



The Implications of Digitalization in Improving Manufacturing Operational Performances : An Operational Excellence Approach

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Abstract: The rapid rise of Industry 4.0 has positioned digital technologies as essential tools for enhancing manufacturing performance. However, empirical evidence indicates that these technologies often fail to produce sustainable improvements. This thesis explores the paradox of Digitalization in manufacturing, arguing that digital tools alone are insufficient to deliver lasting performance gains. Through a historical and conceptual analysis, the study demonstrates that technological revolutions have historically fallen short when not accompanied by human development, organizational learning, and managerial alignment. Drawing on the principles of the Toyota Production System, Lean thinking, and the Shingo Model of Operational Excellence, the thesis positions Digitalization as a supporting element within a broader system of Continuous Improvement. This article also suggests that successful Digital Transformation is more likely when organizations pursue purpose driven and incremental adaptation rather than disruptive, tool-centered strategies. Ultimately, the study advocates for a principle-based approach in which Digitalization is integrated into human-centered systems that prioritize learning, alignment, and sustained excellence.

Key-Words: Digitalization, Digital Technologies, Digital Transformation, Industry 4.0, Industrial Revolutions, Manufacturing Performance, Operational Performance, Continuous Improvement, Operational Excellence, Lean, Shingo Model

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1. Introduction

Digitalization stands at the heart of the current industrial discourse. Across all sectors, manufacturing notably, the promise of Industry 4.0 (I4.0) is widely seen as a key to boost productivity, agility and competitiveness. As described by Kumar et al.[1], Digital Transformation (DT) is a favorable transition for industrials, reshaping how companies operate, innovate, and engage with stakeholders. Technologies such as Internet of Things (IoT), Artificial Intelligence (AI), Edge Computing, and Digital Twins are presented as gateways to a new industrial paradigm.

This transformation is not just technological but also strategic. As described by Nath et al. [2], industrial digitalisation is expected to deliver wide-ranging benefits: increased productivity, reduced waste, shorter time-to-market, improved traceability, and enhanced responsiveness to customer needs. Popkova et al. [3] likewise argue that Industry 4.0 signals a fundamental break with prior modes of industrialization, driven by the convergence of Cyber-Physical Systems (CPS), Machine Learning (ML), and real-time data.

In principle, DT offers an unmatched opportunity to modernize operations and unlock new forms of value. Yet, despite its promise, the outcomes of digitalization remain highly uneven. While some manufacturing sites report dramatic performance gains[4], others face low adoption rates, limited integration, or even operational disruption, McKinsey & Company reports that up to 70% of DTs initiatives fail to meet their original objectives[5]. In the mid-2010s high-profile initiatives, including those at GE and Ford, undertook massive DT's initiative and failed to meet expectations, resulting in abandoned programs, executive turnover, and multi-billion-dollar losses[2]. These patterns reveal a puzzling contradiction: despite heavy investment and technological advancement, digital transformation efforts often fall short of delivering the intended performance outcomes. Several studies have begun to document this gap, offering insights of the obstacles organizations face. For instance, a 2019 Celonis survey found 45% of executives were uncertain about how to initiate a digital transformation strategy underscoring that an ambiguity is persisting in regards to these technological breakthroughs even at the highest levels of leadership. In a related study, a 2018 Jabil report revealed that 74% of respondents viewed organizational and behavioral challenges as more significant than technological barriers[2].

These inconsistencies and findings raise a critical question: under what conditions does Digitalisation actually lead to improved operational performance in a manufacturing context ?

This thesis argues that Digitalisation delivers meaningful and sustainable performance improvements only when it is purposefully integrated, either to address specific human or organizational limitations, or as part of a structured, continuous problem-solving ap-

proach. In contrast, digital initiatives driven by trend-following, vague innovation agendas or tool-first logic often struggle to achieve long-term impact, lacking strategic alignment and measurable value.

The rest of this article is structured as follows. Section 2, Conceptual Foundations, establishes the key concepts that assist the study. Section 3, Argumentative Framework, develops the core arguments of the thesis through literature-based reasoning. Section 4, Synthesis and Analysis summing up on the previous section, returns to the central point of the thesis. Finally, the Conclusion summarizes the main findings and reflects on their implications.

2. Conceptual Foundations

2.1. The Evolution of Industrial Revolutions: A Foundational Overview

To understand the performance challenges that persist today, it helps to revisit the Industrial Revolutions (IRs), not just for their technological breakthroughs, but also for how they changed the role of people and organizations. Before these shifts, production was mostly artisanal and local, with skills passed down through generations and work rooted in family and guild structures[6]. This context highlights just how dramatic the changes brought by industrialization were.

2.1.1 Industry 1.0: Mechanization and the Factory System

The First Industrial Revolution or Industry 1.0 (I1.0) spanned from the 18th century to the late 19th/early 20th century [7]. It was defined by mechanization through water and steam power, as well as the shift from wood to coal [8]. James Watt's steam engine (1788) marked a turning point [9], alongside inventions like the spinning Jenny, power loom, steam locomotives and ships, and early internal combustion engines, all revolutionary for manufacturing [9][10]. While the technological challenges were simple, their impact was profound: mass production emerged, and human productivity increased by 10 to 20 times [9][11]. "Factories" emerged, centralizing production and bringing artisans under one roof [8]. Monitoring became essential as team-based production expanded, giving rise to the factory system with a clear split between managers and workers[8]. The human element was treated as an extension of machines leading to resistance due to the loss of autonomy [12]. Technical training existed but lacked cognitive depth, and the working conditions remained harsh under ineffective disciplinary tools[8]. Rapid technological changes destabilized wage systems, while disputes over speed-up, quality, and deductions often disrupted production[8]. More fundamentally, managerial logic was coercive and exploita-

tive, focused on short input/output gains rather than human development[13]. Technology had outpaced the workforce’s behavioral readiness, making performance issues as much social and managerial as technical.

2.1.2 Industry 2.0: Electrification, Taylorism, and the Bureaucratic Firm

Industry 2.0 (I2.0) spanned from the late 19th to early 20th century. The induction motor introduced by Nikola Tesla replaced steam in industrial settings[14]. Key inventions like the Bessemer process, internal combustion engines, the telephone, and early lighting and recording technologies helped overcome limits in production speed and efficiency [13]. This period also tackled cost-efficiency and the limits of craftsman-based production. Modern accounting emerged, and scientific management took form. Taylor’s time studies (1898), Shop Management (1903), and contributions from Gilbreth, Gantt, and Emerson drove work standardization. Ford’s assembly line (1913) at Highland Park marked the transition to scalable, low-cost mass production [14]. Organizationally, firms responded to scaling issues through vertical integration and later multi-divisional structures to manage growing complexity[13][14]. However, efficiency was prioritized over human development; Henry Ford famously laid off 25% of low-skilled workers after implementing conveyor belts[11], reflecting a bureaucratic model that optimized rather than empowered people [6]. As firms grew vertically, they became siloed, data management became difficult, and the worker-manager gap only widened. Performance evaluation remained financially driven and naturally inadequate [13].

