	49	44	52	42	48	47	54	56	56	56	52
11	25	13	54	56	53	48	50	48	57	56	60	56	53
12	33	28	52	45	54	60	52	50	49	60	50	60	54
13	30	33	60	51	45	60	60	51	43	54	40	54	45
14	40	32	60	58	49	43	56	52	60	57	30	57	49
15	33	31	60	49	52	49	54	54	60	60	20	60	52
16	38	38	59	48	59	57	45	60	48	54	10	54	59
17	14	41	50	50	50	54	55	57	42	52	50	52	50

Hours	Lean	Real Data	TOC with dynamic buffer	Real Data Week 1	Real Data Week 2	Real Data Week 3	Real Data Week 4	Real Data Week 5	Real Data Week 6	Real Data Week 7	Real Data Week 8	Real Data Week 9	Real Data Week 10
18	48	34	53	49	53	60	54	54	44	51	51	51	53
19	25	15	48	54	48	56	50	60	60	50	52	50	48
20	14	-	43	52	47	56	60	56	50	48	54	48	47
21	16	39	52	53	50	49	44	56	54	47	60	47	50
22	8	25	54	60	56	50	42	60	55	50	52	50	56
23	44	26	45	50	50	48	48	50	45	56	54	56	50
24	48	26	60	55	56	49	60	40	54	50	60	50	56
25	18	-	54	60	55	58	60	30	56	56	57	56	47
26	10	28	25	47	53	46	43	20	54	55	54	55	50
27	14	33	48	46	56	10	49	10	50	52	60	52	56
28	14	32	53	45	51	56	57	50	60	53	56	53	50
29	14	31	56	50	42	44	54	51	44	54	56	54	56
30	14	38	54	56	51	50	60	52	54	53	60	53	55
31	40	28	58	55	53	51	56	54	50	45	50	45	52
32	54	29	58	52	52	52	56	60	60	54	49	54	53
33	8	28	60	53	54	54	49	57	44	56	52	56	54
34	48	25	50	54	55	60	50	54	54	54	54	54	53
35	33	23	58	45	38	57	48	60	57	50	60	50	45
36	40	24	45	49	48	54	49	56	60	60	57	60	54
37	30	27	58	52	54	60	58	56	60	44	54	44	56
38	10	28	42	51	50	56	46	60	56	54	60	53	54

Hours	Lean	Real Data	TOC with dynamic buffer	Real Data Week 1	Real Data Week 2	Real Data Week 3	Real Data Week 4	Real Data Week 5	Real Data Week 6	Real Data Week 7	Real Data Week 8	Real Data Week 9	Real Data Week 10
39	38	29	43	47	60	56	45	50	56	50	56	45	50
40	14	-	60	46	44	60	56	49	60	60	56	54	60
41	49	33	55	53	42	50	44	52	54	44	60	56	42
42	33	32	38	49	45	49	50	54	57	54	60	54	45
43	14	-	48	51	45	45	51	60	60	57	57	57	45
44	20	25	54	53	49	45	52	57	54	60	54	60	49
45	14	26	50	54	50	42	54	54	52	60	44	60	50
46	49	26	60	48	60	44	60	60	49	56	60	56	60
47	33	45	48	47	56	60	57	56	50	56	50	56	47
48	16	28	42	52	56	50	54	56	60	60	54	60	50
49	32	33	60	50	60	54	60	60	56	54	44	54	56
50	25	32	60	51	54	12	56	60	56	57	60	57	50
51	49	31	50	48	57	38	56	57	60	60	50	60	56
52	40	25	54	49	60	55	60	54	54	54	54	54	55
53	25	26	55	50	54	54	50	44	57	52	56	52	52
54	48	-	45	54	52	52	49	60	60	49	54	49	53
55	25	24	54	52	51	53	45	50	54	50	45	50	54
56	14	29	56	48	50	51	45	54	52	60	53	60	53
57	20	23	60	42	44	42	42	44	51	56	54	56	45
58	48	33	45	53	56	51	44	60	50	56	53	56	54
59	30	33	24	50	45	56	60	50	10	60	52	60	56

Hours	Lean	Real Data	TOC with dynamic buffer	Real Data Week 1	Real Data Week 2	Real Data Week 3	Real Data Week 4	Real Data Week 5	Real Data Week 6	Real Data Week 7	Real Data Week 8	Real Data Week 9	Real Data Week 10
60	49	32	46	45	46	53	50	54	20	54	55	54	54
61	40	32	32	53	58	55	54	56	30	57	56	57	50
62	54	25	43	56	49	56	48	54	40	60	50	60	60
63	33	26	45	51	48	50	12	45	50	54	56	54	48
64	20	25	45	42	50	56	55	10	60	52	50	52	50
65	21	25	49	51	49	50	54	54	56	60	47	60	49
66	23	28	50	53	56	47	52	50	56	54	48	54	56
67	14	33	60	52	56	52	53	60	60	52	50	52	20
68	41	32	56	54	60	53	51	44	54	51	51	51	30
69	27	31	56	49	54	50	15	42	57	50	52	50	40
70	15	38	60	53	57	59	51	48	30	10	54	10	50
71	40	28	54	51	49	52	56	60	54	20	35	20	60
72	30	29	57	54	43	49	53	60	52	30	57	30	56
73	26	22	49	55	60	45	55	43	51	40	54	40	56
74	28	32	43	48	60	54	56	49	50	50	60	50	60
75	25	-	60	54	48	53	50	57	48	60	56	60	48
76	10	25	60	46	42	52	56	54	47	56	56	56	42
77	33	26	60	57	44	55	50	60	50	56	60	56	44
78	14	23	50	48	60	56	47	56	56	60	40	60	60
79	33	28	60	50	50	50	48	56	50	54	40	54	50
80	28	21	60	49	54	56	53	49	56	57	30	57	54

Hours	Lean	Real Data	TOC with dynamic buffer	Real Data Week 1	Real Data Week 2	Real Data Week 3	Real Data Week 4	Real Data Week 5	Real Data Week 6	Real Data Week 7	Real Data Week 8	Real Data Week 9	Real Data Week 10
81	20	32	53	60	55	50	50	50	55	60	57	10	55
82	38	30	54	54	45	47	59	48	52	54	54	20	45
83	20	-	58	52	54	48	52	49	53	52	60	30	54
84	40	28	55	51	56	50	49	58	54	51	56	40	56
85	35	29	52	50	60	52	45	46	53	50	56	50	60

APPENDIX H - ANOVA LEAN SCENARIO TEST

ANOVA: single actor

SUMMARY

Group	*Count*	*Total*	*Mean*	*Variance*
Scenario: *Lean*	85	2,438	28.68235	178.3384
Real Data	85	2,155	25.35294	105.5406

ANOVA

Source of variation	*SQ*	*gl*	*MQ*	*F*	*p-value*	*F critical*
Between groups	471.1118	1	471.1118	3.319103	0.070258	3.897407
Within groups	23845.84	168	141.9395			
Total	24316.95	169				

APPENDIX I - ANOVA DBR TEST SCENARIO WITH DYNAMIC BUFFER

SUMMARY

Group	*Count*	*Total*	*Mean*	*Variance*
Column 1	85	4,442	52.25882353	57.17030812
Column 2	85	4,335	51	14.92857143

ANOVA

Source of variation	*SQ*	*gl*	*MQ*	*F*	*p-value*	*F critical*
Between groups	67.34705882	1	67.34705882	1.868186004	0.173509269	3.897407169
Within groups	6056.305882	168	36.04943978			
Total	6123.652941	169				

5 DRUM-BUFFER-ROPE IMPACTS ON ECONOMIC EFFICIENCY?

Authors: Lúcio C. Noal [a*], Daniel P. Lacerda [a], Fabio S. Piran [a], Ana S. Camanho[b]

[a] *Programa de Pós-Graduação em Engenharia de Produção e Sistemas, Unsinos, Brasil*
[b] *Faculdade de Engenharia, Universidade do Porto, Portugal*
[*] *Corresponding author (lucionoal@gmail.com)*

Abstract: Improving productivity and efficiency is a constant challenge for industrial organizations. Applying the Theory of Constraints (TOC) and Drum-Buffer-Rope (DBR) are considered alternatives to increase the efficiency of production systems. However, only some studies empirically evaluate the effects of DBR, in general, and on economic efficiency in specific. This study analyzes the effects of DBR on the economic efficiency of a company's production process in the automotive segment. The effects were evaluated longitudinally through a case study using Data Envelopment Analysis (DEA) and T test. The results showed that the implementation of DBR provided a 66.90% increase in economic efficiency. From a theoretical point of view, DBR/TOC has been associated with effectiveness (on-time service) and increment in volume. However, the research supports the hypothesis that DBR improves economic efficiency, an aspect neglected by the literature. From a practical point of view, the study shows DBR as a form of management capable of meeting performance objectives and providing information so that these can guide continuous process improvement.

Keywords: Theory of Constraints (TOC); Data Envelopment Analysis (DEA); Drum-Buffer-Rope (DBR); Economic Efficiency.

5.1 INTRODUCTION

The automotive industry is relevant to economies worldwide. In Brazil, estimates indicate that this sector represents 3% of the Gross Domestic Product (GDP), generating over 125 thousand jobs and a turnover of US$ 28 billion annually (Anfavea, 2021).

In 2021, Brazil's automotive industry manufactured 2.13 million vehicles, with 1.86 million intended for the domestic market and 273 thousand units designated for export (Anfavea, 2021). Passenger cars represent 68.5% of total production, followed by light commercial vehicles, trucks, and buses, representing 24,7%, 6,5% and 0,2% of production respectively (Anfavea, 2021).

The Brazilian automotive manufacturing park has 64 units, where hundreds of different models and configurations of products offered to the market are produced (Globo, 2020). Facing this offer, the competition in the Brazilian context is fierce compared to other countries (Piran et al., 2016). In this competitive landscape, for instance, the case of the automobile manufacturer Ford, which faced the decision to cease its manufacturing operations in Brazil due to the challenges of sustaining competitiveness (BBC, 2021). Improving operational performance and efficiency to ensure profitability rates are increasingly necessary (Marfatia et al., 2020). Two challenges have been identified in the global automotive industry. The first challenge involves fluctuations in product mix and production volume, while the second centers around a company's capability to swiftly respond to market demands and deliver products on schedule (Qamar et al., 2020; Sohrmann et al., 2021).

In the manufacturing context, variability acts as a barrier to production and is among the factors leading to reduced efficiency (Kim; Gershwin, 2006; Wallace J. Hopp, 2011). Elevated levels of work-in-process (WIP) and extended cycle times are a few of the consequences of variability on the efficiency of production systems (S. Wu; Wee, 2009). Moreover, the alignment of equipment, operators, inventory, and other production resources is occasionally inconsistent, leading to disruptions in the workflow and, as a result, diminishing productivity (Stratton; Warburton, 2003). The synchronization in manufacturing systems related to Lean Just-in-Time means supplying the right components for the subsequent production steps at the right time (Abreu-Ledón et al., 2018). In this context, synchronization serves as the foundation for enhancing the logistics performance of manufacturing systems, regarded as a pivotal factor for achieving competitiveness (Chankov; Hütt; Bendul, 2018).

However, there are barriers to obtaining the benefits of synchronization. The obstacles can center around the challenges associated with change management, organizational aspects including leadership, culture, finances, resources, as well as issues related to organizational systems like forecasting, infrastructure facilities, logistics, and support, in addition to technological limitations (Jadhav; Mantha; Rane, 2014b; Lim; Sabil; Othman, 2022). Furthermore, it can focus on lower demand volume and customer orders with expressive variability (Eswaramoorthi et al., 2011), resource shortages, limited top management engagement, and resistance from the workforce, among other influences (Gupta; Modgil; Gunasekaran, 2020; Lim; Sabil; Othman, 2022). In addition to the pursuit of variability reduction, alternative approaches to management and synchronization can be contemplated as a means to enhance the efficiency and effectiveness of production systems, ultimately yielding economic benefits.

The Theory of Constraints (TOC) is a management philosophy that can provide benefits in managing, synchronizing, and mitigating variability. TOC postulates that there are better ways to achieve results than increasing the utilization of all resources and reducing production costs (Pachecoa, 2014; Ikeziri et al., 2018). TOC points out that increasing production efficiency makes sense primarily in constrained resources since local improvements in unconstrained resources would not generate increased earnings because they do not increase sales or customer deliveries (Cox III; Schleier Jr, 2013b). In addition, such local improvements may increase in-process inventory build-up, impact lead times, and not stimulate production to perform better overall.

Drum-Buffer-Rope (DBR) represents the TOC method for achieving synchronization in manufacturing. In DBR, inventory levels are determined by the capacity of the bottleneck operation and are implemented to safeguard the production system from various sources of variability (Kim; Cox; Mabin, 2010). Constrained capacity management using DBR has empirical evidence of increased productivity, on-time delivery, and economic results (Bai et al., 2018b; Cortabarria; Martinez; Mendoza, 2016b; Telles et al., 2020). Nonetheless, research on the effects of DBR/TOC on technical efficiency is limited, and there is a complete absence of studies on its impact on economic efficiency (Telles et al., 2020).

It is imperative to consider economic efficiency alongside technical efficiency evaluations in the context of Data Envelopment Analysis (DEA) applications (Liu et al., 2018; Portela; Thanassoulis, 2014). The predominance of studies that contemplate technical efficiency can be explained by the difficulty of collective price data, which is a requirement for the estimation of economic efficiency (Camanho et al., 2023). Obtaining reliable price data is a complex process, due to inflationary forces and internal or external factors affective prices differently among the DMU's participating in the benchmarking exercise (Camanho; Dyson, 2005; Hatami-Marbini; Arabmaldar, 2021). Nonetheless, technical efficiency analysis can offer only a restricted view of performance. Companies might hesitate to alter inputs unless it translates into tangible monetary benefits (Aparicio; Ortiz; Pastor, 2017), bearing is to enhance their economic outcomes (Kim; Cox; Mabin, 2010). In addition, access to cost and price data can be a significant barrier.

The insights derived from a technical efficiency analysis can be constrained in organizational context. For instance, companies might resist altering input and output quantities if it doesn't result in financial benefits (Aparicio; Ortiz; Pastor, 2017; Camanho et al., 2023; Piran et al., 2021), given that the primary objective of businesses is to enhance their economic performance (Kim; Cox; Mabin, 2010; Machado et al., 2023). Furthermore, managers tend to prioritize information that incorporates economic factors into the decision-making process, as enhancing technical efficiency does not always guarantee an enhancement in economic efficiency (Piran et al., 2021).

Studies have been conducted on the implementation of the TOC in several organizations (Wahlers; Cox, 1994; Balderstone, 2003; H. H. Wu; Liu, 2008; Gonzalez-R et al., 2010; Mabin; Telleset al., 2020). Regarding Drum-Buffer-Rope (TOC/DBR) and its implications for technical efficiency, it's worth noting that there are limited studies that specifically address its application within the Engineering-to-Order (ETO) context (Telles et al., 2020). Hence, there exists an unexplored gap in the application of TOC/DBR within a Make-to-Stock (MTS) environment concerning economic efficiency. Economic efficiency assumes significance since the allocation and composition of resources can have a substantial influence on the financial performance and contribute to improved outcomes for the organization.

In light of this, the aim of this article is to assess the impacts resulting from the implementation of DBR/TOC on the economic efficiency of a company's production process within the automotive sector These effects were scrutinized in a metal-mechanical industry specializing in the manufacturing of parts and assemblies for automotive automobile, highway, agriculture, and construction machinery assemblers. The assessment was carried out via a longitudinal case study employing DEA models for economic evaluation and T test.

The primary findings indicate that the implementation of DBR enhanced the utilization of productive resources, leading to an augmentation in economic efficiency, and consequently, improved economic outcomes. Subsequently, these identified potential enhancements in the model were empirically put into practice and observed over time. The outcomes of the implementation demonstrate a substantial enhancement in productivity, efficiency, and cost-effectiveness, aligning with the model’s projections.

Hence, the principal contribution of this article lies in elucidating the consequences of implementing DBR/TOC within an automotive production line on the system's economic efficiency. Theoretical advancements are evident in the utilization of DEA to facilitate a comparative assessment between the production line's current state and its state post-DBR implementation within the economic context. Additionally, another contribution pertains to the assessment of whether the variabilities within the production system permit the implementation of a continuous flow process without the need for buffering between operations. The research finding affirm, in the context of economic efficiency, that eliminating all variability within the system is not cost-effective and adopting the DBR/TOC approach proves to be a superior strategy (Taylor III, 2000). In terms of managerial insights, this study facilitates and understanding of whether the production synchronization approach leads to improved outcomes.

This paper is structured as follows: in the next section, the theoretical aspects relevant to the study are presented; in section 3, the methodological procedures are presented; in section 4, the results are described; in section 5, the discussions about the result are described, and in section 6 the final considerations are presented.

5.2 THEORETICAL FRAMEWORK

5.2.1 Theory of Constraints and Drum-Buffer-Rope Approach

TOC proposes a set of rules that aim to manage the organization entirely. These rules control production based on constrained capacity resources and enable strategy development. Its central premise is that every system has a constraint that limits performance. This constraint is the basis for managing and improving system performance (Goldratt; Cox, 2005). In according with Goldratt and Cox (2005), a constraint, often refered to as a bottleneck, denotes any element within a system that hinders the system from attaining a higher level of performance relative to its primary objective or goal. The objective of for-profit organizations is to generate profit both in the present and in the foreseeable (Gupta et al., 2010).

The TOC decision-making process consists of five steps (Gupta et al., 2010) which are: (i) identify system restrictions: this step addresses the need to identify possible restrictions that prevent the company from reaching the goal; (ii) explore system restrictions: explore, as best as possible, the previously identified restriction. At this point, more significant investments should not be sought in order to eliminate this restriction; (iii) subordinate all restrictions: the activities of the entire system should be subordinated to the restriction found in the first step; (iv) raise the system's restrictions: at this stage, it is necessary to concentrate efforts to increase the restriction's capacity to generate output; (v) if, in the previous steps, a restriction is eliminated, it is necessary to restart the process by identifying which resource is, at this point, restricting the system (Kendall, 2013).

To manage production in a manufacturing environment, TOC proposes the Drum-Buffer-Rope (DBR) (Goldratt; Cox, 2005). DBR starts its logic by identifying the most limiting component within the system, referred to as the constraint (or bottleneck), and then works on reducing the factors causing variations that lead to delay in the material flow throughout the system (Goldratt, 1988a).

This resource constitutes the drum, i.e., it is responsible for setting the pace of production and all other subordinate operations/processes. The drum is the resource to be scheduled, allowing a realistic date to be proposed to the customer (Chakravorty; Atwater, 2005). The notion of constraint is ascribed to the factor that restricts the performance of the drum (Cox et al., 2012b). The buffer represents inventory protection, quantified either in time or the volume of parts released in advance to reach the bottleneck, thereby safeguarding against issues arising from preceding processes (Lizarralde; Apaolaza; Mediavilla, 2019b). Table 9 describes the buffer types explored in the DBR approach.

Table 9 - Buffer Types

Buffer Types	Descriptions
Time Buffer	Also known as the "protection buffer", it is a time delay intentionally added to compensate for variations and uncertainties in the processing time of operations along the critical path. It is placed before the constraint (the system bottleneck) to ensure that there is enough time for activities to complete and to avoid interrupting the production flow.
Stock Buffer	It is an intentionally maintained inventory before the system constraint to ensure a constant supply of materials for the constrained operation. The stock buffer is used to protect against fluctuations in the availability of raw materials or components, allowing the constraint to operate continuously without interruptions.
Buffer of Variation	Also known as "synchronization buffer," it is used to manage the variations and uncertainties that occur throughout the production process. The buffer of variation is placed before the constraint to handle variations in the processing time of non-critical activities, ensuring that the production flow is not interrupted and delays do not propagate to the constraint.

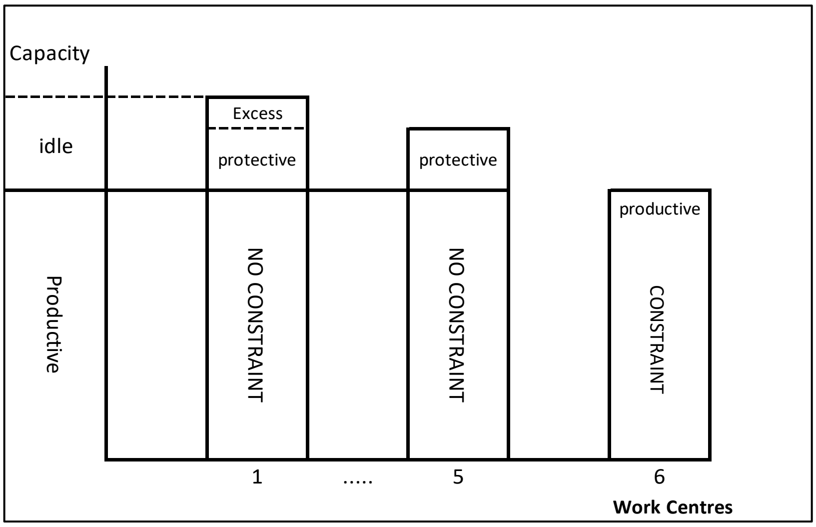
Source: Adapted from Cox, J.F. III and Schleier, J.G. (2013).

Stocks are only allowed in strategic locations relative to restrictive resources (Telles et al., 2020). The sizing and control of buffers must be adaptable to account for statistical fluctuations than can influence both the productivity of the constraint and the generation of gains within the production system. These gains are derived from net sales revenue minus the fully variable cost (Piran et al., 2021).

The rope serves as the communication mechanism that initiates the material's release, directing it to the subsequent step in alignment with the cadence set by the constraint (Cox III; Schleier Jr, 2010). The chord length encompasses the time necessary to hold the buffer plus the processing time from the initiation of the process to the arrival at the buffer (Telles et al., 2020).

Generally, non-restrictive resources are not scheduled because each operation is governed by buffer consumption (Goldratt; Cox, 2005). The primary function of buffers is to ensure that once parts have completed processing at the constraint, they are swiftly moved forward (Goldratt; Fox, 1986). The variability of the non-restrictive resources has the potential to disrupt the supply to the constraint. To address this scenario, two procedures are outlined, as illustrated Figure 17. The first uses the capacity margin on the unconstrained resources (protection capacity), and the second uses the WIP inventory in front of the constraint (protection inventory) (Kim; Cox; Mabin, 2010).

Figure 17 - Productive capacities and idleness



Source: Kim, Cox and Mabin (2010).

The productive capacity is the maximum of a resource's production capacities. Idle capacity is defined as the available capacity required to support the constraint. The idle capacity comprises two elements: i) protective capacity; ii) excess capacity (Kim; Cox; Mabin, 2010). Blackstone and Cox (2002) defined protective capacity as required at non-restrictive workstations to restore WIP to the previous and subsequent location of the restrictive workstation to support full utilization. Caridi et al. (2006) defined that protective capacity plays a relevant role in determining productivity. Atwater and Chakravorty (2002) showed that protective capacity at the second most used station can improve system performance. Lawrence and Buss (1994) reported that higher levels of protective capacity reduce drum oscillation.

However, it is difficult to determine the correct protection capability. The protection inventory has similar implications and definitions regarding the capability (Blackstone; Cox, 2002). The protective inventory is delineated as the quantity of inventory necessary concerning the protective capacity within the system to attain a specific throughput rate at the constraint. However, as Blackstone and Cox (2002) state in their conclusions, there is no mathematical approach to defining protection inventory and capacity.

5.2.2 Effects provided by the use of DBR

By implementing DBR, companies can reduce manufacturing lead time, improve operational performance, decrease inventories, increase production capacity, and increase revenue (Yenradee, 1994). The literature suggests that DBR outperforms other production planning and control tools in scenario instability of machines, people, and processes (Steele et al., 2005; Watson; Patti, 2008; Betterton; Cox, 2009; Millstein; Martinich, 2014). Constraint protection allows the flow of material not to be stopped immediately and the system to have time to return to the normal situation.

In this same context, other authors (Golmohammadi, 2015; Millstein; Martinich, 2014; Watson; Patti, 2008) observed positive effects on throughput in manufacturing environments that used DBR compared to CONWIP, Kanban, and MRP. The WIP reduction effect is observed in research (Darlington et al., 2015; Steele et al., 2005).

Regarding lead time reduction, work-in-process, and inventory indicators, the literature provides evidence of enhancements and favorable outcomes in the works of (Aldás et al., 2018b; Darlingtonet al., 2015; Orue et al., 2021b). Furthermore, the literature shows that using DBR can help improve the technical efficiency of the companies that implement it (Bai et al., 2018b; Cortabarria; Martinez; Mendoza, 2016b; Telles et al., 2020). The reduction in backorder rates and the augmentation of output stream have also been reported as advantages in other studies (Buestán Benavides; Van Landeghem, 2015; Chakravorty; Hales, 2016; Guan et al., 2007; Thürer; Stevenson, 2018b; Woo; Park; Fujimura, 2009). Table 10 provides a summary of studies concerning the described topics and their corresponding findings.

Table 10 - Overview of DBR implementation work

Author and Year	Title	Objective	Results
Telles et al. (2020)	Drum-Buffer-Rope in an engineering-to-order productive system: a case study in a Brazilian aerospace company	Evaluate the implementation of DBR in an ETO productive system, critically analyzing the necessary adaptations for its use.	Comparing the DBR theoretical proposals and Simplified Drum-Buffer-Rope (S-DBR) methods.
Stefano et al. (2021)	The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting	Research proposes the Theory of Constraints (TOC) throughput accounting (TA) as an alternative managerial control mechanism in an international transfer pricing scenario.	Improving transfer pricing efficiency
Orue et al. (2021)	The (sic) Theory of Constraints Case Study in the Make-to-Order Environment	Case study analyzes MTO to identify the factors that influence the execution of the third stage of TOC.	Increase service level 20%, lead time reduction 10%, inventory reduction 20%.
Thürer et al. (2020)	Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation	Comparative analysis between Kanban, MRP, DBR and DDMRP within a simulation scenario for performance evaluation of each methodology.	Better performance in the use of Kanban and DDMRP when compared to MRP
Puche et al. (2019)	The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective	Comparative study between Kanban and DBR in four production scenarios. Proposed method for using each methodology.	8.47% profit increase
Lizarralde et al. (2019)	Enfoque estratégico para la identificación de cuellos de botella en entornos de fabricación contra pedido y plantas tipo V: estudio de caso de DBR.	Presentation of a systematic process for implementing the first two steps of TOC in a production system.	21% improved service level, 35% lead time reduction, 30% inventory reduction
Prasetyaningsih et al. (2019)	Bottleneck Reduction on The Shoes Production Line using the Theory of Constraints Approach	The main objective of this research is the implementation of the Theory of Constraints concepts to reduce the	14% reduction in overtime

Author and Year	Title	Objective	Results
		imbalance problem at bottleneck workstations.	
Bai et al. (2018)	An OEE Improvement Method Based on TOC	Interlinking the OEE analysis method with TOC/DBR in order to increase productivity of equipment and processes.	Increased OEE ++
Thürer and Stevenson (2018a)	Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation	Research on the impact of bottleneck change on management decisions.	Change of bottleneck and DBR, reduction of backlog
Thürer and Stevenson (2018b)	On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism	Research into the potential of using different combinations of rules for sequencing to improve DBR performance.	Backlog reduction
Aldás et al. (2018)	Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry	Comparative study between production control methodologies, Kanban, Conwip and DBR on operational mechanisms.	78.9% WIP reduction
Satya S. Chakravorty and Hales (2016)	Improving labor relations performance using a Simplified Drum-Buffer-Rope (S-DBR) technique	Describe the implementation of DBR in service operations.	37.5% lead time reduction. Number of service complaints fell by 22%
Cortabarria et al. (2016)	Diseño, implementación y análisis de una metodología para aplicar TOC a empresas metalmecánicas con restricciones físicas internas – caso de aplicación: Colombia	To apply the TOC / DBR methodology, highlighting the bottlenecks in one of the processes of a metal-mechanic industry with internal constraints.	Throughput increase, lead time reduction, 12% efficiency increase
Darlington et al. (2015)	Design and implementation of a Drum-Buffer-Rope pull-system	Implementation of DBR in a panel plant, with shared resources for the automotive industry.	Lead time reduction 56%
Hilmola and Gupta (2015)	Throughput accounting and performance of a manufacturing	Proposal of a system dynamic (SD) based on a simulation model to investigate the product mix problem.	Inconclusive - "Future research should be directed toward developing an enabling hybrid expert

Author and Year	Title	Objective	Results
	company under stochastic demand and scrap rates		simulation system underlying constraint theory."
Buestán Benavides and Van Landeghem (2015)	Implementation of S-DBR in four manufacturing SMEs: a research case study	To explore the practical issues related to the implementation of the DBR in four small to medium-sized companies in Ecuador.	24% Throughput gain, 70% service level improvement
Woo, Park and Fujimura (2009)	Real-time buffer management method for DBR scheduling	Proposition of a real-time buffer management method aligned with DBR and TOC methodology.	Stock reduction +, delivery delay reduction ++
Ye and Han (2008)	Determination of buffer sizes for drum–buffer–rope (DBR)-controlled production systems	Description of an analytical approach based on reliability analysis to determine the size of the constraint buffers and the assembly buffer in a DBR controlled system.	Buffer Size Analysis
Guan et al. (2007)	TOC/DBR-based production planning and control in a manufacturing system with multiple system bottlenecks	Proposition of a TOC/DBR-based method for planning and controlling production when multiple bottlenecks exist.	Reducing delivery delay +

Source: Prepared by the author.

It can be seen that the analyses performed in each of the papers are limited to a few specific variables, indicating that these studies need to take a holistic approach and consider all inputs and outputs simultaneously (as DEA allows). Furthermore, the results presented assume that improvements in technical indicators will result in economic improvements, yet previous research has yet to evaluate this assumption. However, the literature suggests that implementing LBR provides economic benefits to the companies that use it and improves in the efficiency of the productive system (Telles et al., 2020). Thus, some hypotheses can be deduced from the research on DBR implementation. Therefore, the following hypotheses are tested:

H0: There is no relationship between the implementation of DBR and the effects on the economic efficiency of the production process.

H1: There is a relationship between the implementation of DBR and the effects on the economic efficiency of the production process.

Therefore, these hypotheses will direct this investigation to evaluate whether DBR improves economic efficiency in an automotive production line.

5.3 METHODOLOGICAL PROCEDURES

To conduct the work, a longitudinal case study was conducted, which is suitable for single or embedded cases and can increase the internal validity of the results. Case studies are appropriate for providing detailed knowledge of the process (Barratt; Choi; Li, 2011). In this regard, the study was conducted by (i) case study definition, (ii) DEA model design, (iii) data collection, (iv) data analysis, and (v) discussion and conclusions. This set of steps was adopted and supported in the works of (Piran et al., 2021; Telles et al., 2020).

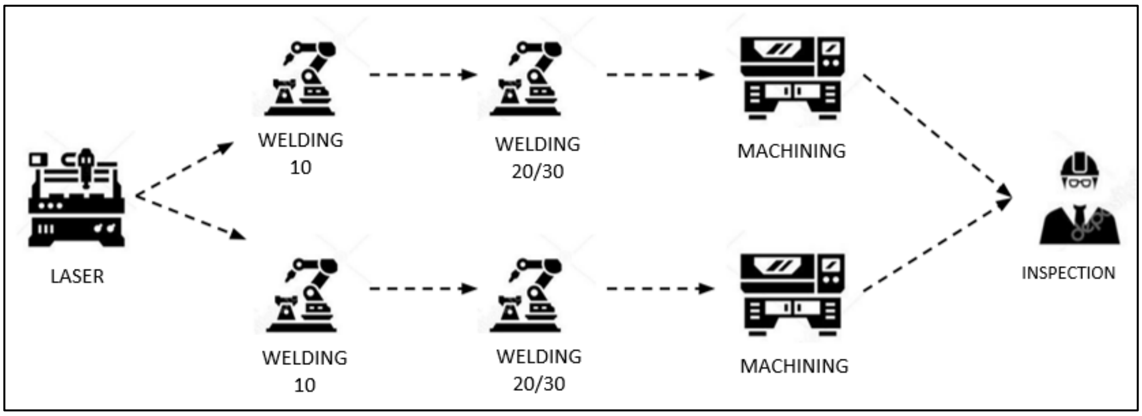
5.3.1 Definition of the case

The study is developed in a Brazilian company that operates in the automotive segment and has expanded its manufacturing park over the past five years (2017-2022). As a result, the company sought to increase the productivity and efficiency of its processes, initially implementing Lean concepts and, recently, the DBR/TOC. Thus, the company presents adequate conditions for the research development, which aims to capture in detail the effects of DBR/TOC in the production process.

In 2019, the company started the development of its primary product in the automotive segment, representing a turnover of R$ 12.5 million per year. As a result, the processes maintain a balance of capacity and time between operations without the need for intermediate stocks, with the aim of maintaining flow and eliminating inventory losses. With the start of production on this line, the performance and compliance with the results planned during development were not observed. The production volume was lower than demand, generating side effects in terms of cost and unplanned general manufacturing expenses.

The manufacturing process is composed of five operations, being these: (i) Laser cutting; (ii) Welding OP.10; (iii) Welding OP.20/30; (iv) Machining; (v) Inspection. Operations ii, iii, and iv are performed on two lines with identical equipment, resources, and specifications. Figure 18 illustrates the flow of the production line under study.

Figure 18 - Operations and production process



Source: Prepared by the author.

Operation 10 (Op 10) is performed on two identical pieces of equipment working in parallel. It is considered that the cycle time in this equipment is equal. The volume of parts produced (reported in Table 11) corresponds to the production of each piece of equipment separately. The same occurs for operations 20/30 (Op20/30) and Machining. The initial output capacity of this flow is 879 pieces in 17h.

Table 11 - Cycle Time and Resource Quantity

Operation	Quantity of Equipment	Available Hours per Week	Operations Cycle Time (Seconds)	Volume Parts/Hour
Laser	1	85	51.43	70
Op 10	2	170	47.37	38
Op 20/30	2	170	51.43	35
Machining	2	170	60.00	30
Inspection	1	85	51.43	70

Source: Prepared by the author.

5.3.2 DEA Model

We use a DEA cost efficiency model to evaluate the effects of DBR on efficiency. Cost efficiency assesses the ability of a DMU to minimize its costs to produce a given output level, given the prices faced by that DMU (Färe et al., 1995). For each DMU j $(j = 1, \dots, n)$, there is a vector x_{ij} represented by $(x_{1j}, x_{2j} \dots, x_{mj})$, which reflects the amount of input i $(i = 1,$ ..., $m)$ used to produce a given vector of output y_{rj}, represented by $(y_{1j}, y_{2j} \dots, y_{sj})$, onde r $(r = 1,$ ..., $s)$ represents the outputs.

$$Min_{\lambda_j, x_i^{CE}} \quad C_o = \sum_{i=1}^{m} c_{io} x_i^{CE}$$

$$s.t. \qquad \sum_{j=1}^{n} \lambda_j \, x_{ij} \leq x_i^{CE}, \quad i = 1, \dots, m,$$

$$\sum_{j=1}^{n} \lambda_j \, y_{rj} \geq y_{ro}, r = 1, \dots, s,$$

$$\lambda_j \geq 0, \quad j = 1, \dots, n. \quad x_i^{CE} \geq 0, \qquad i = 1, \dots, m.$$

(1)

The cost efficiency (CE) of DMU_0 is defined as the ratio between the minimum cost and the observed cost obtained by expression (2) (Färe et al., 1985), which x_{i0} corresponds to the observed value of input i for a DMU_0 under evaluation, and x_i^{CE*} is the minimum cost of DMU_0 obtained from the optimal solution of model (1).

$$CE_0 = \frac{\sum_{i=1}^{m} c_{io} x_i^{CE*}}{\sum_{i=1}^{m} c_{io} x_{io}}$$

(2)

The cost efficiency defined by expression (2) can be broken down into technical efficiency (TE) and allocative efficiency (AE) (see expression (3)). These measures are interpreted as follows: CE measures how much the cost can be reduced if the company selects the optimum input quantities, given the output produced and the input prices it faces. Technical efficiency assesses the ability of a DMU to proportionally reduce the quantities of inputs for a given level of outputs produced. Allocative efficiency assesses the degree of correspondence between the current mix and the ideal mix of inputs for cost minimization (Camanho; Dyson, 2005; Ho; Hoang; Wilson, 2021; Portela; Thanassoulis, 2014).

$$CE = TE \times AE$$

(3)

We opted for the Constant Returns to Scale (CRS) model because the analysis is categorized as an internal benchmarking approach (see Piran et al., 2021). We formulated the DEA model in collaboration with a panel of experts in the automotive production process. The expert group consisted of a Mechanical Engineer and a Ph.D. holder in Production Engineering. The production system of an automotive axle works in weekly batch production. Based on the literature (Barbosa et al., 2017; Piran et al., 2016; Telles et al., 2020) and in the expert opinion, each weekly production lot corresponds to a DMU. The period of analysis corresponds to 40 weeks, 20 before the DBR implementation and 20 weeks after, considering, therefore, 40 DMUs. Among these 40 DMUs, eight refer to 2020 production lots, and the remaining 32 DMUs are from production lots corresponding to 2021. Furthermore, the variables used were defined based on the literature and validated by the process experts. Table 12 shows the variables used.