2.1.3 Industry 3.0: Automation, Information Systems, and Disconnected Workforce

The Third Industrial Revolution or Industry 3.0 (I3.0) brought dramatic change through automation and electronics, driven by computer technologies, nuclear energy, renewables, large-scale storage, and additive manufacturing [13][15][16]. Key milestones included ENIAC (1946), Wiener’s cybernetics (1947), and Intel’s microprocessor (1971), which ushered in information-based manufacturing. These technologies enabled precise control over processes, real-time data collection, and the first steps towards networked production[14]. Industry 3.0 relieved humans as a labor entity[15], but it also demanded greater technical skills and professional training[6][3]. For instance, the first university course in industrial engineering was introduced at Penn State in 1908, and foundational texts like Work Design by Gerald Nadler (1963) emerged[14]. Crucially, I3.0 introduced new forms of flexibility and better coordination by the apparition of Information Systems (IS) [11], softwares’ like ERPs (Enterprise Ressource Planning) and MRPs (Manufacturing Requirement Planning) enabled real-time planning [14] along with horizontal integration in management [15]. Important movement rose as well. One major system

was the Toyota Production System (TPS), finalized by Taiichi Ohno in the early 1970s, which placed people at the core of operations. Shigeo Shingo’s contributions like the Single-minute exchange of die (SMED) and Zero Quality Control also represented a fundamental rethinking of performances, deeply rooted in people, philosophy and vision rather than just machines. By the 1990s, Total Quality Management (TQM) became widespread [14] which demonstrate the growing interest in problem-solving and human-centric practices.

2.1.4 Industry 4.0 and Beyond: Cyber-Physical Systems and Misalignment

The Fourth Industrial Revolution or Industry 4.0 (I4.0) emerged just 40 years after Industry 3.0, building on its digital foundation [9]. First introduced at the 2011 Hannover Fair as part of Germany’s High-Tech Strategy [3], Industry 4.0 centers on the development of smart factories, environments defined by decentralized intelligence, real-time data exchange, and interconnected cyber-physical systems (CPS). Kumar et al. [1] identified nine foundational technologies or “Nine Peers of I4.0” that structure this transformation, as shown in Figure 1 .

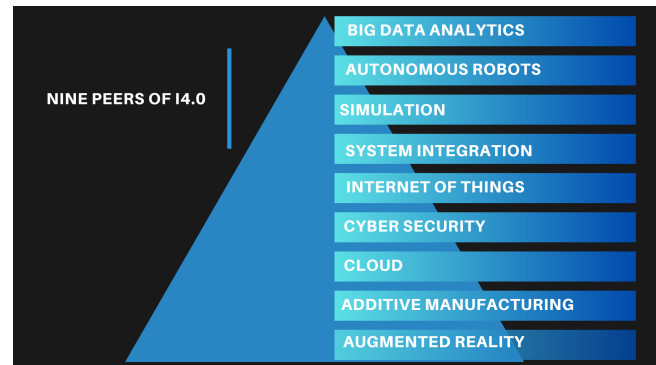


Figure 1: The nine foundational technologies of I4.0 as per Kumar et al. [1]

Unlike its predecessor, I4.0 integrates digital technologies across all layers of production; from design and manufacturing to logistics and customer interaction. According to Kumar et al. [1], Industry 4.0 transforms manufacturing into an intelligent, adaptive system through the Nine Peers of I4.0. In this context, the manufacturing process is no longer merely automated but “augmented,” allowing for self-optimization, predictive maintenance, and real-time reconfiguration of systems. The Smart Factory replaces traditional linear production models with systems where machines, products, and humans constantly communicate. Despite its promising opportunities, Industry 4.0 is not without challenges. The complexity of integration, limited workforce skills, and the lack of managerial roadmaps hinder effective implementation [1]. Social concerns have also emerged, as its implementation may negatively impact human capital and social cohesion [17]. Cultural, structural, and strategic misalignment that many organizations are not fully prepared to make,

are further obstructing successful adoption [5]. This critical reflection has paved the way for the Fifth Industrial Revolution or Industry 5.0 (I5.0), a new paradigm that goes beyond autonomy to reintegrate the human at the center of industrial systems. As Kumar et al. [1] describe, Industry 5.0 envisions a super-smart, human-centered society in which technologies such as AI, robotics, and the Internet of Things are designed to leverage rather than replace human decision-making and well-being.

We can clearly view Industry 5.0 as both a critique and a continuation of Industry 4.0, a shift from efficiency-driven transformation toward purpose-driven innovation. Yet, some authors, including [18], remain skeptical. They argue that neither Industry 4.0 nor the transition to Industry 5.0 has fully delivered on its promises. Rather than introducing successive “revolutions,” they advocate for a synthesis of existing frameworks, emphasizing the need for mature, adaptable, and human-centered organizational systems over purely technological change.

2.2. Digitalization in the context of Industry 4.0

This subsection aims to clarify the terminology surrounding digitalization and Industry 4.0, which are often used interchangeably or understood too narrowly. The objective is to establish a broader understanding of digitalization, not as a specific technology, but as a transformative enabler that reshapes infrastructure, systems, methods, and processes across the organization.

While closely associated, the three main concepts : digitization, digitalization, and digital transformation represent distinct layers of the I4.0 shift. Frenzel et al. [19] clarify these distinctions: digitization is the technical process of converting analog information into digital form; digitalization refers to the socio-technical integration of digital technologies into broader business contexts; and digital transformation incorporate the strategic redesign of organizational models through digital tools. Vrana et al. [20], further clarify these distinctions within the framework of Industry 4.0, they emphasize that Digitalization is built upon Digitization, transforming all the raw digital information into actionable and meaningful values which are then meant to improve specific business processes, such as processes related to manufacturing.

Industry 4.0 is a continuation of the Digital Revolution that has been taking place since I3.0 [7]. Kumar et al. [1] further highlight that Industry 4.0 cannot be dissociated from digitalization..They provide an extensive classification of enabling technologies such as Big Data analytics, cyber-physical systems, 3D printing, autonomous robots, and the Industrial Internet of Things (IIoT) that make up the infrastructure of smart manufacturing and it is important to say that

these technologies are enablers of further capacities and specific solutions. Alqoud et al. [21] also note, these technologies serve not only as stand alone tools for performance enhancement but also as enablers of systemic transformation, provided they are integrated into a framework of organizational learning, process adaptability, and customer-centric value creation.

On the other hand, while often interchangeable with digitalization, Digital Transformation is a broader concept. Unlike digitalization, which focuses on improving specific processes [11], the same authors distinguish Digital Transformation as a strategic endeavor, which differs from the process-driven nature of digitalization. It implies a deep rethinking of value chains, business models, and customer experience.