Table 12 - Model data

Role in the Model	Variable (Measure)	Unit	Reference
Input (x_1)	Normal Labor	Labor Hours	De Souza et al. (2018), Piran et al. (2021) and Telles et al. (2020)
Input (x_2)	Night Labor	Labor Hours	
Input (x_3)	Wip	Part Numbers	Barbosa et al. (2017) and Romero et al. (2010)
Input (x_4)	Electricity	KW	Mahjoor (2013) and Piran et al. (2020)
Input (x_5)	General Manufacturing Expenses	R$	Piran et al. (2021)
Output (y_1)	Quantity Piece Produced	Part Numbers	Cook et al. (2014), Jain et al. (2011), Nanci et al. (2006), Park et al. (2014), Piran et al. (2020) and Telles et al. (2020)

Source: Prepared by the author.

5.3.3 Data Collection and Analysis

Data collection was performed directly from the company's management software (SAP) database and spreadsheets were used for monitoring the production management of the automotive line. With this, a careful evaluation of the available data was carried out together with company experts to confirm the quality of these data for the research progress (Piran et al., 2020; Telles et al., 2020). Table 13 describes the data and the average values for each variable, considering the quantities and their unit prices (in R$). For General Manufacturing Expenses, the total cost value added was considered. The cost of the piece produced was not considered as this is a cost efficiency model. First, the table presents the overall average over the 40 weeks and subsequently presents the average of the 20 weeks before the implementation of the DBR and after the implementation. The period evaluated was from the end of 2019 to 2020 (40 weeks). Prices during this period did not change.

Table 13 - Average Input and Output

Variable (Measure)	Unit	Overall Average General (quantity (x))	Overall Average General (price R$ (c))	Overall Average Lean Before DBR (quantity)	Overall Average After DBR (quantity)
Normal Labor (x_1)	Labor Hours	2,146.55	8.54	2,319.58	1,973.53
Night Labor (x_2)	Labor Hours	167.10	10.25	334.20	0.00
Wip (x_3)	Part Numbers	145.82	282.56	55.00	236.65
Electricity (x_4)	KW	35,157.37	306.39	44,489.30	25,825.45
General Manufacturing Expenses (x_5)	R$	29,254.05	-	32,184.69	26,323.42
Quantity Piece Produced (y_1)	Part Numbers	3,303.75	-	2,242.95	4,364.55

Source: Prepared by the author.

The values presented in Table 13 are average weekly values. In some DMUs, the amount of night hours was zero due to the exclusion of the night shift, and the demand was met by a smaller number of hours. The working conditions were the same as the initial condition, operators, equipment, managers, working hours, daily target, manufacturing inputs, and components. Thus, isolating the competing factors and identifying the implementation's effect is possible.

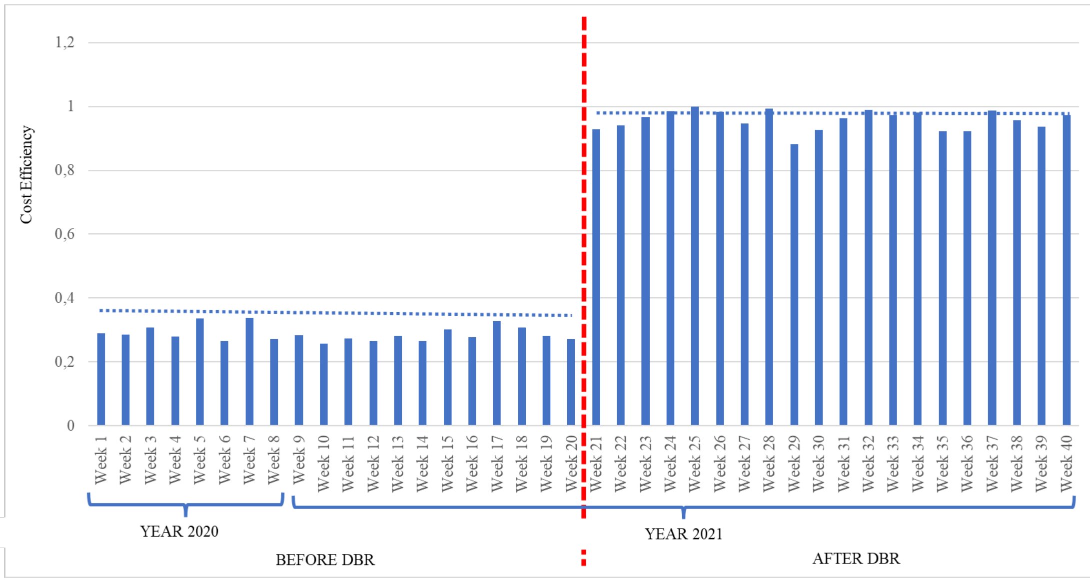
The T test was employed to determine whether there were significant differences between the means of the analyzed periods. However, before applying the T test, the Shapiro-Wilk normality test was conducted to confirm that the data follow a consistent normal distribution.

Based on the results of the Shapiro-Wilk normality test, it was determined that both the input and output data during the 20 weeks before the implementation of DBR and the 20 weeks after its implementation followed a normal distribution, with a p-value of 0.01985, which is less than the significance level of 0.05. Subsequently, Levene's test confirmed the homogeneity of the data sample, as the p-value was also less than 0.05. Given these findings, it is reasonable to conclude that the data conformed to a normal distribution, allowing for the application of the T test.

5.4 RESULTS

Figure 19 illustrates the progression of economic efficiency result over the course of 40 weeks. During the initial 20-week period, the average economic efficiency was 28.81%. Following the implementation of DBR in week 21, the average economic efficiency increased to 95.80%.

Figure 19 - Economic Efficiency (40 weeks)



Source: Prepared by the author.

In the initial 20 weeks of production, the need for an additional production shift (working night hours) was more frequent than initially anticipated. During this period, the average output of the production line fell short of demand, necessitating the introduction of additional expenses to ensure demand fulfillment. However, following the implementation of DBR after week 20, it became possible to boost the production line's output (as indicated in Table 13). Furthermore, the implementation of DBR enabled the elimination of additional costs, such as overtime, increased operator numbers, and extra work shifts, which were introduced prior to DBR. This cost reduction helped in the observed improvement in economic efficiency (see Figure 19).

Following the application of the T test to the cost efficiency results before and after the DBR implementation, we reject the null hypothesis H0 (p-value 0.00), as demonstrated in Table 14. This provides evidence of the positive effects of DBR implementation on the efficiency of the production process. Specifically, the implementation of DBR resulted in an increase in the economic efficiency of the automotive line. To gain a deeper understanding of the factors contributing to this outcome, a detailed evaluation of the results was conducted in collaboration with process experts.

Table 14 - T test results

	Before DBR	**After DBR**
Average	0,28817	0,95809
Variance	0,00058	0,00096
DMU's	20	20
P(T<=t) one-tailed	0,00000	
t critical one-tailed	1,72913	
P(T<=t) two-tailed	0,00000	
t critical two-tailed	2,09302	

Source: Prepared by the author.

Table 14 provides the mean and variance of economic efficiency for the 20 weeks before and after the implementation of DBR. The variance helps ensure the consistency of the data in both scenarios and adds stability to the presented results in the research. There is a noteworthy performance improvement of 0.67 when comparing the two scenarios over the course of 40 weeks following the DBR implementation. During this time, the output was 48% higher than the initial condition (as indicated in Table 13).

It's evident that after week 40, the results exhibit stability. Despite the production line's initial design based on Lean principles, aiming for capacity balance, real-world resource capacity often varies. Without any protection in the system, meaning zero inventory, the system's output is limited by the lowest capacity resource. Therefore, the system's efficiency becomes a product of individual efficiencies. The introduction of strategically located buffers, as recommended by TOC, enables the absorption of resource capacity variations while ensuring a consistent supply to the constrained resource. In this scenario, the system is primarily subject to the capacity fluctuations of the constrained resource.

Table 15 provides an overview of the variables considered in the analysis, comparing their performance before and after the implementation of DBR. Additionally, it includes the standard deviation for each variable and the individual economic impact of these variables. Notably, the work-in-process (WIP) variable indicates an increase in cost, signifying a negative impact on cost efficiency. However, the other variables exhibit a positive impact, contributing to the overall increase in the economic efficiency of the system.

Table 15 - Variable results before and after DBR implementation

Variable	**Unit**	**Before DBR**		**After DBR**		**Economic impact (U$/year)**
		Average	**Standard deviation**	**Average**	**Standard deviation**	
Normal Labor	Worked hours (5 days)	2,319.58	49.04	1,973,53	55.06	U$29,552.58
Night Labor	Worked hours (5 days)	334.20	23.74	0.00	0.00	U$34,255.71
WIP	Part Numbers	55.00	2.34	236.65	4.53	-U$7,270.96
Electricity	KW (5 days)	44,489.30	595.35	25,825.45	691.26	U$97,052.02
General Manufacturing Expenses	U$ / Work hour (5 days)	32,184.69	1,524.93	26,323.42	162.65	U$30,478.59

Source: Prepared by the author.

The Theory of Constraints (TOC) introduces specific performance indicators to monitor system performance. Some of the key TOC indicators include cycle time, throughput, inventory, operating expenses, and net income. In the context of the product cycle time pillar, the implementation of Drum-Buffer-Rope (DBR) did not lead to significant reductions in cycle time because the production line's takt-time remained unchanged. However, there was a noteworthy increase in throughput, as depicted in Figure 20. Regarding the inventory indicator, when looking at the work-in-process (WIP) volume, it appeared to be higher after the DBR implementation compared to the pre-implementation scenario. It's important to clarify that this increase in the indicator was primarily due to the transfer of raw materials into component raw materials. When assessing the entire raw material flow from acquisition to shipment, the overall quantity remained the same in both scenarios.

Operating expenses and net income are two aspects that derived significant benefits from the implementation of DBR. The stabilization of production resulting from DBR enabled the company to operate with a reduced weekly work hour rate and a smaller number of work shifts, these changes contributed to gains for the company. In regular hours, there was a reduction of 14.92% in the absolute number of worked hours, while in night hours, the reduction was 100% as the night shift was eliminated. Additionally, the company achieved a 41.95% reduction in electrical energy consumption within the production process.

5.5 DISCUSSION – PRACTICAL AND THEORETICAL IMPLICATIONS

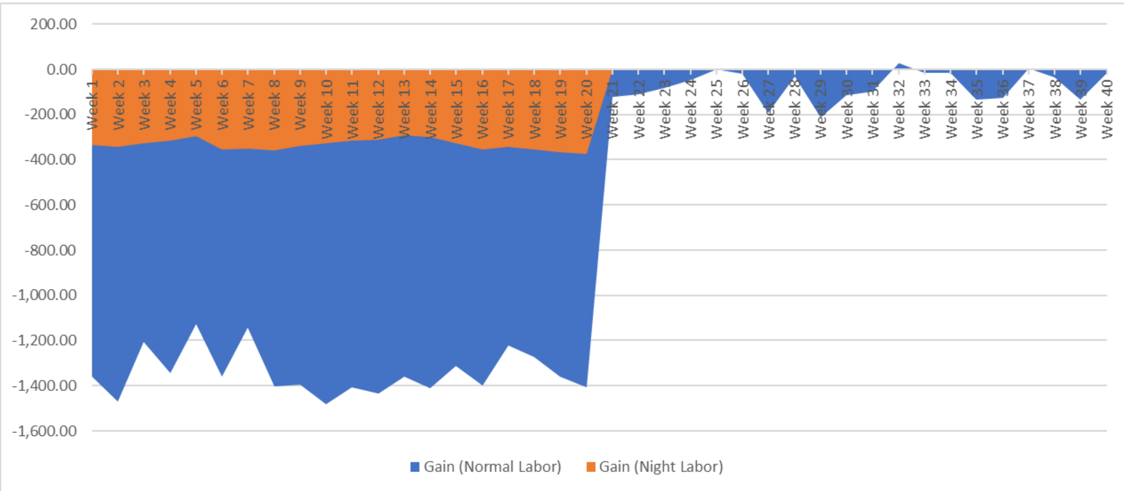
This paper presents theoretical and practical contributions regarding the use of DBR. The theoretical contribution is to apply LBR to an automotive production line and evaluate the effects of economic efficiency over time, considering the variables in the model. Although many types of research have been developed to present the results of the application of DBR (Darlington et al., 2015; Puche et al., 2019; Telles et al., 2020), there are no applications of LBR with evaluation of economic efficiency results using DEA.

This combination of analyzing the effects of DBR implementation using DEA for economic efficiency evaluation fills an existing gap in the literature, thus being relevant in the theoretical research context. The post-implementation production efficiency results discussed in this study further underscore the viability of employing DBR as a strategic management tool to ensure a company's competitiveness in its industry. These findings not only validate the advantages associated with DBR but also contribute to addressing a notable gap within the existing literature.

Regarding its contributions to the company, this study provides insights into efficiency measurements and conclusively demonstrates the advantages of implementing DBR within the production line under investigation.

When the results were presented to the company's specialists, they not only validated the findings but also affirmed the viability of implementing DBR in future projects that the company plans to undertake. The result analysis individually, considering only one parameter, is easy to understand. However, when it involves more than one parameter and the combination of inputs can change the result significantly, this analysis needs to be supported by tools that can help in this process.

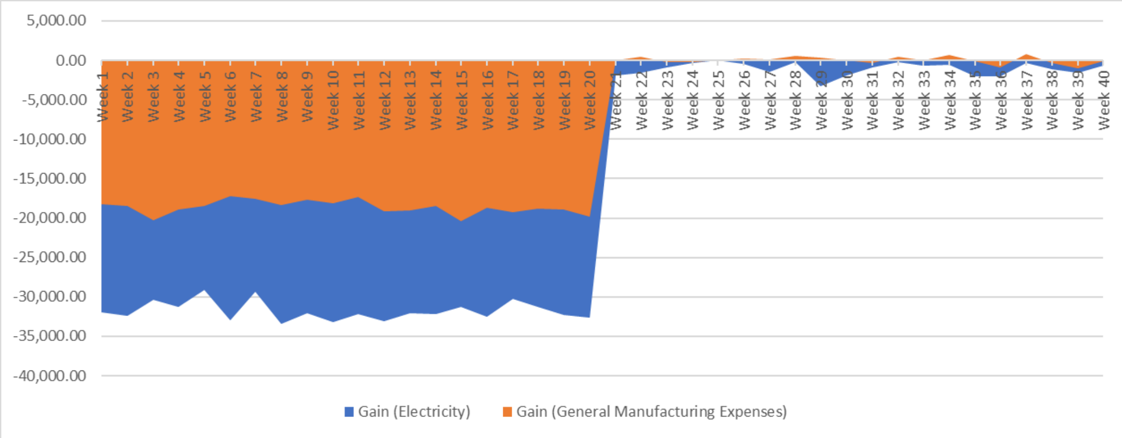
Figure 20 - Gain Normal Hours / Night Hours



Source: Prepared by the author.

For example, Figure 20 shows the gains in the hours worked during regular and night hours. The DEA analysis enables managers to evaluate scenarios holistically and more precisely regarding managing inputs and assertiveness for decision-making. Figure 21 demonstrates the behavior of the existing gains in electric power consumption and the existing gains in general manufacturing expenses.

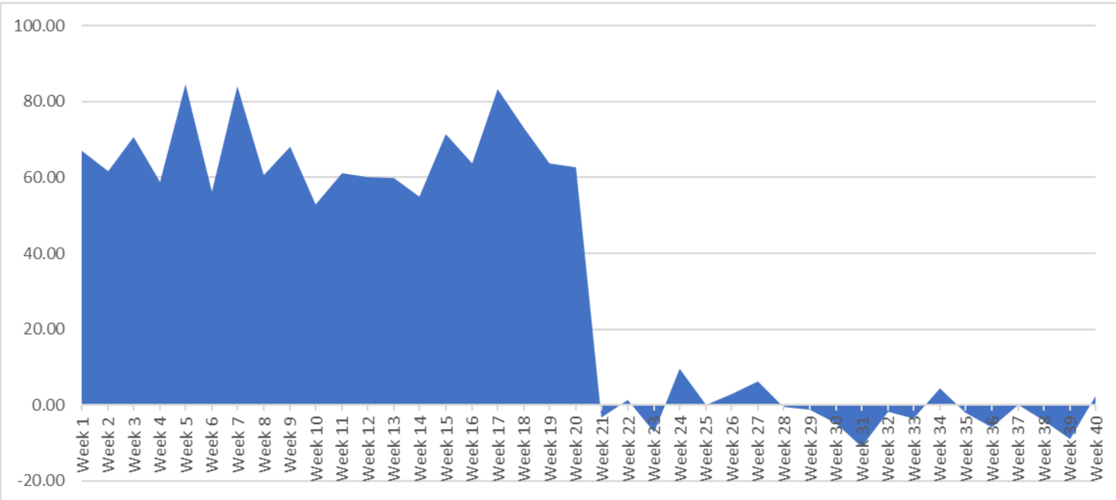
Figure 21 - Gain Electricity / GGF



Source: Prepared by the author.

In Figures 20 and 21, the behavior was the same until week 20, when the DBR was absent in the system. The gains presented higher results, that is, the best opportunities for improvement are observed in this process. Another example in the WIP (Figure 22), the gain behavior oppositely presents itself. That is, in the period before the implementation of the DBR the number of pieces in process was more petite than after the implementation of the DBR, due to not having the protections in the restriction.

Figure 22 - Gain WIP



Source: Prepared by the author.

From the results of productive efficiency, managers can establish and quantify goals for improving organizational results, which is the pillar for sustaining the business in the present and future of the company. In addition, managers prefer information that considers economic aspects in decision-making (Hatami-Marbini; Arabmaldar, 2021).

5.6 CONCLUSIONS

This study assesses the impact of implementing DBR in an automotive production line, specifically focusing on economic efficiency. To evaluate this, the research utilized the DEA technique. The findings indicate that following the DBR implementation, the economic efficiency of the automotive production line improved by an average of 67%. To validate these results, statistical tests, including the Shapiro-Wilk and T-test, were conducted.

The rise in the production output of the line contributes to the observed enhancement in economic efficiency. In the period preceding the DBR implementation, the production output consistently fell below the contracted demand, necessitating additional shifts and unanticipated overtime to meet the demand.With the increased hours worked, the general manufacturing costs have a direct connection and automatically grew in the same intensity as the total hours worked. In this environment, the product's profitability was strongly impacted, causing significant losses to the company, and placing the viability of the business under a more critical eye by management.

After the implementation of DBR as a working method and production line management, the weekly output growth was observed and sustained over the next 20 weeks. With this, removing an entire shift of work and the overtime that had been performed was possible. The WIP variable reports a lower behavior after the implementation of DBR with cost growth, while the others all show a better performance than the scenario before DBR. As this work is based on a single case study, it was not possible to replicate the results for other product lines with process characteristics different from the line in question. Further studies should be conducted using DEA to evaluate the effects of DBR in other goods production systems. In addition, revenue and profit efficiency can also be evaluated.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials (Apppendix 1 – Productive systems data)

REFERENCES

ABDELOUAHED, B. et al. Influence of Lean and Lean Six Sigma on Social Factors in the Moroccan Industry - Case Study. **International Journal of Performability Engineering**, v. 19, n. 8, p. 516, 2023.

ABREU-LEDÓN, R. et al. A meta-analytic study of the impact of Lean Production on business performance. **International Journal of Production Economics**, v. 200, p. 83–102, 2018.

ABU, F. et al. The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications. **Journal of Cleaner Production**, v. 234, p. 660–680, 2019.

AHMED, A.; OLSEN, J.; PAGE, J. Integration of Six Sigma and simulations in real production factory to improve performance – a case study analysis. **International Journal of Lean Six Sigma**, v. 14, n. 2, p. 451–482, 28 fev. 2023.

AHMED, S.; SOBUZ, M. H. R. Challenges of implementing lean construction in the construction industry in Bangladesh. **Smart and Sustainable Built Environment**, v. 9, n. 2, p. 174–207, 2020.

ALBLIWI, S. et al. Critical failure factors of lean Six Sigma: A systematic literature review. **International Journal of Quality and Reliability Management**, v. 31, n. 9, p. 1012–1030, 30 set. 2014.

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALMASHAQBEH, S.; HERNANDEZ, E. M. EVALUATION AND IMPROVEMENT OF A PLASTIC PRODUCTION SYSTEM USING INTEGRATED OEE METHODOLOGY: A CASE STUDY. **Management Systems in Production Engineering**, v. 32, n. 3, p. 450–463, 1 ago. 2024.

ALMEIDA, M. R. Princípios Básicos Para Uma Proposta De Ensino Sobre. p. 37–50, 2006.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015a.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015b.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015c.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015d.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. Lean production as promoter of thinkers to achieve companies’ agility. **Learning Organization**, v. 19, p. 219–237, 2012a.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. **Lean production as promoter of thinkers to achieve companies’ agility**. **Learning Organization**, abr. 2012b.

ALZUBI, E. et al. Hybrid integrations of value stream mapping, theory of constraints and simulation: Application to wooden furniture industry. **Processes**, v. 7, n. 11, 2019.

ANDERSSON, C.; BELLGRAN, M. On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity. **Journal of Manufacturing Systems**, v. 35, p. 144–154, 2015.

ANFAVEA. **Anuário da indústria automobilística brasileira**. [s.l: s.n.].

ANFAVEA, A. N. DOS F. DE V. A. **Anuário Estatístico da Indústria Automobilística Brasileira**.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013a.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013b.

APARICIO, J. et al. Measuring and decomposing firm's revenue and cost efficiency: The Russell measures revisited. **International Journal of Production Economics**, v. 165, p. 19–28, 1 jul. 2015.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017a.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017b.

AYOUBA, K. et al. A measure of price advantage and its decomposition into output- and input-specific effects. **European Journal of Operational Research**, v. 276, n. 2, p. 688–698, 16 jul. 2019.

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAKER, P. Why is lean so far off? v. 55, p. 26–29, 2002.

BANKES, S. **Exploratory Modeling for Policy AnalysisOperations Research**. [s.l: s.n.].

BANKES, S.; WALKER, W.; KWAKKEL, J. **Exploratory Modeling and Analysis**. [s.l: s.n.].

BAPTISTA, A.; ABREU, L.; BRITO, E. APPLICATION OF LEAN TOOLS CASE STUDY IN A TEXTILE COMPANY. **Proceedings on Engineering Sciences**, v. 3, n. 1, p. 93–102, 2021.

BARBERIO MARIANO, E. Conceitos Básicos de Análise de Eficiência produtiva. 2007.

BARBOSA, L. M. et al. Exploratory analysis of the variables prevailing on the effects of product modularization on production volume and efficiency. **International Journal of Production Economics**, v. 193, p. 677–690, 2017.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016a.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016b.

BARRATT, M.; CHOI, T. Y.; LI, M. Qualitative case studies in operations management: Trends, research outcomes, and future research implications. **Journal of Operations Management**, v. 29, n. 4, p. 329–342, 2011.

BBC. **Entenda por que a produtividade no Brasil não cresce**. Disponível em: <https://www.bbc.com/portuguese/noticias/2014/05/140519_produtividade_porque_ru>. Acesso em: 29 abr. 2023.

BBC. **Ford: afinal, por que a montadora decidiu encerrar a produção de veículos no Brasil?** Disponível em: <https://www.bbc.com/portuguese/internacional-55640907>. Acesso em: 7 maio. 2023.

BERGENWALL, A. L.; CHEN, C.; WHITE, R. E. TPSs process design in American automotive plants and its effects on the triple bottom line and sustainability. **International Journal of Production Economics**, v. 140, n. 1, p. 374–384, nov. 2012.

BETTERTON, C. E.; COX, J. F. Espoused drum-buffer-rope flow control in serial lines: A comparative study of simulation models. **International Journal of Production Economics**, v. 117, n. 1, p. 66–79, 2009.

BHASIN, S. An appropriate change strategy for lean success. **Management Decision**, v. 50, n. 3, p. 439–458, 2012.

BHASIN, S. Impact of corporate culture on the adoption of the lean principles. **International Journal of Lean Six Sigma**, v. 4, n. 2, p. 118–140, 2013.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002a.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002b.

BLANCHARD, D. Census of U.S. Manufactures: Lean Green and Low Cost. **Industry Week**, v. October, 2007.

BORTOLOTTI, T.; BOSCARI, S.; DANESE, P. Successful lean implementation: Organizational culture and soft lean practices. **International Journal of Production Economics**, v. 160, p. 182–201, 2015.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015a.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015b.

CAMANHO et al. A literature review of economic efficiency assessments using Data Envelopment Analysis. **European Journal of Operational Research**, 2023.

CAMANHO, A. S.; DYSON, R. G. Cost efficiency measurement with price uncertainty: A DEA application to bank branch assessments. **European Journal of Operational Research**, v. 161, n. 2, p. 432–446, 2005.

CARDOSO ERMEL, A. P. et al. **Literature Reviews**. Cham: Springer International Publishing, 2021.

CESARONI, G.; GIOVANNOLA, D. Average-cost efficiency and optimal scale sizes in non-parametric analysis. **European Journal of Operational Research**, v. 242, n. 1, p. 121–133, 1 abr. 2015.

CHAKRAVORTY, S. S.; ATWATER, J. B. The impact of free goods on the performance of drumbuffer-rope scheduling systems. **International Journal of Production Economics**, v. 95, n. 3, p. 347–357, 2005.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016a.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016b.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018a.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018b.

CHARNES, A.; COOPER, W. W.; RHODES, E. Measuring the efficiency of decision making units. **European Journal of Operational Research**, v. 2, n. 6, p. 429–444, 1978.

CHIZARI, A. H.; FEHRESTI-SANI, M. Evaluation of the economic efficiency of vegetable oil supply chains. **Supply Chain Forum**, v. 19, n. 2, p. 132–141, 3 abr. 2018.

COOK, W. D.; TONE, K.; ZHU, J. Data envelopment analysis: Prior to choosing a model. **Omega (United Kingdom)**, v. 44, p. 1–4, 2014.

CORRALES, L. DEL C. N. et al. Overall equipment effectiveness: Systematic literature review and overview of different approaches. **Applied Sciences (Switzerland)**, v. 10, n. 18, 2020.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016a.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016b.

COSTA, B.; VAREJÃO, J.; GASPAR, P. D. Development of a Value Stream Map to Optimize the Production Process in a Luxury Metal Piece Manufacturing Company. **Processes**, v. 12, n. 8, 1 ago. 2024.

COSTA, F. et al. How to foster Sustainable Continuous Improvement: A cause-effect relations map of Lean soft practices. **Operations Research Perspectives**, v. 6, n. December, p. 100091, 2019.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010a.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010b.

COX III, J. F.; SCHLEIER JR, J. G. **Handbook da Teoria das Restrições.** Bookman ed. Porto Alegre: [s.n.].

COX, J. F. I. et al. The TOCICO dictionary. v. 2, p. 1–135, 2012.

COX, J.F. III; SCHLEIER, J.G., J. **Handbook Theory of Constraints**. [s.l.] Bookman, 2013.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021a.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021b.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015a.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015b.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015c.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015d.

DAS, S.; PATEL, G. N. Cost efficiency of pharmaceutical firms manufacturing drugs for specific diseases prevalent in India: A data envelopment analysis approach. **Journal of Medical Marketing**, v. 14, n. 1, p. 5–19, 1 fev. 2014.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018a.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018b.

DE TREVILLE, S. et al. Editorial: Toyota Production System practices as Fast-and-Frugal heuristics. **Journal of Operations Management**, v. 69, n. 4, p. 522–535, 2023.

DIAS, R. M. F.; SILVA, L. D.; TENERA, A. Application of a proposed TLS model in a Lean Productive System. **Independent Journal of Management & Production**, v. 10, n. 1, p. 076, 2019.

DOBRA, P.; JÓSVAI, J. Overall Equipment Effectiveness (OEE) Life Cycle at the Automotive Semi-Automatic Assembly Lines. **Acta Polytechnica Hungarica**, v. 19, n. 9, p. 141–155, 2022.

DOGAN, N.; KAYGISIZ, F.; ALTINEL, A. Technical and economic efficiency of laying hen farms in Konya, Turkey. **Revista Brasileira de Ciencia Avicola**, v. 20, n. 2, p. 263–272, 2018.

DORA, M.; KUMAR, M.; GELLYNCK, X. Determinants and barriers to lean implementation in food-processing SMEs - A multiple case analysis. **Production Planning and Control**, v. 27, n. 1, p. 1–23, 2 jan. 2016.

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011a.

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011b.

FGV. **BRASILEIRO LEVA 1 HORA PARA PRODUZIR O QUE AMERICANO FAZ EM 15 MINUTOS**. Disponível em: <https://eesp.fgv.br/noticia/brasileiro-leva-1-hora-para-produzir-o-que-americano-faz-em-15-minutos>. Acesso em: 29 abr. 2023.

FILIPE, D.; PIMENTEL, C. Production and Internal Logistics Flow Improvements through the Application of Total Flow Management. **Logistics**, v. 7, n. 2, 1 jun. 2023.

FOUND, P. et al. Towards a theory of operational excellence. **Total Quality Management and Business Excellence**, v. 29, n. 9–10, p. 1012–1024, 29 jul. 2018.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020a.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020b.

FURLAN, A.; VINELLI, A.; PONT, G. D. Complementarity and lean manufacturing bundles: An empirical analysis. **International Journal of Operations and Production Management**, v. 31, n. 8, p. 835–850, 2011.

GAUSS, L. et al. Design science in operations management: A review and synthesis of the literature. **International Journal of Management Reviews**, 5 dez. 2024.

GLOBO. **Mapa: todas as fábricas de carros, motos e caminhões estão paradas no Brasil por pandemia**. Disponível em: <https://autoesporte.globo.com/carros/noticia/2020/03/mapa-todas-fabricas-de-carros-motos-e-caminhoes-estao-paradas-no-brasil-por-pandemia.ghtml>.

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E. M. Computerized shop floor scheduling. 1988a.

GOLDRATT, E. M. Computerized shop floor scheduling. 1988b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009a.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009c.

GOLDRATT, E. M. & F. R. E. **The Race**. [s.l: s.n.].

GOLDRATT, E. M.; COX, J. **A Meta**. 3° ed. [s.l: s.n.].

GOLDRATT, E. M.; FOX, R. E. **The Race**. [s.l: s.n.].

GOLMOHAMMADI, D. A study of scheduling under the theory of constraints. **International Journal of Production Economics**, v. 165, p. 38–50, 2015.

GONZALEZ-R, P. L.; FRAMINAN, J. M.; RUIZ-USANO, R. A multi-objective comparison of dispatching rules in a drum-buffer-rope production control system. **International Journal of Computer Integrated Manufacturing**, v. 23, n. 2, p. 155–167, 2010.

GOSLING, J.; NAIM, M. M. Engineer-to-order supply chain management: A literature review and research agenda. **International journal of production economics**, v. 122(2), p. 741–754, 2009.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007a.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007b.

GUILLEN, K. et al. LEAN model for optimizing plastic bag production in small and medium sized companies in the plastics sector. **International Journal of Engineering Research and Technology**, v. 11, n. 11, p. 1713–1734, 2018.

GUPTA, A.; BHARDWAJ, A.; KANDA, A. Fundamental concepts of theory of constraints: An emerging philosophy. **World Academy of Science, Engineering and Technology**, v. 46, n. 10, p. 686–692, 2010.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022a.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022b.

GUPTA, S.; MODGIL, S.; GUNASEKARAN, A. Big data in lean six sigma: a review and further research directions. **International Journal of Production Research**, v. 58, n. 3, p. 947–969, 2020.

HARDCOPF, R.; LIU, G. (JASON); SHAH, R. Lean production and operational performance: The influence of organizational culture. **International Journal of Production Economics**, v. 235, n. March 2020, p. 108060, 2021.

HATAMI-MARBINI, A.; ARABMALDAR, A. Robustness of Farrell cost efficiency measurement under data perturbations: Evidence from a US manufacturing application. **European Journal of Operational Research**, v. 295, n. 2, p. 604–620, 2021.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015a.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015b.

HO, T. Q.; HOANG, V. N.; WILSON, C. Trade-off analysis of cost and nutrient efficiency of coffee farms in vietnam: A more generalised approach. **Journal of Environmental Management**, v. 279, n. August, p. 111601, 2021.

HOPP, W. J. Positive lean: merging the science of efficiency with the psychology of work. **International Journal of Production Research**, v. 56, n. 1–2, p. 398–413, 2018.

HOPP, W. J.; SPEARMAN, M. L. To pull or not to pull: What is the question? **Manufacturing and Service Operations Management**, v. 6, n. 2, p. 133–148, 2004.

HOPP, W. J.; SPEARMAN, M. S. The lenses of lean: Visioning the science and practice of efficiency. **Journal of Operations Management**, v. 67, n. 5, p. 610–626, 2021.

HÜTTMEIR, A. et al. Trading off between heijunka and just-in-sequence. **International Journal of Production Economics**, v. 118, n. 2, p. 501–507, abr. 2009.

IKEZIRI, L. M. et al. Theory of constraints: review and bibliometric analysis. **International Journal of Production Research**, v. 57, n. 15–16, p. 1–35, 2018.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023a.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023b.

INAN, G. G.; et al. Operational performance improvement through continuous improvement initiatives in micro-enterprises of Turkey. **Asia-Pacific Journal of Business Administration,** v. 14, n. 3, p. 335–361, 2021.

IOANA, A. D.; MARIA, E. D.; CRISTINA, V. **Case study regarding the implementation of one-piece flow line in automotive company**. Procedia Manufacturing. **Anais**...Elsevier B.V., 2020.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014a.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014b.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014a.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014b.

JAIN, S.; TRIANTIS, K. P.; LIU, S. Manufacturing performance measurement and target setting: A data envelopment analysis approach. **European Journal of Operational Research**, v. 214, n. 3, p. 616–626, 2011.

JRADI, S.; BOUZDINE CHAMEEVA, T.; APARICIO, J. The measurement of revenue inefficiency over time: An additive perspective. **Omega (United Kingdom)**, v. 83, p. 167–180, 1 mar. 2019.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013a.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013b.

KERSTENS, K.; SADEGHI, J.; VAN DE WOESTYNE, I. Convex and nonconvex input-oriented technical and economic capacity measures: An empirical comparison. **European Journal of Operational Research**, v. 276, n. 2, p. 699–709, 2019.

KIM, J.; GERSHWIN, S. B. Integrated quality and quantity modeling of a production line. **Stochastic Modeling of Manufacturing Systems: Advances in Design, Performance Evaluation, and Control Issues**, p. 121–148, 2006.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010a.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010b.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, jan. 2010c.

KONOPKA, J. M. Capacity Utilization Bottleneck Efficiency System—CUBES. **IEEE Transactions on Components Packaging and Manufacturing Technology Part A**, v. 18, n. 3, p. 484–491, 1995.