As such, the full potential of Industry 4.0 is only realized when digital technologies and digitalization solutions are embedded into specific tailored solutions and integrated into a holistic transformation agenda rather than pursued through fragmented technology deployment.

2.3. Toyota Production System, Lean Philosophy and Operational Excellence

This subsection aims to trace the conceptual and practical lineage from the Toyota Production System, to the broader Lean Philosophy, culminating in the principles of Operational Excellence (OpEx). By doing so, it clarifies how these frameworks evolved to place increasing emphasis not only on efficiency and waste elimination, but also on the strategic integration of people, processes, and Continuous Improvement (CI). This section sets the foundation for understanding Lean not merely as a set of tools, but as a philosophy of adaptation and alignment leading to Excellence.

2.3.1 Toyota Production System

The Toyota Production System, originated at Toyota Motor Company, primarily under the leadership of Taiichi Ohno, and drew heavily from the insights of the company’s founders, Sakichi and Kiichiro Toyoda. Sakiichi Toyoda’s personal and professional philosophy influenced the company with principles like being faithful to duties, being studious and creative, being practical, building a homelike atmosphere, and having respect for spiritual matters and gratitude.

Kiichiro Toyoda articulated the principle of just-in-time in 1938, emphasizing that goods should be produced only as needed, neither too early nor too late and Sakichi Toyoda’s inventions, such as automated looms that stopped when a thread broke, gave rise to the concept of jidoka or built-in quality, a foundational principle of TPS [22].

TPS emerged in post-WWII Japan, when Toyota faced limited capital, minimal demand, and tight space, forcing the company to eliminate waste rigorously. This

environment led to the crystallization of Jidoka and Just-in-Time as the two main pillars of TPS, typically depicted as a "house", as shown in Figure 2. This house is built on a foundation of stable, leveled processes. Through the elimination of the "three Ms": Muda (waste), Mura (unevenness), and muri (overburden) and the standardization. The TPS system is also grounded in scientific thinking and, where iterative learning and problem solving are key to the Continuous Improvement or what is called Kaizen, creating the house's dynamic[22].

Far from being just a collection of tools, TPS is a collection of principle and a system of people, equipment, and processes designed to meet key business objectives like quality, cost, and delivery in a sustainable way [22].

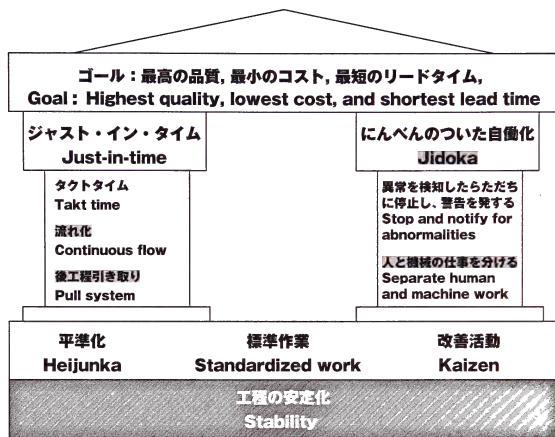


Figure 2: The TPS House - Narusawa and Shook [23]

2.3.2 The Emergence of the Lean Movement

The Toyota Production System, earned global attention, in 1991, when Womack, Jones, and Roos introduced the concept of "Lean Production" in their seminal work *The Machine That Changed the World*, highlighting its ability to merge the efficiency of mass production with the adaptability of craftsmanship [24]. As lean principles spread especially within manufacturing organizations, their application often became diluted. A comprehensive survey carried out by Industry Week in 2007 revealed that merely 2 percent of organizations implementing lean initiatives were able to fully realize the outcomes they had expected [25]. Liker [22] critiques this as turning a dynamic, evolving system into a static set of tools, and instead emphasizes the need for a more holistic approach, one rooted in cultivating people, fostering a culture of learning, and applying scientific thinking in everyday work. Masaaki Imai also [26] observed that many companies adopted a surface-level approach to Kaizen, focusing narrowly on isolated tools and improvement events rather than embracing it as a comprehensive, people-driven management system. This fragmented implementation tends to reduce lean to a checklist of methods and performance targets, neglecting the essential mindset and cultural shift required for lasting improvement. In his book [26], he clearly explains the central concept of Continuous Im-

provement or Kaizen, and the essential role of leadership in understanding the Gemba (The Place Where Value is Created) to foster the culture and driving the best out of people through coaching and scientific thinking. He also emphasizes that CI is not done for CI's sake but rather through a clear interest to the client and proper strategic alignment.

2.3.3 The Toyota Way As a Path to Excellence

Liker [25] formalized the key management ideas he learned from studying Toyota as the 4P model (depicted in Figure 3), which brings together four main parts: philosophy, processes, people, and problem solving. This model is central to Toyota's approach to sustainable performance.

The four dimensions are understood as follow :

- Philosophy: Prioritizing long-term thinking over short-term results.
- Process: Creating continuous flow and exposing problems through standardized work and pull systems and ensuring process stability.
- People: Respecting and developing people; leaders act as coaches and deeply understand the work.
- Problem Solving: Using scientific thinking, especially the Plan-Do-Check-Act (PDCA) cycle for iterative, evidence-based learning, and continuous improvement.

As liker in his book argue, Kaizen, or CI, is embedded in this framework as a structured Problem-Solving methodology to foster Scientific Thinking and consistently challenge People to improve the existing Processes, all of which is subscribed to in a greater strategic vision or Philosophy[22].

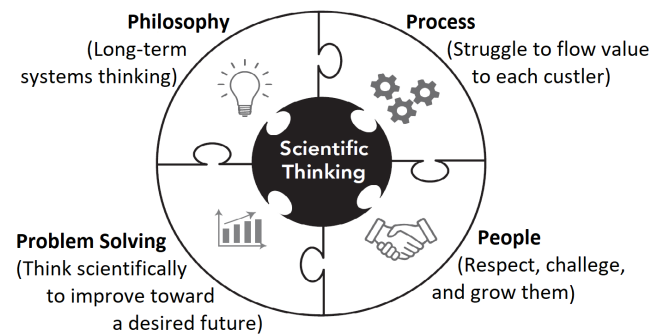


Figure 3: The 4 P Model of the Toyota Way by Liker[22]

2.3.4 Operational Excellence and The Shingo Model

The term "Operational Excellence" (OpEx) is widely used but often lacks a unified definition, making it subject to varying interpretations [19]. Various authors and institutions have attempted to define it, emphasizing dimensions such as performance improvement, customer value creation, continuous improvement, organizational alignment, and a culture of excellence

[14, 27, 28].