KUMAR, R.; KUMAR, V. Barriers in implementation of lean manufacturing system in Indian industry: A survey. **International Journal of Latest Trends in Engineering & Technology**, v. 4, p. 243–251, 2014.

KWAKKEL, J. H.; PRUYT, E. Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. **Technological Forecasting and Social Change**, v. 80, n. 3, p. 419–431, 2013.

LACERDA, D. P. et al. Design Science Research: Método de pesquisa para a engenharia de produção. **Gestao e Producao**, v. 20, n. 4, p. 741–761, 26 nov. 2013.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021a.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021b.

LANZA, G. et al. Measuring global production effectiveness. **Procedia CIRP**, v. 7, p. 31–36, 2013.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024a.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024b.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024c.

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LEITE, H.; RADNOR, Z.; BATEMAN, N. Meaningful inhibitors of the lean journey: a systematic review and categorisation of over 20 years of literature. **Production Planning and Control**, v. 33, n. 5, p. 403–426, 2022.

LIKER, J.; ROTHER, M. Why Lean Programs Fail. **Lean Enterprise Institute**, p. 1–5, 2011.

LIM, A. S. S.; SABIL, S.; OTHMAN, A. E. B. A. the Mediating Role of Continuous Improvement on the Relationship Between Workplace Learning Dimensions and Sustainable Lean Manufacturing. **International Journal of Business and Society**, v. 23, n. 1, p. 260–278, 2022.

LIU, J. et al. A DEA-based approach for competitive environment analysis in global operations strategies. **International Journal of Production Economics**, v. 203, p. 110–123, 2018.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019a.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019b.

LUZ, G. P. et al. Proposition of a method for stochastic analysis of value streams. **Production Planning and Control**, v. 33, n. 8, p. 741–757, 2022.

MABIN, V. J.; BALDERSTONE, S. J. The performance of the theory of constraints methodology: Analysis and discussion of successful TOC applications. **International Journal of Operations and Production Management**, v. 23, n. 5–6, p. 568–595, 2003.

MAHJOOR, A. A. Technical, allocative and economic efficiencies of broiler farms in Fars Province, Iran: A Data Envelopment Analysis (DEA) approach. **World Applied Sciences Journal**, v. 21, n. 10, p. 1427–1435, 2013.

MANAVIZADEH, N. et al. A Simulated Annealing algorithm for a mixed model assembly U-line balancing type-I problem considering human efficiency and Just-In-Time approach. **Computers and Industrial Engineering**, v. 64, p. 669–685, 2013.

MARFATIA, H. et al. S earch and s urvey. n. February 2021, p. 10–17, 2020.

MARODIN, G. A. et al. Model of risk interactions hindering lean production implementation. **Gestao e Producao**, v. 25, n. 4, p. 696–712, 2018.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019a.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019b.

MARTINS, J. C. et al. Systems dynamic modeling to analyze the systemic viability of the combined use of regenerative converters and energy storage in a UPS manufacturer. **Journal of Cleaner Production**, v. 246, n. xxxx, p. 118950, 2020.

MEMARI, A. et al. The impact of lean production on operational performance: a case study. **Asia-Pacific Journal of Business Administration**, 2022.

MILLSTEIN, M. A.; MARTINICH, J. S. Takt Time Grouping: Implementing kanban-flow manufacturing in an unbalanced, high variation cycle-time process with moving constraints. **International Journal of Production Research**, v. 52, n. 23, p. 6863–6877, 2014.

MOHANAVELU, T.; KRISHNASWAMY, R.; MARIMUTHU, P. Simulation modelling and development of analytic hierarchy process-based priority dispatching rule for a dynamic press shop. **nternational Journal of Industrial and Systems Engineering**, v. 27(3), p. 340–364, 2017.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023a.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023b.

MOHD AZHAR SAHWAN; MOHD NIZAM AB RAHMAN; BABA MD DEROS. Barriers to Implement Lean Manufacturing in Malaysian Automotive Industry. **Jurnal Teknologi (Sciences and Engineering)**, v. 59, p. 107–110, 2012.

MORANDI, M. I. W. M. et al. Foreseeing Iron Ore Prices Using System Thinking and Scenario Planning. **Systemic Practice and Action Research**, v. 27, n. 3, p. 287–306, 2014.

MORANDI, M. I. W. M.; CAMARGO, L. F. R. **Revisão sistemática da literatura. Design science research: Método de pesquisa para avanço da ciência e tecnologia**. [s.l.] Bookman, 2015.

MUCHIRI, P.; PINTELON, L. Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. **International Journal of Production Research**, v. 46, n. 13, p. 3517–3535, 2008.

MUTHIAH, K. M. N.; HUANG, S. H. Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection. **International Journal of Production Research**, v. 45, n. 20, p. 4753–4769, 2007.

NACIRI, L. et al. **Lean and industry 4.0: A leading harmony**. Procedia Computer Science. **Anais**...Elsevier B.V., 2022.

NANCI, L. C.; AZEREDO, S. M.; MELLO, J. C. C. B. S. DE. Estudo da eficiência de empresas distribuidoras de jornais usando análise envoltória de dados. **Produto & Produção**, v. 7, n. 3, p. 27–35, 2006.

NARASIMHAN, R.; SWINK, M.; KIM, S. W. Disentangling leanness and agility: An empirical investigation. **Journal of Operations Management**, v. 24, n. 5, p. 440–457, 2006.

NARASSIMA, M. S. et al. Implementation of lean principles in the yarn manufacturing industry: a system dynamics approach. **Benchmarking**, 2023.

NEELY, A.; GREGORY, M.; PLATTS, K. A literature review and research agenda. **International Journal of Operations & Production Management**, v. 15, n. 4, p. 80–116, 2002.

NETLAND, T. H.; SCHLOETZER, J. D.; FERDOWS, K. Learning lean: rhythm of production and the pace of lean implementation. **International Journal of Operations and Production Management**, v. 41, n. 2, p. 131–156, 2021.

NG CORRALES, L. D. C. et al. Developing and Implementing a Lean Performance Indicator: Overall Process Effectiveness to Measure the Effectiveness in an Operation Process. **Machines**, v. 10, n. 2, 1 fev. 2022.

OECHSNER, R. et al. From overall equipment efficiency (OEE) to overall Fab effectiveness (OFE). **Materials Science in Semiconductor Processing**, v. 5, n. 4- 5 SPEC., p. 333–339, 2002.

OH, I. et al. Analysis of product efficiency in the Korean automobile market from a consumer's perspective. **Empirical Economics**, v. 38, n. 1, p. 119–137, fev. 2010.

OHNO, T. Toyota Production System: beyond large-scale production. **Oregon: Productivity Press**, 1988.

OHNO, T. **O Sistema Toyota de Produção Além da Produção em Larga Escala**. [s.l.] Bookman, 1997.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021a.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021b.

PACHECOA, D. A. DE J. Theory of Constraints, Lean Manufacturing and Six Sigma: Limits to and possibilities for integration. **Producao**, v. 24, n. 4, p. 940–956, 2014.

PARK, J.; LEE, D.; ZHU, J. An integrated approach for ship block manufacturing process performance evaluation: Case from a Korean shipbuilding company. **International Journal of Production Economics**, v. 156, p. 214–222, 2014.

PEARCE, A.; PONS, D.; NEITZERT, T. Implementing lean—Outcomes from SME case studies. **Operations Research Perspectives**, v. 5, p. 94–104, 2018.

PEREIRA, L.; TORTORELLA, G. Identification of the relationships between critical success factors, barriers and practices for lean implementation in a small company. **Brazilian Journal of Operations & Production Management**, v. 15, n. 2, p. 232–246, 1 jun. 2018.

PERVAZ, J. et al. SIMULATION-BASED ALGORITHM FOR CONTINUOUS IMPROVEMENT OF ENTERPRISES PERFORMANCE. **International Journal of Simulation Modelling**, v. 23, n. 2, p. 215–226, 1 jun. 2024.

PIRAN, F. A. S. et al. Product modularization and effects on efficiency: An analysis of a bus manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 182, p. 1–13, 2016.

PIRAN, F. A. S. et al. Overall Equipment Effectiveness: Required but not Enough—An Analysis Integrating Overall Equipment Effect and Data Envelopment Analysis. **Global Journal of Flexible Systems Management**, v. 21, n. 2, p. 191–206, 1 jun. 2020.

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, 2021a.

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, n. April, p. 108173, 2021b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020b.

PONT, G. D.; FURLAN, A.; VINELLI, A. Interrelationships among lean bundles and their effects on operational performance. **Operations Management Research**, v. 1, n. 2, p. 150–158, 2009.

PORTELA, M. C. A. S.; THANASSOULIS, E. Economic efficiency when prices are not fixed: Disentangling quantity and price efficiency. **Omega (United Kingdom)**, v. 47, p. 36–44, 2014.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019a.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019b.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 2019a.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019b.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019c.

QAMAR, A. et al. Quality and flexibility performance trade-offs between lean and agile manufacturing firms in the automotive industry. **Production Planning and Control**, v. 31, n. 9, p. 723–738, 2020.

QURESHI, K. M. et al. Exploring the Lean Implementation Barriers in Small and Medium-Sized Enterprises Using Interpretive Structure Modeling and

Interpretive Ranking Process. **Applied System Innovation**, v. 5, n. 4, p. 1–20, 2022.

RAMADAS, T.; SATISH, K. P. Identification and modeling of process barriers: Implementing lean manufacturing in small-and medium-size enterprises. **International Journal of Lean Six Sigma**, v. 12, n. 1, p. 61–77, 2021.

RAOUF, A. Improving capital productivity through maintenance. . **International Journal of Operations & Production Management**, v. 14 (7), p. 44–52, 1994.

REPONEN, E. et al. Benchmarking outcomes on multiple contextual levels in lean healthcare: a systematic review, development of a conceptual framework, and a research agenda. **BMC Health Services Research**, v. 21, n. 1, 1 dez. 2021.

ROCHMAN, Y. A.; SUDIARSO, A.; HERLIANSYAH, M. K. Development of Lean Implementation Framework for Indonesian Batik Small and Medium-Sized Enterprises. **International Journal of Engineering, Transactions B: Applications**, v. 37, n. 11, p. 2223–2238, 1 nov. 2024.

ROJON, C.; OKUPE, A.; MCDOWALL, A. Utilization and development of systematic reviews in management research: What do we know and where do we go from here? **International Journal of Management Reviews**, v. 23, n. 2, p. 191–223, 1 abr. 2021.

ROMERO, L. F. et al. A data envelope analysis to assess factors affecting technical and economic efficiency of individual broiler breeder hens. **Poultry Science**, v. 89, n. 8, p. 1769–1777, 2010.

SARTAL, A.; VAZQUEZ, X. H.; LOZANO-LOZANO, L. M. Organizational Tools and Cultural Change in the Success of Lean Transformations: Delving Into Sequence and Rhythm. **IEEE Transactions on Engineering Management**, v. 69, n. 5, p. 2205–2217, 1 out. 2022.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023a.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023b.

SCOTT, D.; PISA, R. Can overall factory effectiveness prolong Mooer's law? **Solid State Technology**, p. 75–81, 1998.

SECCHI, R.; CAMUFFO, A. Lean implementation failures: The role of organizational ambidexterity. **International Journal of Production Economics**, v. 210, p. 145–154, 1 abr. 2019.

SILVA, F.; MENEZES-FILHO, N.; KOMATSU, B. Evolução da produtividade no Brasil: comparações internacionais. **Insper Policy Paper**, n. 15, p. 30, 2016.

SOHRMANN, C. et al. Towards a Standardized Format for Automotive Mission Profiles State of the Art Use Cases for Mission Profiles Application of MPs in Verification and. **Proc. Automotive meets Electronics 10**, n. March, p. 39–44, 2021.

SPEAR, S.; BOWEN, H. K. Decoding the DNA of the Toyota Production System. **Harvard Business Review**, v. 77, n. 5, p. 96–106, 1999.

STAUDACHER, A. P.; TANTARDINI, M. **Lean production implementation: a survey in Italy**. XI Congreso de Ingeniería de Organizacion International Conference on Industrial Engineering and Industrial Management,. **Anais**...Madri: 2007.

STEELE, D. C. et al. Comparisons between drum-buffer-rope and material requirements planning: A case study. **International Journal of Production Research**, v. 43, n. 15, p. 3181–3208, 2005.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022a.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022b.

STRATTON, R.; WARBURTON, R. D. H. The strategic integration of agile and lean supply. **International Journal of Production Economics**, v. 85, n. 2, p. 183–198, 2003.

SUKWADI, R.; FELICIA, Y.; MUAFI. TOC, lean, and six sigma: An integrated model to increase the productivity of the textile industry. **Journal of Mechanical Engineering Research and Developments**, v. 44, n. 1, p. 327–336, 2021.

SUSAETA, A. et al. Technical, allocative, and total profit efficiency of loblolly pine forests under changing climatic conditions. **Forest Policy and Economics**, v. 72, p. 106–114, 1 nov. 2016.

SWEETSER, A. **A Comparison of System Dynamics (SD) and Discrete Event Simulation (DES)**. [s.l: s.n.].

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000a.

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, n. February, p. 107500, 2020a.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020c.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020d.

TELLES, E. S. et al. Drum-Buffer-Rope in an engineering-to-order productive system: a case study in a Brazilian aerospace company. **Journal of Manufacturing Technology Management**, v. 33, n. 6, p. 1190–1209, 6 set. 2022.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020a.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020b.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020c.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018a.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018b.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018c.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018d.

THÜRER, M.; TOMAŠEVIĆ, I.; STEVENSON, M. **On the meaning of ‘Waste’: review and definition**. **Production Planning and Control**Taylor and Francis Ltd., , 17 fev. 2017.

TOMA, S.; NARUO, S. Total Quality Management and Business Excellence: the Best Practices At Toyota Motor Corporation. 2017.

TORTORELLA, G. L. et al. The impact of contextual variables on learning organization in firms that are implementing lean: a study in Southern Brazil. **International Journal of Advanced Manufacturing Technology**, v. 78, n. 9–12, p. 1879–1892, 18 jun. 2015.

TORTORELLA, G. L. et al. Learning organisation and lean production: an empirical research on their relationship. **International Journal of Production Research**, v. 58, n. 12, p. 3650–3666, 2020.

VEGA-ALVITES, J. C. Q.-F. & M. L. Review Lean Manufacturing Model of Production Management Under the Preventive. **South African Journal of Industrial Engineering**, v. 33, n. 2, p. 143–156, 2022.

VENKATESH, A.; KUSHWAHA, S. Short and long-run cost efficiency in Indian public bus companies using Data Envelopment Analysis. **Socio-Economic Planning Sciences**, v. 61, p. 29–36, 1 mar. 2018.

VON GILSA, C. et al. Longitudinal evaluation of efficiency in a petrochemical company. **Benchmarking**, v. 24, n. 7, p. 1786–1813, 2017.

WAHAB, A. et al. Improvement on bill of materials formatting process by adopting lean and six sigma approaches-A case study in a semiconductor industry ilhammee. **International Journal of Integrated Engineering**, v. 11, n. 8, p. 81–90, 2019.

WAHLERS, J. L.; COX, J. F. Competitive factors and performance measurement: Applying the theory of constraints to meet customer needs. **International Journal of Production Economics**, v. 37, n. 2–3, p. 229–240, 1994.

WALLACE J. HOPP, M. L. S. **Factory Physics**. Third Edit ed. [s.l: s.n.].

WATSON, K. J.; BLACKSTONE, J. H.; GARDINER, S. C. The evolution of a management philosophy: The theory of constraints. **Journal of Operations Management**, v. 25, n. 2, p. 387–402, 2007.

WATSON, K. J.; PATTI, A. A comparison of JIT and TOC buffering philosophies on system performance with unplanned machine downtime. **International Journal of Production Research**, v. 46, n. 7, p. 1869–1885, 2008.

WEBSTER, J.; WATSON, R. MIS Quarterly. **Analyzing the Past To Prepare for the Future : Writing a Literature Review**, v. 26, n. 2, p. 13–23, 2002.

WONG, Y. C.; WONG, K. Y.; ALI, A. A study on Lean Manufacturingimplementation in the Malaysian electrical and electronics industry. **European Journal of Scientific Research**, v. Vol. 38, 2009.

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WU, H. H.; LIU, J. Y. A capacity available-to-promise model for drum-buffer-rope systems. **International Journal of Production Research**, v. 46, n. 8, p. 2255–2274, 2008.

WU, S.; WEE, H. M. Why the big three decline despite their lean management - A study based on the theory of constraints. **Global Perspective for Competitive Enterprise, Economy and Ecology - Proceedings of the 16th ISPE International Conference on Concurrent Engineering**, p. 691–699, 2009.

YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008a.

YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008b.

YENRADEE, P. Application of optimized production technology ina capacity constrained flow shop: a case study in a battery factory. **Comput. Ind. Eng.**, v. 27, p. 217–220, 1994.