Operational Excellence, according to P. Found et al. [29], was first introduced in The Discipline of Market Leaders as one of the core value disciplines organizations choose to adopt in shaping their operating model and value proposition to drive better results. This positioning framed OpEx not only as a performance model but also as a strategic and cultural orientation, influencing both internal operations and external identity.

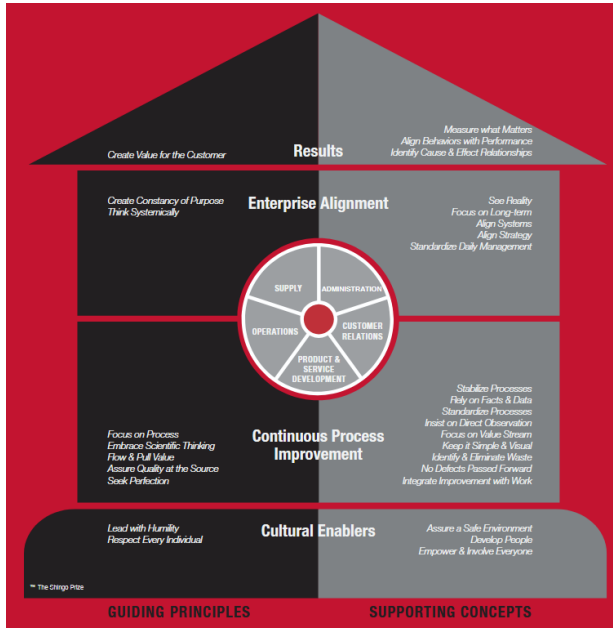


Figure 4: The Four Pillars of Operational Excellence depicted as a House in the Shingo Model for Operational Excellence along with Shingo’s Guiding Principles and Their Supporting Concepts [30]

Over time, the concept evolved in response to broader shifts in management thinking, incorporating insights from Lean, Six Sigma, (TQM), and CI. While these methodologies vary in form, the most consistently effective approaches share common traits: they are grounded in a strong focus on customer value, emphasize direct engagement with the workplace (Gemba), and rely on structured, incremental improvement logic. These characteristics have proven to be critical for sustained performance, regardless of how the strategy is labeled [26].

A lot of models such as Boston Scientific’s (one solid theoretical base for OE), Oakland’s ,Crawford’s approach and the EFQM framework has appeared [28, 29, 31] but the broader and more principle-based scope of Operational Excellence was notably formalized in 1993 by the Shingo Institute of Utah, through the development of the Shingo Model for Operational Excellence. Rooted in the philosophy of Shigeo Shingo, an influential figure in the TPS,the model defines Operational Excellence as :

“A consequence of applying enterprise-wide practices based on principles classified in four dimensions: Culture, Continuous Process Improvement, Enterprise Alignment, and Results.”

The Shingo model organizes its principles into four dimensions, four of which are pretty similar to other models and can be seen in Figure 4. This consistency across multiple approaches underscores the legitimacy of adoption of these four dimensions as foundational pillars for understanding and implementing OpEx:

- Cultural Enablers [30] or Organizational Learning [28]
- Continuous Process Improvement [30] or Process Excellence [28]
- Enterprise Alignment [30] or Business Value [28]
- Results[30] or Delight Stakeholder[28]

The Shingo Model represents a significant evolution from Lean and tool-based systems to a principle-centered framework, emphasizing that excellence is not achieved by applying tools alone but by creating a principle-based culture where ideal behaviors are cultivated through leadership and aligned systems [30].

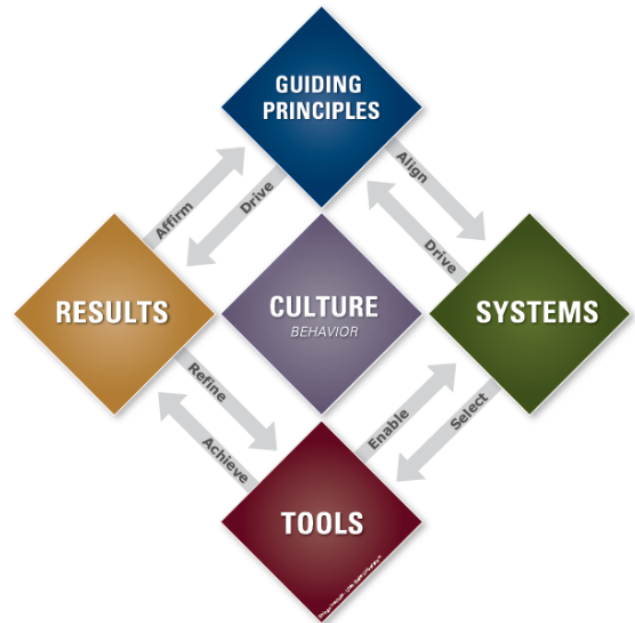


Figure 5: Shingo’s Diamond[32]

These principles span across all business systems and are designed to build a culture of operational excellence rooted in scientific thinking, respect, humility, and constancy of purpose. Results are later achieved with the deep alignment of systems, tools, behaviors, and those very guiding principles, The Shingo Diamond in Figure 5 visually synthetise the latter description.

3. Argumentative Framework

To develop and substantiate our thesis claim, this section draws on three distinct but complementary argumentative perspectives. The first adopts a historical lens that examines how previous IRs unfolded. The second introduces a systems-based view, repositioning Digitalization within the broader logic of Operational Excellence frameworks. The third presents a strategic transformation perspective, contrasting current approaches and their alignment with sustainable change. Together these perspectives offer a multidimensional demonstration of the conditions under which Digitalization can truly lead to sustainable performances gains.

3.1. A Historical Perspective: Technology Alone Never Brought Sustainable Performances

A critical examination of the four Industrial Revolutions reveals a recurring pattern: each wave of technological innovation initially emerged as a response to the limitations of the previous era, yet in doing so, introduced new organizational and human challenges. Contrary to the popular narrative that technology is the primary driver of economic growth and industrial transformation, historical evidence consistently shows that technology alone has never been sufficient. Real performance improvements have only been achieved when innovation was accompanied by organizational adaptation, human development, and managerial transformation. This pattern helps re-frame Industry 4.0 not as a rupture, but as the latest phase in a recurring cycle of innovation, adaptation, and performance.

The Industrial Revolutions were not isolated technical events, but rather complex responses to structural bottlenecks in production, labor, and economic systems. As [6] notes, the initial shift from agrarian to industrial economies was not purely technological; it was grounded in the interplay between innovation, economic development, and social transformation. This multidimensional perspective remains relevant today, particularly as we analyze the modern industrial shift and challenges. Similarly, Taskan et al. [13] affirm that each revolution did not simply build on new inventions, but rather arose as a necessity, a human and systemic response to new troubles brought by earlier developments. Innovation has always been an enabler, not the driver itself. Yet despite this historical proof, the myth of technology as a self-sufficient solution persists. Kohnová et al. [33] provide strong empirical evidence against this misconception, arguing that education, the development of adaptive skills, and the implementation of new managerial practices have been the true enablers of technological utilization. Their findings emphasize that countries or organizations with the ca-

pability to rapidly retrain, upskill, and manage talent were not only more likely to adopt technologies, but also more successful in transforming them into performance gains. Similarly, Rasool [34] highlights that technological advancement carries both rewards and risks, particularly when adopted without thoughtful integration into human-centered systems such as education or coaching. This point is reinforced by more recent critiques of the overhyped discourse surrounding Industry 4.0 and the rushed advent of Industry 5.0. The research in [9], stated that Industry 4.0 is still in its infancy, introduced prematurely and often without a clear strategic vision. Its evolution into Industry 5.0 has not solved the foundational issues; it has simply layered additional expectations, particularly around sustainability and personalization on top of unresolved challenges.

In this regard, Melnyk et al. [15] draw attention to an interesting aspect of IRs, mostly the cognitive and emotional overload experienced by individuals during the first four industrial revolutions and argue that, Industry 5.0, though promising deeper personalization and human-centric design, risks overcorrecting without addressing the root cause: the absence of human alignment in technological strategies.

This concern is not new, Coleman's, in the late fifties [35], had made an early critique of the term "industrial revolution" which remains highly relevant. He warns against labeling each technological advancement as a "revolution" when it lacks transformative social and economic impact. His historical study of the English paper industry demonstrates that mechanization alone, however efficient, does not constitute systemic change. This conceptual drift persists in contemporary discourse, as terms like Industry 4.0 and 5.0 are often adopted without the societal changes needed to truly deserve that title. Groumpos [7] adds that I4.0 builds on the digital revolution of the 20th century (I3.0) but was introduced without strategic human alignment, an issue that is now addressed in speculative discussions about I5.0 and I6.0. The authors [9] had stated that instead of chasing new "Revolutions" every few years, industries should aim to integrate technology with the missing aspects of adaptability, aligning innovation with sustainability and human values. This observation reflects a deeper structural issue: technological development has overtaken human and organizational readiness, creating a recurring performance gap.

Finally, even within technologically advanced firms, the managerial dimension remains underdeveloped. As Torres et al. [36] observe, while digital systems allow managers to assess operational outputs, they continue to struggle with understanding employee behavior, decision-making, and multi-departmental dynamics, the very factors that shape long-term organizational performance. Tools such as the Balanced Scorecard which was developed by Norton and referenced by Zaritskyi et al. [11], remind us that technological investments must be integrated into broader strategic frameworks if they are to generate meaningful, mea-

surable results.

In conclusion, the historical pattern is clear: technological innovation, while essential, is not inherently transformative. This is especially true today, as technology alone proves insufficient. Performance gaps arise when technological adoption outpaces organizational readiness, strategic alignment, and human capability.

3.2. Reframing Digitalization as a Tool Within a Broader Excellence System

After establishing in the previous argument that technology alone cannot drive sustainable performance, it becomes essential to rethink how digitalization should be positioned today within manufacturing organizations.

It is true that today's data-driven technologies are undeniably critical to achieving excellence [14], but, as M. L. Kawashima et al [37] cautions, their implementation must be subordinated to the needs of the production system, serving them, rather than dominating them. This warning aligns with a fundamental critique articulated by the Shingo Institute through their observations, articulated as "*Corporate's largest mistake*". They warned against the widespread organizational mistake of relying on tool-sets in isolation in order to drive improvement [30]. In other words, without the supporting behaviors, systems, and leadership, tools, digital or not, rarely yield the intended performance gains.

This message resonates with many of the challenges currently faced in the digital era. If digitalization as tools are deployed without meaningful alignment, they will at best automate existing inefficiencies and at worst, introduce new ones. From this perspective, an important insight emerges: studies such as R. Ade Octaviano et al. [38] describe Industry 5.0 as a strategic effort to harmonize the advancements of digitalization with human excellence. This "human excellence" encompasses the very competencies now presented as essential for Industry 4.0. Yet as A. Dermawan et al [18] and M. M. Balog and S. E. Demidova [17] affirm, these human-centric capacities (lifelong learning, teamwork, continuous improvement...etc) are not only critical for driving performance gain, but have long been foundational to high-performing organizations and are far from new. What has changed is the growing realization that such competencies are not peripheral but central to sustainable performance in the digital era. As previously argued, the Lean movement had appeared by the Third IR. The current revival of its principles reflects the failure to embed them properly within organizational systems before the onset of digital transformation or the IR4.0. In essence, the so-called "new" competencies are a rediscovery of neglected Lean principles.

This brings us to the Shingo Model for Operational Excellence, which is deeply rooted in Lean thinking. Through its triad of systems, people, and tools, it reinforces this notion by emphasizing that organizations cannot unleash the potential of their people through tool-centered approaches alone. Tools are enablers not solutions, and they must be subordinated to systems and guided by principles to generate long-term value [30].

People and Philosophy

This rediscovery is backed by performance data. SW. Hahn [39] study on workforce performance in the context of the 4th IR, found that learning orientation and change acceptance were stronger predictors of performance than familiarity with digital tools. Workers who received training or worked in innovation-friendly environments were significantly more engaged and effective than those who did not. This underscores the importance of systems that promote human development and learning over tools alone. In his famous book, "The Toyota Way" [22], Liker emphasized that the true engine of improvement is not automation itself, but the people who drive and enhance the processes. While digital tools and advanced technologies may offer operational advantages, he warned against relying on them blindly. Instead, organizations should focus on empowering their workforce, as people are inherently more adaptable and capable of CI than machines. Automation is a fixed investment -useful but limited-, whereas people, when engaged and supported, represent a renewable source of innovation and resilience. According to him, even the most sophisticated systems prove ineffective if not embedded within a culture where every individual feels responsible for quality. Ultimately, sustainable improvement stems from reinforcing shared accountability and enabling people at all levels to contribute meaningfully to excellence.

In light of these findings, calls for new industrial revolutions, such as Industry 5.0 and even 6.0, risk appearing as attempts to patch over foundational failures rather than address them. Groumpos [7] confirm this, saying that many of the aspirational elements of I6.0 dignity, empowerment, sustainability, are already embedded in the Lean principles through respect for people and long-term thinking.

What remains is not to invent new paradigms but to deploy the existing ones with rigor, maturity, and alignment.

Process and Problem Solving

Additional studies reinforce our message. Vilkas et al. [40] report that Lean methods for continuous process improvement, and not digital manufacturing innovations, contributed the most to digitalization performance, accounting for over 23% of the variation of performances. Lean methods effectiveness is also supported by operational data. They showed that setup time reduction, task integration, and visual management, essential tools of lean, are significantly correlated

with successful digitalization outcomes.