Apppendix 1 – Productive systems data

DMU	Normal Labor	Night Labor	WIP	Electricity (KW)	General Manufacturing Expenses	Output	DMU	Cost Efficiency	Benchmark
Week 1	2,343.88	334.18	55	44,784.00	31,904.53	2,265.00	**Week 1**	**0.289017679**	**Week 25(0,515124)**
Week 2	2,451.02	343.75	60	45,231.00	32,067.70	2,256.00	**Week 2**	**0.284960857**	**Week 25(0,513077)**
Week 3	2,227.28	328.57	56	43,711.00	34,509.71	2,350.00	**Week 3**	**0.307211395**	**Week 25(0,534455)**
Week 4	2,262.48	316.58	55	43,210.00	31,616.83	2,110.00	**Week 4**	**0.279110328**	**Week 25(0,479873)**
Week 5	2,244.00	295.79	54	43,621.00	33,993.26	2,570.00	**Week 5**	**0.336688574**	**Week 25(0,584489)**
Week 6	2,263.58	353.76	56	44,712.00	29,741.31	2,080.00	**Week 6**	**0.265876808**	**Week 25(0,473050)**
Week 7	2,282.28	350.57	57	44,153.00	33,356.24	2,615.00	**Week 7**	**0.338413188**	**Week 25(0,594724)**
Week 8	2,343.44	357.94	56	45,654.00	31,383.75	2,163.00	**Week 8**	**0.270712941**	**Week 25(0,491926)**
Week 9	2,357.08	339.68	51	44,611.00	30,956.22	2,210.00	**Week 9**	**0.283151694**	**Week 25(0,502615)**
Week 10	2,353.56	325.93	55	44,521.00	30,191.31	2,004.00	**Week 10**	**0.257275485**	**Week 25(0,455765)**
Week 11	2,329.14	313.94	53	44,123.00	30,058.46	2,116.00	**Week 11**	**0.274135924**	**Week 25(0,481237)**
Week 12	2,341.90	309.98	52	44,899.00	31,679.80	2,082.00	**Week 12**	**0.265022683**	**Week 25(0,473505)**
Week 13	2,319.02	292.05	59	44,587.00	32,323.71	2,203.00	**Week 13**	**0.282345304**	**Week 25(0,501023)**
Week 14	2,291.08	301.51	54	43,611.00	30,657.81	2,019.00	**Week 14**	**0.264641048**	**Week 25(0,459177)**
Week 15	2,331.56	327.58	55	44,522.00	34,501.40	2,345.00	**Week 15**	**0.3009526**	**Week 25(0,533318)**
Week 16	2,341.68	353.98	53	44,759.00	31,770.68	2,167.00	**Week 16**	**0.276688904**	**Week 25(0,492836)**
Week 17	2,344.54	342.54	56	44,888.00	34,891.15	2,583.00	**Week 17**	**0.328728099**	**Week 25(0,587446)**
Week 18	2,322.10	353.76	57	44,898.00	33,419.32	2,412.00	**Week 18**	**0.306924558**	**Week 25(0,548556)**
Week 19	2,319.02	365.97	55	44,777.00	32,154.84	2,201.00	**Week 19**	**0.280869447**	**Week 25(0,500569)**
Week 20	2,322.98	375.98	51	44,514.00	32,515.78	2,108.00	**Week 20**	**0.270609768**	**Week 25(0,479418)**
Week 21	2,007.28	0	237	26,435.00	26,180.00	4,335.00	**Week 21**	**0.929275318**	**Week 25(0,985899)**
Week 22	2,027.08	0	236	26,544.00	26,154.35	4,403.00	**Week 22**	**0.940038829**	**Week 25(1,001365)**
Week 23	1,968.34	0	241	25,411.00	26,420.94	4,336.00	**Week 23**	**0.966316843**	**Week 25(0,986127)**
Week 24	1,939.08	0	225	24,999.00	26,517.88	4,350.00	**Week 24**	**0.985786309**	**Week 25(0,989311)**
Week 25	1,913.56	0	237	24,898.00	26,541.65	4,397.00	**Week 25**	**1**	**Week 25(1,000000)**
Week 26	1,939.08	0	235	25,412.00	26,420.71	4,412.00	**Week 26**	**0.983461015**	**Week 25(1,003411)**
Week 27	2,093.74	0	229	26,144.00	26,248.47	4,366.00	**Week 27**	**0.946372383**	**Week 25(0,992950)**
Week 28	1,975.16	0	241	25,462.00	26,408.94	4,463.00	**Week 28**	**0.992650091**	**Week 25(1,015010)**
Week 29	2,100.34	0	235	27,878.00	25,840.47	4,338.00	**Week 29**	**0.882326546**	**Week 25(0,986582)**
Week 30	2,005.96	0	239	26,555.00	26,151.76	4,342.00	**Week 30**	**0.926563839**	**Week 25(0,987491)**
Week 31	1,979.12	0	244	25,412.00	26,420.71	4,323.00	**Week 31**	**0.963266914**	**Week 25(0,983170)**
Week 32	1,913.12	0	242	25,499.00	26,400.24	4,456.00	**Week 32**	**0.989708417**	**Week 25(1,013418)**
Week 33	1,917.08	0	239	25,432.00	26,416.00	4,370.00	**Week 33**	**0.973227069**	**Week 25(0,993859)**
Week 34	1,965.92	0	237	25,874.00	26,312.00	4,477.00	**Week 34**	**0.980282596**	**Week 25(1,018194)**
Week 35	2,015.86	0	235	26,532.00	26,157.18	4,321.00	**Week 35**	**0.922984964**	**Week 25(0,982715)**
Week 36	1,961.08	0	233	25,858.00	26,315.76	4,213.00	**Week 36**	**0.923173369**	**Week 25(0,958153)**
Week 37	1,948.10	0	242	25,744.00	26,342.59	4,489.00	**Week 37**	**0.987649505**	**Week 25(1,020923)**
Week 38	1,917.08	0	237	25,564.00	26,384.94	4,322.00	**Week 38**	**0.957707419**	**Week 25(0,982943)**
Week 39	1,967.24	0	236	25,444.00	26,413.18	4,211.00	**Week 39**	**0.937429958**	**Week 25(0,957698)**
Week 40	1,916.42	0	233	25,412.00	26,420.71	4,367.00	**Week 40**	**0.973524161**	**Week 25(0,993177)**

6 DISCUSSIONS AND RESEARCH CONCLUSION

The primary objective of this study is to test the hypothesis that continuous improvement invariably leads to increased economic efficiency. This goal is further divided into three specific aims: (i) Understanding the relationship between continuous improvement and economic efficiency within the Lean Manufacturing framework by analyzing how the key underlying assumptions of this relationship have evolved over time; (ii) Evaluating the adequacy of Lean Manufacturing’s assumptions, principles, and techniques in supporting the hypothesis that continuous improvement enhances economic efficiency; e (iii) Comparing the performance of Lean Manufacturing and the Theory of Constraints (TOC) in a single-product automotive production line designed based on Lean Manufacturing principles.

To achieve these objectives, this study follows the Design Science Research (DSR) methodology. The research process began with the formulation of the problem, followed by analysis and diagnosis. Chapter 3 presents a systematic literature review, exploring the impact of continuous improvement on manufacturing efficiency. This theoretical foundation provides valuable insights into the relationship between Lean Manufacturing and economic efficiency indicators, guiding the subsequent analyses.

Chapter 4 outlines the solution design, detailing the development of an automotive production line model using System Dynamics (SD). The Theory of Constraints (TOC) was then applied through the Drum-Buffer-Rope (DBR) approach, and its results were compared to those of Lean Manufacturing. To facilitate this comparison, System Dynamics (SD) modeling was employed to develop and simulate various scenarios, which were subsequently evaluated against empirical data.

Chapter 5 explores the intervention, which involved analyzing the economic efficiency of the same automotive production line using Data Envelopment Analysis (DEA). This approach provided a structured and comparative evaluation of the proposed solution's economic efficiency.

The results presented in Chapters 3, 4, and 5 provided both theoretical and practical contributions, outlined in Table 16, reinforcing the study's implications for academic literature and industrial management.

Table 16 - Theoretical and practical contributions

Theoretical Contributions	Pratical Contributions
The literature suggests that Lean approaches economic efficiency indirectly, viewing it as a consequence of technical improvements and waste reduction.	The research emphasizes the need to prioritize economic efficiency as a core element in the implementation of Lean methodology.
The study reveals that improvements in technical efficiency do not always translate into economic gains, underscoring the need for an approach that seamlessly integrates both dimensions.	Managers typically prioritize initiatives with clear economic returns, recognizing their crucial role in strategic decision-making. Integrating an economic perspective into Lean can therefore expand its applicability and organizational impact, driving more substantial and sustainable results.
Application of the DBR-TOC Method: System Dynamics (SD) modeling enabled a comparison between Lean and TOC, providing insights into why the DBR (Drum-Buffer-Rope) method yielded superior results.	Enhanced Understanding of Production Synchronization: The study highlights the importance of selecting between Lean and TOC based on the organizational context, rather than adopting Lean as a mere management trend.
Empirical Comparison Between Lean and TOC: The study offers empirical support for comparative analyses by isolating confounding factors and emphasizing the outcomes of each approach.	Advantages of System Dynamics (SD) Modeling: The modeling process eased the adoption of the DBR-TOC approach, minimizing resistance to factory testing and enabling the simulation of various scenarios before implementation.
The Central Role of Manufacturing Concepts: While automation plays a role, the study highlights that manufacturing outcomes are influenced more by the concepts adopted than by the technology itself.	Supporting Decision-Making: The developed model can be applied to other production lines with similar characteristics, assisting managers in managing urgent orders while enhancing production stability.
Empirical Evidence on TOC and Lean: The research provides a robust comparative analysis with controlled external variables, showcasing the performance of DBR-TOC relative to Lean's Heijunka concept.	The study highlights DBR as an efficient management approach for achieving performance goals and driving continuous process improvement.
The research confirms that, beyond improving effectiveness such as on-time delivery and increased production volume DBR also boosts economic efficiency, a factor that has been largely overlooked in the literature.	

Source: Prepared by the author.

The intervention allowed for testing the hypothesis that continuous improvement invariably leads to increased economic efficiency. However, the results suggest that this relationship is not absolute. While continuous improvement enhances technical efficiency, it does not automatically translate into economic efficiency. The transformation of technical efficiency into economic gains depends on additional factors, including internal operational elements and external variables such as market conditions and macroeconomic influences.

This study underscores the importance of prioritizing economic efficiency as a core element in the implementation of Lean Manufacturing. Since managers tend to favor initiatives with clear economic returns due to their role in strategic decision-making, incorporating an economic perspective into Lean Manufacturing can expand its applicability and strengthen its organizational impact, ultimately driving more meaningful and sustainable results.

The research findings highlight the importance of a holistic approach to production processes, ensuring that the chosen methodologies are closely aligned with organizational strategies. Without this integration, Lean Manufacturing may not reach its full potential, diminishing its impact on competitiveness and return on investment. Establishing a clear connection between technical improvements and economic outcomes is therefore crucial to maximizing the benefits of this approach across diverse business contexts.

However, this study has certain limitations, primarily related to the scope of the intervention, which was conducted on a single production line, within one company, and in a single market—the automotive sector. This narrow focus may restrict the generalizability of the findings to other industrial settings.

For future research, expanding the scope of the investigation to include multiple production lines across different companies and sectors is recommended. This broader approach would enable a more comprehensive assessment of the impacts and validity of the underlying assumptions across diverse scenarios. Another promising research avenue involves examining buffer sizing in the implementation of the Drum-Buffer-Rope (DBR) approach, with a focus on the economic perspective of manufacturing systems. This could yield valuable insights into optimizing both production efficiency and economic performance.

REFERENCES

ABDELOUAHED, B. et al. Influence of Lean and Lean Six Sigma on Social Factors in the Moroccan Industry - Case Study. **International Journal of Performability Engineering**, v. 19, n. 8, p. 516, 2023.

ABREU-LEDÓN, R. et al. A meta-analytic study of the impact of Lean Production on business performance. **International Journal of Production Economics**, v. 200, p. 83–102, 2018.

ABU, F. et al. The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications. **Journal of Cleaner Production**, v. 234, p. 660–680, 2019.

AHMED, A.; OLSEN, J.; PAGE, J. Integration of Six Sigma and simulations in real production factory to improve performance – a case study analysis. **International Journal of Lean Six Sigma**, v. 14, n. 2, p. 451–482, 28 fev. 2023.

AHMED, S.; SOBUZ, M. H. R. Challenges of implementing lean construction in the construction industry in Bangladesh. **Smart and Sustainable Built Environment**, v. 9, n. 2, p. 174–207, 2020.

ALBLIWI, S. et al. Critical failure factors of lean Six Sigma: A systematic literature review. **International Journal of Quality and Reliability Management**, v. 31, n. 9, p. 1012–1030, 30 set. 2014.

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALDÁS, D. S. et al. **Manufacturing Strategies for an optimal pull-type production control system. Case study in a textile industry**. [s.l: s.n.].

ALMASHAQBEH, S.; HERNANDEZ, E. M. EVALUATION AND IMPROVEMENT OF A PLASTIC PRODUCTION SYSTEM USING

INTEGRATED OEE METHODOLOGY: A CASE STUDY. **Management Systems in Production Engineering**, v. 32, n. 3, p. 450–463, 1 ago. 2024.

ALMEIDA, M. R. Princípios Básicos Para Uma Proposta De Ensino Sobre. p. 37–50, 2006.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015a.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015b.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015c.

ALMEIDA MARODIN, G.; SAURIN, T. A. Managing barriers to lean production implementation: Context matters. **International Journal of Production Research**, v. 53, n. 13, p. 3947–3962, 2015d.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. Lean production as promoter of thinkers to achieve companies' agility. **Learning Organization**, v. 19, p. 219–237, 2012a.

ALVES, A. C.; DINIS-CARVALHO, J.; SOUSA, R. M. **Lean production as promoter of thinkers to achieve companies' agility**. **Learning Organization**, abr. 2012b.

ALZUBI, E. et al. Hybrid integrations of value stream mapping, theory of constraints and simulation: Application to wooden furniture industry. **Processes**, v. 7, n. 11, 2019.

ANDERSSON, C.; BELLGRAN, M. On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity. **Journal of Manufacturing Systems**, v. 35, p. 144–154, 2015.

ANFAVEA. **Anuário da indústria automobilística brasileira**. [s.l: s.n.].

ANFAVEA, A. N. DOS F. DE V. A. **Anuário Estatístico da Indústria Automobilística Brasileira**.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013a.

APARICIO, J. et al. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. **European Journal of Operational Research**, v. 231, n. 2, p. 443–451, 2013b.

APARICIO, J. et al. Measuring and decomposing firm's revenue and cost efficiency: The Russell measures revisited. **International Journal of Production Economics**, v. 165, p. 19–28, 1 jul. 2015.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017a.

APARICIO, J.; ORTIZ, L.; PASTOR, J. T. Measuring and decomposing profit inefficiency through the Slacks-Based Measure. **European Journal of Operational Research**, v. 260, n. 2, p. 650–654, 2017b.

AYOUBA, K. et al. A measure of price advantage and its decomposition into output- and input-specific effects. **European Journal of Operational Research**, v. 276, n. 2, p. 688–698, 16 jul. 2019.

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAI, Z. Q. et al. **An OEE Improvement Method Based on TOC2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)**. [s.l: s.n.].

BAKER, P. Why is lean so far off? v. 55, p. 26–29, 2002.

BANKES, S. **Exploratory Modeling for Policy AnalysisOperations Research**. [s.l: s.n.].

BANKES, S.; WALKER, W.; KWAKKEL, J. **Exploratory Modeling and Analysis**. [s.l: s.n.].

BAPTISTA, A.; ABREU, L.; BRITO, E. APPLICATION OF LEAN TOOLS CASE STUDY IN A TEXTILE COMPANY. **Proceedings on Engineering Sciences**, v. 3, n. 1, p. 93–102, 2021.

BARBERIO MARIANO, E. Conceitos Básicos de Análise de Eficiência produtiva. 2007.

BARBOSA, L. M. et al. Exploratory analysis of the variables prevailing on the effects of product modularization on production volume and efficiency. **International Journal of Production Economics**, v. 193, p. 677–690, 2017.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016a.

BARDIN, L. **Análise de Conteúdo**. **Analisis de balances. Interprete sus estados financieros sin saber de numeros**, 2016b.

BARRATT, M.; CHOI, T. Y.; LI, M. Qualitative case studies in operations management: Trends, research outcomes, and future research implications. **Journal of Operations Management**, v. 29, n. 4, p. 329–342, 2011.

BBC. **Entenda por que a produtividade no Brasil não cresce**. Disponível em: <https://www.bbc.com/portuguese/noticias/2014/05/140519_produtividade_porque_ru>. Acesso em: 29 abr. 2023.

BBC. **Ford: afinal, por que a montadora decidiu encerrar a produção de veículos no Brasil?** Disponível em: <https://www.bbc.com/portuguese/internacional-55640907>. Acesso em: 7 maio. 2023.

BERGENWALL, A. L.; CHEN, C.; WHITE, R. E. TPSs process design in American automotive plants and its effects on the triple bottom line and sustainability. **International Journal of Production Economics**, v. 140, n. 1, p. 374–384, nov. 2012.

BETTERTON, C. E.; COX, J. F. Espoused drum-buffer-rope flow control in serial lines: A comparative study of simulation models. **International Journal of Production Economics**, v. 117, n. 1, p. 66–79, 2009.

BHASIN, S. An appropriate change strategy for lean success. **Management Decision**, v. 50, n. 3, p. 439–458, 2012.

BHASIN, S. Impact of corporate culture on the adoption of the lean principles. **International Journal of Lean Six Sigma**, v. 4, n. 2, p. 118–140, 2013.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002a.

BLACKSTONE, J. H.; COX, J. F. Designing unbalanced lines - Understanding protective capacity and protective inventory. **Production Planning and Control**, v. 13, n. 4, p. 416–423, jun. 2002b.

BLANCHARD, D. Census of U.S. Manufactures: Lean Green and Low Cost. **Industry Week**, v. October, 2007.

BORTOLOTTI, T.; BOSCARI, S.; DANESE, P. Successful lean implementation: Organizational culture and soft lean practices. **International Journal of Production Economics**, v. 160, p. 182–201, 2015.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015a.

BUESTÁN BENAVIDES, M.; VAN LANDEGHEM, H. Implementation of S-DBR in four manufacturing SMEs: A research case study. **Production Planning and Control**, v. 26, n. 13, p. 1110–1127, 3 out. 2015b.

CAMANHO et al. A literature review of economic efficiency assessments using Data Envelopment Analysis. **European Journal of Operational Research**, 2023.

CAMANHO, A. S.; DYSON, R. G. Cost efficiency measurement with price uncertainty: A DEA application to bank branch assessments. **European Journal of Operational Research**, v. 161, n. 2, p. 432–446, 2005.

CARDOSO ERMEL, A. P. et al. **Literature Reviews**. Cham: Springer International Publishing, 2021.

CESARONI, G.; GIOVANNOLA, D. Average-cost efficiency and optimal scale sizes in non-parametric analysis. **European Journal of Operational Research**, v. 242, n. 1, p. 121–133, 1 abr. 2015.

CHAKRAVORTY, S. S.; ATWATER, J. B. The impact of free goods on the performance of drumbuffer-rope scheduling systems. **International Journal of Production Economics**, v. 95, n. 3, p. 347–357, 2005.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016a.