Beyond process efficiency, one of the defining strengths of Lean systems is the structured involvement of employees in problem solving. Vilkas et al. [40] emphasize that extensive employee participation in process improvement is a core practice of the lean template, specifically through methods like Kaizen and value stream mapping. These practices are not only designed to reduce waste but are grounded in hypothesis-driven problem-solving, empowering teams across organizational levels to identify and eliminate root causes of inefficiency within their processes. As Liker explains [22], While Toyota does use advanced technologies, he emphasizes that these are introduced selectively, only when they support human-centered processes and do not compromise flexibility or learning. Problem solving is not just a skill, it is an operational system embedded at every level of Toyota. Employees are trained to observe processes, detect deviations, and implement countermeasures in real time. This capability is supported by visual controls and standardized tasks, which make abnormalities visible and solvable at the source. In Toyota’s system, continuous improvement is not driven by the technology used, but by the structured problem-solving capacity of the entire workforce, making it a core enabler of performance.

Most importantly, the relationship between digitalization and Lean is mutually reinforcing, not antagonistic. According to Vilkas et al. [40], Industry 4.0 accelerates the adoption of OpEx methodologies by providing new resources and capabilities. In turn, these methodologies offer the structure and discipline needed to make technology deployment effective. Even so, F. Rosin et al. [41] interesting finding demonstrated that when digital technologies can support Lean methods like Just-in-Time and Jidoka, they have limited influence on people-centric dimensions such as teamwork, problem-solving, and learning. This is why it remains important to start with OpEx guiding principles deployment, avoiding the recurrent mistake companies make when they misapply Lean by copying tools without the underlying philosophy [22].

3.3. Incremental Adaptation over Disruption: Addressing the Digitalization Paradox

The advent of digital technologies has undeniably re-defined industrial operations. I4.0 technologies have introduced not only new capabilities but also a new pace, scale, and logic of transformation.

According to Nath et al. [2], the primary aim of these transformations is to achieve a competitive edge, boost revenue generation, increase productivity and efficiency, and strengthen engagement with customers and stakeholders. These goals have materialized rapidly in certain sectors, particularly under the pressure of global crises. For example, Microsoft CEO Satya Nadella stated that two months worth of digital transformation were recorded during the early months

of the COVID-19 pandemic through remote collaboration tools, and digital platforms.. Likewise, Badiru and Cromarty [14] report that the application of digital tools at HID Global led to 97%+ on-time delivery reducing lead times by 60% with decreased defect, demonstrating the tangible operational impact of digital technologies.

However, these success cases remain the exception rather than the rule. In manufacturing specifically, Over 56.6% of companies surveyed by Duobiené et al. [40] did not even know their digital performance relative to competitors, which is a clear lack of vision and strategic alignment. In addition, the adoption of Industry 4.0 technologies continues to face serious constraints. Alqoud et al. [21] highlight that while the integration of advanced technologies holds the potential to improve efficiency, quality, and cost performance, companies often face financial, knowledge-based, and implementation barriers. More critically, as Martinez [42] framed it: Industry 4.0 lacks managerial procedures and implementation roadmaps.

This implementation gap supports what Duobiené et al. [40] have termed the “digitalization paradox” with Rosin et al. [41] also confirming it; It paradox represents the growing distinction between technological potential and actual performance outcomes; while companies pursue full digitalization of their processes, results remain marginal or absent unless technologies are embedded within a culture of continuous improvement, structured capability development, and cross-functional coordination. This paradox is echoed in broader transformation efforts. McKinsey & Company [5] reports that 70% of large-scale transformations fail to meet their predetermined objectives, largely due to weak cross-functional collaboration, employee disengagement and insufficient leadership support. Moreover, they emphasize that sustaining transformation outcomes requires deep and sustained changes in mindsets and behaviors, challenges that most organizations are not structurally equipped to manage. This reinforces the view that digital transformation is not merely a technological challenge but a fundamentally organizational one. As Wu et al. [43] emphasize, digital transformation is more about developing organizational capabilities than simply implementing new technologies. This perspective highlights the need for companies to invest not only in tools, but in developing the organizational competencies, systems, and alignment necessary to realize digital benefits.

Within this context, we can bring out the two distinct approaches to transformation that are commonly identified by F. Martinez [42], Rossini et al. [44] and Wu et al. [43]. The first, Disruptive Transformation, involves radical overhauls of business models or operational systems, often creating new complexities and digitalization paradoxes along the way. The second, Incremental Transformation, focuses on gradual, step-by-step improvements to existing processes. This latter approach aligns closely with the principles of Lean and Continuous Improvement, and is increasingly recognized as the more sustainable and strategically

sound option. The latter, closely with the principles of Lean and Continuous Improvement, is proving to be more sustainable and destructive if absent within organization digital strategie. As Badiru and Cromarty [14] argue, operational efficiency is best achieved not through abrupt, large-scale interventions, but through “gradual and consistent closing of gaps,” as drastic improvement efforts tend to disrupt process optimization rather than support it. Empirical research supports this position. Martinez [42] demonstrates that firms adopting an incremental, process-driven approach to digitalization rooted in principles of operational excellence and lean are significantly more likely to succeed. In this view, Process Excellence or Process Continuous Improvement becomes the enabler of digital transformation, not the other way around. Through incremental transformation, organizations refine workflows, build stability, and foster alignment between digital investments and operational priorities. This approach not only improves readiness for digital solutions but also ensures their long-term sustainability and measurable impact. Moreover, organizations that apply Lean principles in their digital journey experience better results. Rosin et al. [41], building on the idea of Kolberg and Zühlke (2015), show that the integration of Industry 4.0 tools within a Lean production system reduces the risk of failure by creating organizational resilience and experience in change management, a huge challenge facing practitioners when digitally transforming organizations[5]. It also supports adopting the positive attitude and enhancing needed skills such as cross-functional collaboration [39], a common pitfall for digital transformation [5].

To support this even further, Toyota offers a compelling example of this logic. Liker [22] explains that Toyota’s response to technological disruption has not been to abandon its core principles, but rather to deepen them. Faced with transformative shifts in software and mobility services, Toyota reinforced its commitment to continuous improvement and people development. New technology may be disrupting the automotive industry but Toyota’s response was to maintain its Lean foundation while developing new technological capabilities, not to chase disruption uncritically. The core message is that technology must be aligned with values, culture, and systems, not treated as a goal in itself. As emphasized by Masaaki Imai [26], improvement can be classified as either Kaizen (CI) or Innovation. While innovation involves a drastic improvement resulting from a large investment in new technology or equipment, it is often an endeavor with problematic outcomes. In contrast, the continuous improvement perspective reinforces that in the context of digital transformation, incremental adaptation is not only more sustainable but strategically wiser.