CHAKRAVORTY, S. S.; HALES, D. N. Improving labour relations performance using a Simplified Drum Buffer Rope (S-DBR) technique. **Production Planning and Control**, v. 27, n. 2, p. 102–113, 25 jan. 2016b.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018a.

CHANKOV, S.; HÜTT, M. T.; BENDUL, J. Influencing factors of synchronization in manufacturing systems. **International Journal of Production Research**, v. 56, n. 14, p. 4781–4801, 18 jul. 2018b.

CHARNES, A.; COOPER, W. W.; RHODES, E. Measuring the efficiency of decision making units. **European Journal of Operational Research**, v. 2, n. 6, p. 429–444, 1978.

CHIZARI, A. H.; FEHRESTI-SANI, M. Evaluation of the economic efficiency of vegetable oil supply chains. **Supply Chain Forum**, v. 19, n. 2, p. 132–141, 3 abr. 2018.

COOK, W. D.; TONE, K.; ZHU, J. Data envelopment analysis: Prior to choosing a model. **Omega (United Kingdom)**, v. 44, p. 1–4, 2014.

CORRALES, L. DEL C. N. et al. Overall equipment effectiveness: Systematic literature review and overview of different approaches. **Applied Sciences (Switzerland)**, v. 10, n. 18, 2020.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016a.

CORTABARRIA, L. A.; MARTINEZ, S. J.; MENDOZA, O. H. Diseño, Implementación y Análisis de una Metodología para Aplicar TOC aEmpresas Metalmecánicas con Restricciones Internas-Caso de Aplicación:Colombia. v. 37, n. 31, p. 30, 2016b.

COSTA, B.; VAREJÃO, J.; GASPAR, P. D. Development of a Value Stream Map to Optimize the Production Process in a Luxury Metal Piece Manufacturing Company. **Processes**, v. 12, n. 8, 1 ago. 2024.

COSTA, F. et al. How to foster Sustainable Continuous Improvement: A cause-effect relations map of Lean soft practices. **Operations Research Perspectives**, v. 6, n. December, p. 100091, 2019.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010a.

COX III, J. F.; SCHLEIER JR, J. G. **Theory of constraints handbook.** [s.l.] McGraw-Hill Education, 2010b.

COX III, J. F.; SCHLEIER JR, J. G. **Handbook da Teoria das Restrições.** Bookman ed. Porto Alegre: [s.n.].

COX, J. F. I. et al. The TOCICO dictionary. v. 2, p. 1–135, 2012.

COX, J.F. III; SCHLEIER, J.G., J. **Handbook Theory of Constraints**. [s.l.] Bookman, 2013.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021a.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, 2021b.

DA SILVA STEFANO, G. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015a.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 2015b.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015c.

DARLINGTON, J. et al. Design and implementation of a Drum-Buffer-Rope pull-system. **Production Planning and Control**, v. 26, n. 6, p. 489–504, 26 abr. 2015d.

DAS, S.; PATEL, G. N. Cost efficiency of pharmaceutical firms manufacturing drugs for specific diseases prevalent in India: A data envelopment analysis approach. **Journal of Medical Marketing**, v. 14, n. 1, p. 5–19, 1 fev. 2014.

DE NEGRI, F.; CAVALCANTE, L. R. **Produtividade No Brasil**. 2014.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018a.

DE SOUZA, I. G. et al. Do the improvement programs really matter? An analysis using data envelopment analysis. **BRQ Business Research Quarterly**, v. 21, n. 4, p. 225–237, 2018b.

DE TREVILLE, S. et al. Editorial: Toyota Production System practices as Fast-and-Frugal heuristics. **Journal of Operations Management**, v. 69, n. 4, p. 522–535, 2023.

DIAS, R. M. F.; SILVA, L. D.; TENERA, A. Application of a proposed TLS model in a Lean Productive System. **Independent Journal of Management & Production**, v. 10, n. 1, p. 076, 2019.

DOBRA, P.; JÓSVAI, J. Overall Equipment Effectiveness (OEE) Life Cycle at the Automotive Semi-Automatic Assembly Lines. **Acta Polytechnica Hungarica**, v. 19, n. 9, p. 141–155, 2022.

DOGAN, N.; KAYGISIZ, F.; ALTINEL, A. Technical and economic efficiency of laying hen farms in Konya, Turkey. **Revista Brasileira de Ciencia Avicola**, v. 20, n. 2, p. 263–272, 2018.

DORA, M.; KUMAR, M.; GELLYNCK, X. Determinants and barriers to lean implementation in food-processing SMEs - A multiple case analysis. **Production Planning and Control**, v. 27, n. 1, p. 1–23, 2 jan. 2016.

ELKHAIRI, A.; FEDOUAKI, F.; EL ALAMI, S. Barriers and critical success factors for implementing lean manufacturing in SMEs. **IFAC-PapersOnLine**, v. 52, n. 13, p. 565–570, 2019.

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ERMEL, A. P. C. **LITERATURE GROUNDED THEORY: MÉTODO DE PESQUISA PARA INVESTIGAÇÃO SOBRE O CONHECIMENTO CIENTÍFICO E TECNOLÓGICO**. [s.l: s.n.].

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011a.

ESWARAMOORTHI, M. et al. A survey on Lean practices in Indian machine tool industries. **International Journal of Advanced Manufacturing Technology**, v. Vol. 52, n. No. 9–12, p. 1091–1101, 2011b.

FGV. **BRASILEIRO LEVA 1 HORA PARA PRODUZIR O QUE AMERICANO FAZ EM 15 MINUTOS**. Disponível em: <https://eesp.fgv.br/noticia/brasileiro-leva-1-hora-para-produzir-o-que-americano-faz-em-15-minutos>. Acesso em: 29 abr. 2023.

FILIPE, D.; PIMENTEL, C. Production and Internal Logistics Flow Improvements through the Application of Total Flow Management. **Logistics**, v. 7, n. 2, 1 jun. 2023.

FOUND, P. et al. Towards a theory of operational excellence. **Total Quality Management and Business Excellence**, v. 29, n. 9–10, p. 1012–1024, 29 jul. 2018.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020a.

FRANKOWSKA, M.; CZERNIACHOWICZ, B. Introduction Barriers of Lean Implementation in the Polish Manufacturing Sector Introduction Barriers of Lean Implementation in Polish Manufacturing Sector. n. March, 2020b.

FURLAN, A.; VINELLI, A.; PONT, G. D. Complementarity and lean manufacturing bundles: An empirical analysis. **International Journal of Operations and Production Management**, v. 31, n. 8, p. 835–850, 2011.

GALEAZZO, A.; FURLAN, A. Lean bundles and configurations: a fsQCA approach. **International Journal of Operations and Production Management**, v. 38, n. 2, p. 513–533, 2018.

GAUSS, L. et al. Design science in operations management: A review and synthesis of the literature. **International Journal of Management Reviews**, 5 dez. 2024.

GLOBO. **Mapa: todas as fábricas de carros, motos e caminhões estão paradas no Brasil por pandemia**. Disponível em: <https://autoesporte.globo.com/carros/noticia/2020/03/mapa-todas-fabricas-de-carros-motos-e-caminhoes-estao-paradas-no-brasil-por-pandemia.ghtml>.

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E.; COX, J. **La Meta Un proceso de mejora continua**. Castillo ed. [s.l: s.n.].

GOLDRATT, E. M. Computerized shop floor scheduling. 1988a.

GOLDRATT, E. M. Computerized shop floor scheduling. 1988b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009a.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009b.

GOLDRATT, E. M. Standing on the shoulders of giants - Production concepts versus production applicationsthe Hitachi Tool Engineering example. **Gestao e Producao**, v. 16, n. 3, p. 333–343, 2009c.

GOLDRATT, E. M. & F. R. E. **The Race**. [s.l: s.n.].

GOLDRATT, E. M.; COX, J. **A Meta**. 3° ed. [s.l: s.n.].

GOLDRATT, E. M.; FOX, R. E. **The Race**. [s.l: s.n.].

GOLMOHAMMADI, D. A study of scheduling under the theory of constraints. **International Journal of Production Economics**, v. 165, p. 38–50, 2015.

GONZÁLEZ ALEU, F.; GARZA-REYES, J. A. **Leading continuous improvement projects: Lessons from successful, less successful, and unsuccessful continuous improvement case studies**. 2020.

GONZALEZ-R, P. L.; FRAMINAN, J. M.; RUIZ-USANO, R. A multi-objective comparison of dispatching rules in a drum-buffer-rope production control system. **International Journal of Computer Integrated Manufacturing**, v. 23, n. 2, p. 155–167, 2010.

GOSLING, J.; NAIM, M. M. Engineer-to-order supply chain management: A literature review and research agenda. **International journal of production economics**, v. 122(2), p. 741–754, 2009.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007a.

GUAN, Z. L. et al. OC/DBR based production planning and control in a manufacturing system with multiple system bottlenecks. **IEEE International Conference on Industrial Engineering and Engineering Management** , p. 1078–1082, 2007b.

GUILLEN, K. et al. LEAN model for optimizing plastic bag production in small and medium sized companies in the plastics sector. **International Journal of Engineering Research and Technology**, v. 11, n. 11, p. 1713–1734, 2018.

GUPTA, A.; BHARDWAJ, A.; KANDA, A. Fundamental concepts of theory of constraints: An emerging philosophy. **World Academy of Science, Engineering and Technology**, v. 46, n. 10, p. 686–692, 2010.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022a.

GUPTA, M. et al. Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. **Production Planning and Control**, v. 0, n. 0, p. 1–24, 2022b.

GUPTA, S.; MODGIL, S.; GUNASEKARAN, A. Big data in lean six sigma: a review and further research directions. **International Journal of Production Research**, v. 58, n. 3, p. 947–969, 2020.

HARDCOPF, R.; LIU, G. (JASON); SHAH, R. Lean production and operational performance: The influence of organizational culture. **International Journal of Production Economics**, v. 235, n. March 2020, p. 108060, 2021.

HATAMI-MARBINI, A.; ARABMALDAR, A. Robustness of Farrell cost efficiency measurement under data perturbations: Evidence from a US manufacturing application. **European Journal of Operational Research**, v. 295, n. 2, p. 604–620, 2021.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015a.

HILMOLA, O. P.; GUPTA, M. Throughput accounting and performance of a manufacturing company under stochastic demand and scrap rates. **Expert Systems with Applications**, v. 42, n. 22, p. 8423–8431, 1 dez. 2015b.

HO, T. Q.; HOANG, V. N.; WILSON, C. Trade-off analysis of cost and nutrient efficiency of coffee farms in vietnam: A more generalised approach. **Journal of Environmental Management**, v. 279, n. August, p. 111601, 2021.

HOPP, W. J. Positive lean: merging the science of efficiency with the psychology of work. **International Journal of Production Research**, v. 56, n. 1–2, p. 398–413, 2018.

HOPP, W. J.; SPEARMAN, M. L. To pull or not to pull: What is the question? **Manufacturing and Service Operations Management**, v. 6, n. 2, p. 133–148, 2004.

HOPP, W. J.; SPEARMAN, M. S. The lenses of lean: Visioning the science and practice of efficiency. **Journal of Operations Management**, v. 67, n. 5, p. 610–626, 2021.

HÜTTMEIR, A. et al. Trading off between heijunka and just-in-sequence. **International Journal of Production Economics**, v. 118, n. 2, p. 501–507, abr. 2009.

IKEZIRI, L. M. et al. Theory of constraints: review and bibliometric analysis. **International Journal of Production Research**, v. 57, n. 15–16, p. 1–35, 2018.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023a.

IKEZIRI, L. M. et al. Pulling the distribution in supply chains: simulation and analysis of Dynamic Buffer Management approach. **International Journal of Systems Science: Operations and Logistics**, v. 10, n. 1, 2023b.

INAN, G. G. ; et al. Operational performance improvement through continuous improvement initiatives in micro-enterprises of Turkey. **Asia-Pacific Journal of Business Administration,** v. 14, n. 3, p. 335–361, 2021.

IOANA, A. D.; MARIA, E. D.; CRISTINA, V. **Case study regarding the implementation of one-piece flow line in automotive company**. Procedia Manufacturing. **Anais**...Elsevier B.V., 2020.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014a.

JADHAV, J. R.; MANTHA, S. S.; RANE, S. B. Development of framework for sustainable Lean implementation: an ISM approach. **Journal of Industrial Engineering International**, v. 10, n. 3, 1 set. 2014b.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014a.

JAGDISH R. JADHAV; SHANKAR S. MANTHA; SANTOSH B. RANE. Exploring barriers in lean implementation. **International Journal of Lean Six Sigma**, v. 5, n. Unit 02, p. 122–148, 2014b.

JAIN, S.; TRIANTIS, K. P.; LIU, S. Manufacturing performance measurement and target setting: A data envelopment analysis approach. **European Journal of Operational Research**, v. 214, n. 3, p. 616–626, 2011.

JRADI, S.; BOUZDINE CHAMEEVA, T.; APARICIO, J. The measurement of revenue inefficiency over time: An additive perspective. **Omega (United Kingdom)**, v. 83, p. 167–180, 1 mar. 2019.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013a.

KENDALL, G. **Estratégia da teoria das restrições. In: COX III, James F. (Org.); SCHLEIER, John G. (Org.). Handbook da teoria das restrições**. 1 ed. ed. Porto Alegre - RS: Capítulo 18, p. 535-567, 2013b.

KERSTENS, K.; SADEGHI, J.; VAN DE WOESTYNE, I. Convex and nonconvex input-oriented technical and economic capacity measures: An empirical comparison. **European Journal of Operational Research**, v. 276, n. 2, p. 699–709, 2019.

KIM, J.; GERSHWIN, S. B. Integrated quality and quantity modeling of a production line. **Stochastic Modeling of Manufacturing Systems: Advances in Design, Performance Evaluation, and Control Issues**, p. 121–148, 2006.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010a.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, 2010b.

KIM, S.; COX, J. F.; MABIN, V. J. An exploratory study of protective inventory in a re-entrant line with protective capacity. **International Journal of Production Research**, v. 48, n. 14, p. 4153–4178, jan. 2010c.

KONOPKA, J. M. Capacity Utilization Bottleneck Efficiency System—CUBES. **IEEE Transactions on Components Packaging and Manufacturing Technology Part A**, v. 18, n. 3, p. 484–491, 1995.

KUMAR, R.; KUMAR, V. Barriers in implementation of lean manufacturing system in Indian industry: A survey. **International Journal of Latest Trends in Engineering & Technology**, v. 4, p. 243–251, 2014.

KWAKKEL, J. H.; PRUYT, E. Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. **Technological Forecasting and Social Change**, v. 80, n. 3, p. 419–431, 2013.

LACERDA, D. P. et al. Design Science Research: Método de pesquisa para a engenharia de produção. **Gestao e Producao**, v. 20, n. 4, p. 741–761, 26 nov. 2013.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021a.

LAND, M. J. et al. Inventory diagnosis for flow improvement—A design science approach. **Journal of Operations Management**, v. 67, n. 5, p. 560–587, 2021b.

LANZA, G. et al. Measuring global production effectiveness. **Procedia CIRP**, v. 7, p. 31–36, 2013.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024a.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024b.

LAROCA, A. et al. Optimization of an Air Conditioning Pipes Production Line for the Automotive Industry—A Case Study. **Systems**, v. 12, n. 2, 1 fev. 2024c.

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LAW, A. M. **Simulation modeling and analysis**. 5th ed. ed. [s.l: s.n.].

LEITE, H.; RADNOR, Z.; BATEMAN, N. Meaningful inhibitors of the lean journey: a systematic review and categorisation of over 20 years of literature. **Production Planning and Control**, v. 33, n. 5, p. 403–426, 2022.

LIKER, J.; ROTHER, M. Why Lean Programs Fail. **Lean Enterprise Institute**, p. 1–5, 2011.

LIM, A. S. S.; SABIL, S.; OTHMAN, A. E. B. A. the Mediating Role of Continuous Improvement on the Relationship Between Workplace Learning Dimensions and Sustainable Lean Manufacturing. **International Journal of Business and Society**, v. 23, n. 1, p. 260–278, 2022.

LIU, J. et al. A DEA-based approach for competitive environment analysis in global operations strategies. **International Journal of Production Economics**, v. 203, p. 110–123, 2018.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019a.

LIZARRALDE, A.; APAOLAZA, U.; MEDIAVILLA, M. Enfoque estratégico para la identificación de cuellos de botella en entornos de fabri-cación contra pedido y plantas tipo V: estudio de caso de DBR. **Dirección y Organización** , v. 67, p. 46–51, 2019b.

LUZ, G. P. et al. Proposition of a method for stochastic analysis of value streams. **Production Planning and Control**, v. 33, n. 8, p. 741–757, 2022.

MABIN, V. J.; BALDERSTONE, S. J. The performance of the theory of constraints methodology: Analysis and discussion of successful TOC applications. **International Journal of Operations and Production Management**, v. 23, n. 5–6, p. 568–595, 2003.

MAHJOOR, A. A. Technical, allocative and economic efficiencies of broiler farms in Fars Province, Iran: A Data Envelopment Analysis (DEA) approach. **World Applied Sciences Journal**, v. 21, n. 10, p. 1427–1435, 2013.

MANAVIZADEH, N. et al. A Simulated Annealing algorithm for a mixed model assembly U-line balancing type-I problem considering human efficiency and Just-In-Time approach. **Computers and Industrial Engineering**, v. 64, p. 669–685, 2013.

MARFATIA, H. et al. S earch and s urvey. n. February 2021, p. 10–17, 2020.

MARODIN, G. A. et al. Model of risk interactions hindering lean production implementation. **Gestao e Producao**, v. 25, n. 4, p. 696–712, 2018.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019a.

MARODIN, G. A. et al. Lean production and operational performance in the Brazilian automotive supply chain. **Total Quality Management and Business Excellence**, v. 30, n. 3–4, p. 370–385, 2019b.

MARTINS, J. C. et al. Systems dynamic modeling to analyze the systemic viability of the combined use of regenerative converters and energy storage in a UPS manufacturer. **Journal of Cleaner Production**, v. 246, n. xxxx, p. 118950, 2020.

MEMARI, A. et al. The impact of lean production on operational performance: a case study. **Asia-Pacific Journal of Business Administration**, 2022.

MILLSTEIN, M. A.; MARTINICH, J. S. Takt Time Grouping: Implementing kanban-flow manufacturing in an unbalanced, high variation cycle-time process with moving constraints. **International Journal of Production Research**, v. 52, n. 23, p. 6863–6877, 2014.

MOHANAVELU, T.; KRISHNASWAMY, R.; MARIMUTHU, P. Simulation modelling and development of analytic hierarchy process-based priority dispatching rule for a dynamic press shop. **nternational Journal of Industrial and Systems Engineering**, v. 27(3), p. 340–364, 2017.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023a.

MOHD ARIPIN, N. et al. Systematic Literature Review: Theory Perspective in Lean Manufacturing Performance. **Management Systems in Production Engineering**, v. 31, n. 2, p. 230–241, 2023b.

MOHD AZHAR SAHWAN; MOHD NIZAM AB RAHMAN; BABA MD DEROS. Barriers to Implement Lean Manufacturing in Malaysian Automotive Industry. **Jurnal Teknologi (Sciences and Engineering)**, v. 59, p. 107–110, 2012.

MORANDI, M. I. W. M. et al. Foreseeing Iron Ore Prices Using System Thinking and Scenario Planning. **Systemic Practice and Action Research**, v. 27, n. 3, p. 287–306, 2014.

MORANDI, M. I. W. M.; CAMARGO, L. F. R. **Revisão sistemática da literatura. Design science research: Método de pesquisa para avanço da ciência e tecnologia**. [s.l.] Bookman, 2015.

MUCHIRI, P.; PINTELON, L. Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. **International Journal of Production Research**, v. 46, n. 13, p. 3517–3535, 2008.

MUTHIAH, K. M. N.; HUANG, S. H. Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection. **International Journal of Production Research**, v. 45, n. 20, p. 4753–4769, 2007.

NACIRI, L. et al. **Lean and industry 4.0: A leading harmony**. Procedia Computer Science. **Anais**...Elsevier B.V., 2022.

NANCI, L. C.; AZEREDO, S. M.; MELLO, J. C. C. B. S. DE. Estudo da eficiência de empresas distribuidoras de jornais usando análise envoltória de dados. **Produto & Produção**, v. 7, n. 3, p. 27–35, 2006.

NARASIMHAN, R.; SWINK, M.; KIM, S. W. Disentangling leanness and agility: An empirical investigation. **Journal of Operations Management**, v. 24, n. 5, p. 440–457, 2006.

NARASSIMA, M. S. et al. Implementation of lean principles in the yarn manufacturing industry: a system dynamics approach. **Benchmarking**, 2023.

NEELY, A.; GREGORY, M.; PLATTS, K. A literature review and research agenda. **International Journal of Operations & Production Management**, v. 15, n. 4, p. 80–116, 2002.

NETLAND, T. H.; SCHLOETZER, J. D.; FERDOWS, K. Learning lean: rhythm of production and the pace of lean implementation. **International Journal of Operations and Production Management**, v. 41, n. 2, p. 131–156, 2021.

NG CORRALES, L. D. C. et al. Developing and Implementing a Lean Performance Indicator: Overall Process Effectiveness to Measure the Effectiveness in an Operation Process. **Machines**, v. 10, n. 2, 1 fev. 2022.

OECHSNER, R. et al. From overall equipment efficiency (OEE) to overall Fab effectiveness (OFE). **Materials Science in Semiconductor Processing**, v. 5, n. 4- 5 SPEC., p. 333–339, 2002.

OH, I. et al. Analysis of product efficiency in the Korean automobile market from a consumer's perspective. **Empirical Economics**, v. 38, n. 1, p. 119–137, fev. 2010.

OHNO, T. Toyota Production System: beyond large-scale production. **Oregon: Productivity Press**, 1988.

OHNO, T. **O Sistema Toyota de Produção Além da Produção em Larga Escala**. [s.l.] Bookman, 1997.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021a.

ORUE, A. et al. Theory of constraints case study in the make-to-order environment. **Journal of Industrial Engineering and Management**, v. 14, n. 1, p. 72–85, 2021b.

PACHECOA, D. A. DE J. Theory of Constraints, Lean Manufacturing and Six Sigma: Limits to and possibilities for integration. **Producao**, v. 24, n. 4, p. 940–956, 2014.

PARK, J.; LEE, D.; ZHU, J. An integrated approach for ship block manufacturing process performance evaluation: Case from a Korean shipbuilding company. **International Journal of Production Economics**, v. 156, p. 214–222, 2014.

PEARCE, A.; PONS, D.; NEITZERT, T. Implementing lean—Outcomes from SME case studies. **Operations Research Perspectives**, v. 5, p. 94–104, 2018.

PEREIRA, L.; TORTORELLA, G. Identification of the relationships between critical success factors, barriers and practices for lean implementation in a small company. **Brazilian Journal of Operations & Production Management**, v. 15, n. 2, p. 232–246, 1 jun. 2018.

PERVAZ, J. et al. SIMULATION-BASED ALGORITHM FOR CONTINUOUS IMPROVEMENT OF ENTERPRISES PERFORMANCE. **International Journal of Simulation Modelling**, v. 23, n. 2, p. 215–226, 1 jun. 2024.

PIRAN, F. A. S. et al. Product modularization and effects on efficiency: An analysis of a bus manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 182, p. 1–13, 2016.

PIRAN, F. A. S. et al. Overall Equipment Effectiveness: Required but not Enough—An Analysis Integrating Overall Equipment Effect and Data

Envelopment Analysis. **Global Journal of Flexible Systems Management**, v. 21, n. 2, p. 191–206, 1 jun. 2020.

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. A. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e gestão da eficiência: Aplicação em sistemas produtivos de bens e serviços**. 1° ed. [s.l: s.n.].

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, 2021a.

PIRAN, F. S. et al. Internal benchmarking to assess the cost efficiency of a broiler production system combining data envelopment analysis and throughput accounting. **International Journal of Production Economics**, v. 238, n. April, p. 108173, 2021b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. **Análise e Gestão da Eficiência**. [s.l.] Elsevier, 2018b.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020a.

PIRAN, F. S.; LACERDA, D. P.; CAMARGO, L. F. R. Analysis and Management of Productivity and Efficiency in Production Systems for Goods and

Services. **Analysis and Management of Productivity and Efficiency in Production Systems for Goods and Services**, n. December 2019, p. 10–11, 2020b.

PONT, G. D.; FURLAN, A.; VINELLI, A. Interrelationships among lean bundles and their effects on operational performance. **Operations Management Research**, v. 1, n. 2, p. 150–158, 2009.

PORTELA, M. C. A. S.; THANASSOULIS, E. Economic efficiency when prices are not fixed: Disentangling quantity and price efficiency. **Omega (United Kingdom)**, v. 47, p. 36–44, 2014.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019a.

PRASETYANINGSIH, E.; DEFERINANDA, C. A.; AMARANTI, R. **Bottleneck Reduction at the Shoes Production Line using Theory of Constraints Approach**. ICSECC 2019 - International Conference on Sustainable Engineering and Creative Computing: New Idea, New Innovation, Proceedings. **Anais**...Institute of Electrical and Electronics Engineers Inc., 1 ago. 2019b.

PSAROMMATIS, F.; AZAMFIREI, V. **Zero Defect Manufacturing: A complete guide for advanced and sustainable quality management**. **Journal of Manufacturing Systems**Elsevier B.V., , 1 dez. 2024.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 2019a.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019b.

PUCHE, J. et al. The effect of supply chain noise on the financial performance of Kanban and Drum-Buffer-Rope: An agent-based perspective. **Expert Systems with Applications**, v. 120, p. 87–102, 15 abr. 2019c.

QAMAR, A. et al. Quality and flexibility performance trade-offs between lean and agile manufacturing firms in the automotive industry. **Production Planning and Control**, v. 31, n. 9, p. 723–738, 2020.

QURESHI, K. M. et al. Exploring the Lean Implementation Barriers in Small and Medium-Sized Enterprises Using Interpretive Structure Modeling and Interpretive Ranking Process. **Applied System Innovation**, v. 5, n. 4, p. 1–20, 2022.

RAMADAS, T.; SATISH, K. P. Identification and modeling of process barriers: Implementing lean manufacturing in small-and medium-size enterprises. **International Journal of Lean Six Sigma**, v. 12, n. 1, p. 61–77, 2021.

RAOUF, A. Improving capital productivity through maintenance. . **International Journal of Operations & Production Management**, v. 14 (7), p. 44–52, 1994.

REPONEN, E. et al. Benchmarking outcomes on multiple contextual levels in lean healthcare: a systematic review, development of a conceptual framework, and a research agenda. **BMC Health Services Research**, v. 21, n. 1, 1 dez. 2021.

ROCHMAN, Y. A.; SUDIARSO, A.; HERLIANSYAH, M. K. Development of Lean Implementation Framework for Indonesian Batik Small and Medium-Sized Enterprises. **International Journal of Engineering, Transactions B: Applications**, v. 37, n. 11, p. 2223–2238, 1 nov. 2024.

ROJON, C.; OKUPE, A.; MCDOWALL, A. Utilization and development of systematic reviews in management research: What do we know and where do we go from here? **International Journal of Management Reviews**, v. 23, n. 2, p. 191–223, 1 abr. 2021.

ROMERO, L. F. et al. A data envelope analysis to assess factors affecting technical and economic efficiency of individual broiler breeder hens. **Poultry Science**, v. 89, n. 8, p. 1769–1777, 2010.

SARTAL, A.; VAZQUEZ, X. H.; LOZANO-LOZANO, L. M. Organizational Tools and Cultural Change in the Success of Lean Transformations: Delving Into Sequence and Rhythm. **IEEE Transactions on Engineering Management**, v. 69, n. 5, p. 2205–2217, 1 out. 2022.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023a.

SCHULZE, F.; DALLASEGA, P. Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. **Production Planning and Control**, v. 34, n. 1, p. 91–115, 2023b.

SCOTT, D.; PISA, R. Can overall factory effectiveness prolong Mooer’s law? **Solid State Technology**, p. 75–81, 1998.

SECCHI, R.; CAMUFFO, A. Lean implementation failures: The role of organizational ambidexterity. **International Journal of Production Economics**, v. 210, p. 145–154, 1 abr. 2019.

SILVA, F.; MENEZES-FILHO, N.; KOMATSU, B. Evolução da produtividade no Brasil: comparações internacionais. **Insper Policy Paper**, n. 15, p. 30, 2016.

SOHRMANN, C. et al. Towards a Standardized Format for Automotive Mission Profiles State of the Art Use Cases for Mission Profiles Application of MPs in Verification and. **Proc. Automotive meets Electronics 10**, n. March, p. 39–44, 2021.

SPEAR, S.; BOWEN, H. K. Decoding the DNA of the Toyota Production System. **Harvard Business Review**, v. 77, n. 5, p. 96–106, 1999.

STAUDACHER, A. P.; TANTARDINI, M. **Lean production implementation: a survey in Italy**. XI Congreso de Ingeniería de Organizacion International Conference on Industrial Engineering and Industrial Management,. **Anais**...Madri: 2007.

STEELE, D. C. et al. Comparisons between drum-buffer-rope and material requirements planning: A case study. **International Journal of Production Research**, v. 43, n. 15, p. 3181–3208, 2005.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022a.

STEFANO, G. DA S. et al. The impacts of inventory in transfer pricing and net income: Differences between traditional accounting and throughput accounting. **British Accounting Review**, v. 54, n. 2, p. 101001, 2022b.

STRATTON, R.; WARBURTON, R. D. H. The strategic integration of agile and lean supply. **International Journal of Production Economics**, v. 85, n. 2, p. 183–198, 2003.

SUGIARTO, H. et al. SEIKO : Journal of Management & Business Exploration Financial Performance Optimization Strategies on Business Success: A Literature Review. **SEIKO : Journal of Management & Business**, v. 6, n. 2, p. 402–411, 2023.

SUKWADI, R.; FELICIA, Y.; MUAFI. TOC, lean, and six sigma: An integrated model to increase the productivity of the textile industry. **Journal of Mechanical Engineering Research and Developments**, v. 44, n. 1, p. 327–336, 2021.

SUSAETA, A. et al. Technical, allocative, and total profit efficiency of loblolly pine forests under changing climatic conditions. **Forest Policy and Economics**, v. 72, p. 106–114, 1 nov. 2016.

SWEETSER, A. **A Comparison of System Dynamics (SD) and Discrete Event Simulation (DES)**. [s.l: s.n.].

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000a.

TAYLOR III, L. J. A Simulation Study of Work-in-Process In- ventory Drive Systems and Their Effect on Operatio- nal Measures. **British Journal of Management**, p. 47–59, 2000b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, n. February, p. 107500, 2020a.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020b.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020c.

TELLES, E. S. et al. Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). **International Journal of Production Economics**, v. 222, 1 abr. 2020d.

TELLES, E. S. et al. Drum-Buffer-Rope in an engineering-to-order productive system: a case study in a Brazilian aerospace company. **Journal of Manufacturing Technology Management**, v. 33, n. 6, p. 1190–1209, 6 set. 2022.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020a.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020b.

THÜRER, M.; FERNANDES, N. O.; STEVENSON, M. Production planning and control in multi-stage assembly systems: an assessment of Kanban, MRP, OPT (DBR) and DDMRP by simulation. **International Journal of Production Research**, 2020c.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018a.

THÜRER, M.; STEVENSON, M. Bottleneck-oriented order release with shifting bottlenecks: An assessment by simulation. **International Journal of Production Economics**, v. 197, p. 275–282, 1 mar. 2018b.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018c.

THÜRER, M.; STEVENSON, M. On the beat of the drum: improving the flow shop performance of the Drum–Buffer–Rope scheduling mechanism. **International Journal of Production Research**, v. 56, n. 9, p. 3294–3305, 3 maio 2018d.

THÜRER, M.; TOMAŠEVIĆ, I.; STEVENSON, M. **On the meaning of 'Waste': review and definition**. **Production Planning and Control**Taylor and Francis Ltd., , 17 fev. 2017.

TOMA, S.; NARUO, S. Total Quality Management and Business Excellence: the Best Practices At Toyota Motor Corporation. 2017.

TORTORELLA, G. L. et al. The impact of contextual variables on learning organization in firms that are implementing lean: a study in Southern Brazil. **International Journal of Advanced Manufacturing Technology**, v. 78, n. 9–12, p. 1879–1892, 18 jun. 2015.

TORTORELLA, G. L. et al. Learning organisation and lean production: an empirical research on their relationship. **International Journal of Production Research**, v. 58, n. 12, p. 3650–3666, 2020.

TSUKADA, O. et al. Is lean manufacturing maturity a prerequisite for industry 4.0? Survey of SMEs in Japan and Brazil. **International Journal of Lean Six Sigma**, v. 15, n. 5, p. 1102–1126, 27 ago. 2024.

VEGA-ALVITES, J. C. Q.-F. & M. L. Review Lean Manufacturing Model of Production Management Under the Preventive. **South African Journal of Industrial Engineering**, v. 33, n. 2, p. 143–156, 2022.

VENKATESH, A.; KUSHWAHA, S. Short and long-run cost efficiency in Indian public bus companies using Data Envelopment Analysis. **Socio-Economic Planning Sciences**, v. 61, p. 29–36, 1 mar. 2018.

VON GILSA, C. et al. Longitudinal evaluation of efficiency in a petrochemical company. **Benchmarking**, v. 24, n. 7, p. 1786–1813, 2017.

WAHAB, A. et al. Improvement on bill of materials formatting process by adopting lean and six sigma approaches-A case study in a semiconductor industry ilhammee. **International Journal of Integrated Engineering**, v. 11, n. 8, p. 81–90, 2019.

WAHLERS, J. L.; COX, J. F. Competitive factors and performance measurement: Applying the theory of constraints to meet customer needs. **International Journal of Production Economics**, v. 37, n. 2–3, p. 229–240, 1994.

WALLACE J. HOPP, M. L. S. **Factory Physics**. Third Edit ed. [s.l: s.n.].

WATSON, K. J.; BLACKSTONE, J. H.; GARDINER, S. C. The evolution of a management philosophy: The theory of constraints. **Journal of Operations Management**, v. 25, n. 2, p. 387–402, 2007.

WATSON, K. J.; PATTI, A. A comparison of JIT and TOC buffering philosophies on system performance with unplanned machine downtime. **International Journal of Production Research**, v. 46, n. 7, p. 1869–1885, 2008.

WEBSTER, J.; WATSON, R. MIS Quarterly. **Analyzing the Past To Prepare for the Future : Writing a Literature Review**, v. 26, n. 2, p. 13–23, 2002.

WONG, Y. C.; WONG, K. Y.; ALI, A. A study on Lean Manufacturingimplementation in the Malaysian electrical and electronics industry. **European Journal of Scientific Research**, v. Vol. 38, 2009.

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WOO, K.; PARK, S.; FUJIMURA, S. **Real-time buffer management method for DBR scheduling Real-time buffer management method for DBR scheduling 43Int. J. Manufacturing Technology and Management**. [s.l: s.n.].

WU, H. H.; LIU, J. Y. A capacity available-to-promise model for drum-buffer-rope systems. **International Journal of Production Research**, v. 46, n. 8, p. 2255–2274, 2008.

WU, S.; WEE, H. M. Why the big three decline despite their lean management - A study based on the theory of constraints. **Global Perspective for Competitive Enterprise, Economy and Ecology - Proceedings of the 16th ISPE International Conference on Concurrent Engineering**, p. 691–699, 2009.

YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008a.

YE, T.; HAN, W. Determination of buffer sizes for drum-buffer-rope (DBR)-controlled production systems. **International Journal of Production Research**, v. 46, n. 10, p. 2827–2844, maio 2008b.

YENRADEE, P. Application of optimized production technology ina capacity constrained flow shop: a case study in a battery factory. **Comput. Ind. Eng.**, v. 27, p. 217–220, 1994.

ZHANG, L.; NARKHEDE, B. E.; CHAPLE, A. P. Evaluating lean manufacturing barriers: An interpretive process. **Journal of Manufacturing Technology Management**, v. 28, n. 8, p. 1086–1114, 2017.