In sum, the promise of digital transformation is real, but its impact is limited when pursued through disruptive, tool-first strategies. The evidence from both practice and research suggests that incremental adaptation grounded in continuous improvement and Lean

Principles is the most reliable path to successful digitalization and thus achieving Excellence. Rather than viewing digital tools as solutions in themselves, organizations must treat them as enablers within a broader framework of cultural alignment, leadership engagement, and incremental capability building.

4. Synthesis and Analysis

In this thesis, we proposed that Digitalization delivers meaningful and sustainable performance gains in manufacturing only when it is deliberately integrated into organizational systems designed to compensate for human limitations and to unlock their potential through structured, continuous problem-solving. Through a layered demonstration across industrial history, organizational principles, and transformation strategy, we have substantiated this claim. Our objective was not to explore digitalization broadly, but to prove that its impact depends on how it is integrated. Specifically, meaningful results arise only when digital tools and solutions are aligned purposefully within human-centered, principle-based, and strategically aligned systems which makes operational excellence. This perspective challenges the dominant narrative, which often assumes that adopting technology in itself is a sufficient condition for performance transformation.

To understand this, we first examined the industrial revolutions from a historical perspective. We observed that throughout each era of industrial change, technology was never the sole driver of performance. Instead, genuine progress emerged when technological advancement was accompanied by human development, managerial evolution, and system-wide adaptation. This pattern remains valid today: even as we embrace Industry 4.0, and more recently, Industry 5.0, we continue to see performance gaps when digital solutions are deployed without aligning organizational readiness and people systems. These insights led us to reframe digitalization not as a revolution in itself, but as part of a recurring cycle of innovation that must be rooted in purpose, structure, and capability development.

From there, we argued that the key to unlocking digitalization’s potential lies in how it is positioned within the organization. We found that tools alone, no matter how advanced, do not generate lasting improvement unless supported by systems that promote continuous learning, human development, and leadership. Conversely, when technologies are subordinated to a broader operational excellence approach, their potential is amplified. The Shingo Model helped us formalize this view, particularly through its emphasis on the interdependence between people, systems, and tools. We saw that principle-driven environments that are in line with lean thinking are far better equipped to absorb, adapt, and scale digital innovations in a sustainable way.

We then explored the transformation process itself. In doing so, we identified two dominant approaches: one disruptive, tool-first and top-down; the other incremental, system-focused and continuous. Our findings clearly favor the latter. We concluded that organizations which adopt digital tools as part of a continuous improvement journey are more likely to achieve measurable performance results, while those that rush to implement technologies without a guiding philosophy or capability base often fail to reach their objectives. Studies showing that up to 70% of digital transformation programs fail [5] short further validate this concern. We observed that these failures rarely stem from the technology itself, but from weak cross-functional collaboration between people, poor change management, and the absence of a shared purpose or vision.

In summary, our analysis reveals that digitalization must not be treated as a goal in itself. It is a mean that becomes valuable only when aligned with human systems, operational discipline, and long-term strategic intent. We believe that future digital success will depend less on the tools adopted and more on the readiness of the organizations that adopt them. That readiness, we argue, is best developed through Shingo’s operational excellence guiding principle grounded in purpose, people, and continuous improvement.

5. Conclusion

This thesis has argued that digitalization in manufacturing only delivers lasting performance improvements when it is deliberately integrated within human-centered and principle-based organizational systems. By tracing industrial history, analyzing operational models, and comparing transformation strategies, we demonstrated that technological tools alone are insufficient. Instead, success depends on how digital solutions are aligned with a culture of continuous improvement, employee engagement, and strategic clarity. The analysis showed that the most sustainable and impactful transformations occur when digitalization is treated not as a revolution in itself, but as a strategic lever within a broader system of operational excellence. Lean principles and the Shingo Model offered a framework to formalize this, emphasizing the necessary interdependence between people, tools, and systems.

This analysis challenges a common misconception in the industrial world: that adopting advanced technologies will automatically lead to progress. The reality is more complex, and, more human. As organizations rush to digitize, they often overlook the very systems and people that must support these technologies. This oversight explains why so many digital transformation programs fail. What this thesis contributes is a reframing: technology should not be the starting point, but the consequence of an organization that is already committed to excellence, learning, and purposeful im-

provement.

Why does this matter? Because the implications are significant. As industries confront increasing complexity, global competition, and the pressures of sustainability, misguided digital strategies risk wasting resources and distancing the workforce. Conversely, organizations that invest in their people and systems first (those that lead with purpose) are better equipped to transform technology into performance. This insight is not only relevant to manufacturers, but to any organization navigating change in the digital era.

Ultimately, this thesis invites a shift in mindset: from chasing tools to cultivating capabilities, from isolated innovation to integrated excellence. That, we believe, is where real transformation begins.

References

- [1] A. Kumar, S. Sagar, P. Thangamuthu, and B. Balamurugan. *Digital Transformation: Industry 4.0 to Society 5.0*. Disruptive Technologies and Digital Transformations for Society 5.0. Springer Nature Singapore, 2024.
- [2] S.V. Nath, A. Dunkin, M. Chowdhary, and N. Patel. *Industrial Digital Transformation: Accelerate digital transformation with business optimization, AI, and Industry 4.0*. Packt Publishing, 2020.
- [3] Elena G Popkova, Yulia V Ragulina, and Aleksei V Bogoviz. *Industry 4.0: Industrial revolution of the 21st century*, volume 169. Springer, 2019.
- [4] PwC. Industry 4.0- opportunities and challenges of the industrial internet, 2014. Accessed: 2025-05-21.
- [5] The ‘how’ of transformation | McKinsey. Accessed: 2025-05-18.
- [6] SO Taiwo and MF Vezi-Magigaba. Human capital perspective of previous industrial revolutions: Review in support of 4IR and its possible impacts. *Multicultural Education*, 7(8):86–96, 2021.
- [7] Peter P Groumpos. A critical historical and scientific overview of all industrial revolutions. *IFAC-PapersOnLine*, 54(13):464–471, 2021.
- [8] Joel Mokyr. The rise and fall of the factory system: technology, firms, and households since the industrial revolution. *Carnegie-Rochester Conference Series on Public Policy*, 55(1):1–45, 2001.
- [9] Ashwani Sharma and Bikram Jit Singh. Evolution of industrial revolutions: A review. *International Journal of Innovative Technology and Exploring Engineering*, 9(11):66–73, 2020.
- [10] Mengchen Jiang. A Review of the Impacts of Industrial Revolutions in World History. *Communications in Humanities Research*, 39(1):234–239, August 2024.

- [11] Oleg Zaritskyi and Oleksandr Ponomarenko. Technology in the industrial revolutions and its impact on the key performance indicators of organizations. In *TTSIIT*, pages 87–96, 2022.
- [12] Sidney Pollard. Factory discipline in the industrial revolution. *The Economic History Review*, 16(2):254–271, 1963.
- [13] Buğra Taşkan, Buket Karatop, and Cemalettin Kubat. Impacts of industrial revolutions on the enterprise performance management: A literature review. *Journal of Business and Management*, 26(1):79–119, 2020.
- [14] Adedeji B Badiru and Lauralee Cromarty. *Operational Excellence in the New Digital Era*. CRC Press, 2021.
- [15] Leonid Melnyk, Oleksandr Kubatko, Iryna Dehtyarova, Oleksandr Matsenko, and Oleksandr Rozhko. The effect of industrial revolutions on the transformation of social and economic systems. *Problems and Perspectives in Management*, 17:381–391, 12 2019.
- [16] Min Xu, Jeanne M David, Suk Hi Kim, et al. The fourth industrial revolution: Opportunities and challenges. *International journal of financial research*, 9(2):90–95, 2018.
- [17] M M Balog and S E Demidova. Human capital development in the context of the fourth industrial revolution. *IOP Conference Series: Earth and Environmental Science*, 666(6):062120, mar 2021.
- [18] Arief Dermawan, Nur Wening, Yohannes Vemberi, and Lucia Ika Fitriastuti. A systematic literature review of digital skills and human resource readiness for the industrial revolution era 4.0 and 5.0. *JMKSP (Jurnal Manajemen, Kepemimpinan, dan Supervisi Pendidikan)*, 10(1):245–259, Feb. 2025.
- [19] Adeline Frenzel, Jan C Muench, Moritz Bruckner, and Daniel Veit. Digitization or digitalization?—toward an understanding of definitions, use and application in IS research. 2021.
- [20] Johannes Vrana and Ripudaman Ripi Singh. Digitization, Digitalization, Digital Transformation, and Beyond. In Norbert Meyendorf, Nathan Ida, Ripi Singh, and Johannes Vrana, editors, *Handbook of Nondestructive Evaluation 4.0*, pages 1–26. Springer Nature Switzerland, Cham, 2024.
- [21] A Alqoud, D Schaefer, and J Milisavljevic-Syed. Industry 4.0: challenges and opportunities of digitalisation manufacturing systems. *Advances in Manufacturing Technology XXXV*, pages 25–30, 2022.
- [22] Jeffrey Liker. *The Toyota way: 14 management principles from the world’s greatest manufacturer*. McGraw-Hill, 2020.
- [23] Toshiko Narusawa and John Shook. *Kaizen express: fundamentals for your lean journey*. Lean Enterprise Institute, 2009.
- [24] James P Womack, Daniel T Jones, and Daniel Roos. *The machine that changed the world: The story of lean production—Toyota’s secret weapon in the global car wars that is now revolutionizing world industry*. Simon and Schuster, 2007.
- [25] Jeffrey K. Liker and James K. Franz. *The Toyota way to continuous improvement: linking strategy with operational excellence to achieve superior performance*. McGraw-Hill, New York, NY, 2011.
- [26] M. Imai. *Gemba Kaizen: A Commonsense Approach to a Continuous Improvement Strategy, Second Edition*. McGraw-Hill Education, 2012.
- [27] Emmanuel Jengwa and Rene Pellissier. An operational excellence strategy implementation model for growth in a volatile, uncertain, complex, and ambiguous environment. *Acta Commercii*, 22(1):1–11, 2022.
- [28] Gopal K. Kanji and. Measurement of business excellence. *Total Quality Management*, 9(7):633–643, 1998.
- [29] Pauline Found, Andrew Lahy, Sharon Williams, Qing Hu, and Robert Mason. Towards a theory of operational excellence. *Total Quality Management & Business Excellence*, 29(9-10):1012–1024, 2018.
- [30] Jon M. Huntsman School of Business. The shingo model for operational excellence handbook, 2014. Accessed: 2025-05-21.
- [31] Mariana Carvalho, José Carlos Sá, Pedro Alexandre Marques, Gilberto Santos, and António Mário Pereira. Development of a conceptual model integrating management systems and the shingo model towards operational excellence. *Total Quality Management & Business Excellence*, 34(3-4):397–420, 2023.
- [32] Shingo Institute. The shingo model™ is not just another initiative; it is a new way of thinking. Accessed: 2025-05-21.
- [33] Lucia Kohnová and Nikola Salajová. Industrial revolutions and their impact on managerial practice: Learning from the past. *Problems and Perspectives in Management*, 17(2):462, 2019.
- [34] Jazz Rasool. Coaching 5.0, coaching for the fifth industrial revolution. *Frontiers in Virtual Reality*, 5:1474053, 2025.
- [35] Donald C Coleman. Industrial growth and industrial revolutions. *Economica*, 23(89):1–22, 1956.

- [36] Maximilian B Torres, Diego Gallego-García, Sergio Gallego-García, and Manuel García-García. Development of a business assessment and diagnosis tool that considers the impact of the human factor during industrial revolutions. *Sustainability*, 14(2):940, 2022.
- [37] Mariana Lazari Kawashima, Daniel Braatz, and Fabiane Letícia Lizarelli. Work throughout the industrial revolutions and the impacts of industry 4.0 on workers. In *Global Conference on Sustainable Manufacturing*, pages 269–276. Springer, 2023.
- [38] Rini Ade Octaviany, Winda Sihotang, Petrus Sanjaya Simarmata, Arif Rahman, and Agustina Muliati. Human resource development strategy as preparation for the industrial revolution era 5.0. *International Journal of Educational Research amp; Social Sciences*, 3(3):1157–1164, 2022.
- [39] SangWoo Hahm. Attitudes and performance of workers preparing for the fourth industrial revolution. *KSII Transactions on Internet and Information Systems (TIIS)*, 12(8):4038–4056, 2018.
- [40] Mantas Vilkas, Jurga Duobienė, Rimantas Rauleckas, Aušra Rūtelionė, and Beata Šeinauskienė. *Organizational models for industry 4.0*. Springer, 2022.
- [41] Frédéric Rosin, Pascal Forget, Samir Lamouri, and Robert Pellerin. Impacts of industry 4.0 technologies on lean principles. *International Journal of Production Research*, 58(6):1644–1661, 2020.
- [42] Felipe Martinez. Process excellence the key for digitalisation. *Business Process Management Journal*, 25(7):1716–1733, 2019.
- [43] Chia-Hung Wu, Che-Wei Chou, Chen-Fu Chien, and Yun-Siang Lin. Digital transformation in manufacturing industries: Effects of firm size, product innovation, and production type. *Technological Forecasting and Social Change*, 207:123624, 2024.
- [44] Matteo Rossini, Fabiana Dafne Cifone, Bassel Kassem, Federica Costa, and Alberto Portioli-Staudacher. Being lean: how to shape digital transformation in the manufacturing sector. *Journal of Manufacturing Technology Management*, 32(9):239–259, 2021.