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Management Control in the Space of Industry 4.0: A Holistic Perspective for Organisations Using Systems Thinking Approach

Anitha Siriwardana[1], Siegfried Zürn[2], Abeysinghe Arachchige Chandrasiri Abeysinghe[1]

[1]Faculty Management and Finance, University of Colombo, Colombo, Sri Lanka
[2]Faculty Management and Technology, Esslingen University of Applied Sciences, Esslingen am Neckar, Germany
Email: anitha.siriwardana@gmail.com

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Abstract

The rapid digital transformation driven by Industry 4.0 has redefined traditional management control practices and necessitated a holistic rethinking of corporate governance. This paper presents an integrative framework that blends established management control systems with the dynamic demands of Industry 4.0 through the application of a comprehensive systems thinking approach. By developing an influence matrix, the work systematically maps the interdependencies between key elements of management control—such as budgeting, performance appraisal and organisational culture and key design principles of Industrie 4.0, including interoperability, virtualisation and real-time capability. The framework not only highlights the complex feedback loops and bidirectional influences that underpin digital transformation efforts but also provides actionable insights for organisations looking to adapt their control mechanisms to the rapidly evolving technology landscape and ensure a sustainable competitive advantage in an increasingly connected industrial environment.

Keywords

Digital Transformation, Management Control, Industry 4.0, Systems Thinking, Influence Matrix

1. Introduction

Digital transformation is redefining the competitive landscape for organizations worldwide. Industry 4.0 integrates cyber-physical systems, the Internet of Things

(IoT), cloud computing, artificial intelligence, and big data analytics to create highly interconnected and automated industrial ecosystems. This transformation presents both opportunities and challenges for management control systems, which serve as the backbone of organizational governance and decision-making. Traditional management control mechanisms such as budgeting, performance appraisal, and incentive systems were designed in an era of relatively stable environments. However, the interconnected nature of Industry 4.0 necessitates adaptive, real-time, and data-driven control frameworks to effectively manage digital transformations. This shift underscores the importance of integrating Systems Thinking into management control, providing a holistic approach to understanding the complex interdependencies between technological, human, and organizational elements.

While the technological and economical benefits of digital transformation are well documented, many organizations struggle with aligning management control practices with the fast-paced, decentralized, and technology-driven landscape of Industry 4.0. In particular, small and medium-sized enterprises (SMEs) often face funding constraints, skills gaps, and infrastructural limitations, making it difficult to leverage advanced technologies (Zürn & Joe, 2024). Without a structured framework that links Industry 4.0 principles with management control systems, organizations risk inefficiencies, poor resource allocation, and resistance to change.

This paper addresses these concerns by developing an integrated framework that synthesizes management control aspects with Industry 4.0 design principles using a qualitative, goal-oriented Systems Thinking approach. By mapping the interdependencies between six core management control elements (budgeting, performance appraisal, compensation systems, organizational culture, change management, and information feedback loops) and six Industry 4.0 principles (interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity), this study provides a structured way to evaluate the impact of digital transformation on organizational control mechanisms. To illustrate the practical applicability of this framework, recent studies (Rajagopal, Hettiarachchi, & Zürn, 2024) have shown how SMEs in manufacturing can use influence matrices to identify and sequence technology investments, resulting in more resilient budgeting processes and improved employee readiness.

This research aims to:

1) Examine the evolving role of management control systems in the context of Industry 4.0.

2) Develop an influence matrix that maps the interactions between management control aspects and Industry 4.0 principles.

3) Apply Systems Thinking to visualize feedback loops and interdependencies, offering deeper insights into digital transformation challenges.

4) Provide actionable recommendations for businesses to align their management control systems with digital imperatives.

2. Literature Review

2.1. Management Control as a Socially Constructed Practice

Management control is increasingly recognized as a socially constructed practice involving interactions between senior and functional managers (Abeysinghe, 2010). The primary objective of senior managers who personify capital (Steele & Albright, 2004) and practice management control is to guide and direct organizational members towards aligning with their vision (Greve et al., 2017; Cardinal et al., 2019). The presence of social groups within organizations significantly influences the effectiveness of these control mechanisms (Ahrens & Chapman, 2005). Furthermore, Management control practices can act as "anchor practices" that structure subsidiary organizational practices by defining key social relationships and enacting constitutive rules (Ahrens, 2016). Structurationist analysis provides insights into how controls mediate and participate in social activity (Briand & Bellemare, 1999; Briand, 2004). Furthermore, organizational members actively reconstitute control systems as shared resources, demonstrating situated functionality where accounting processes both shape and are shaped by shared norms and understandings (Ahrens & Chapman, 2005). Budgeting, performance appraisal, and compensation are key tools of management controls; which influence behaviors and directs actions towards organizational goals (Stede, 2015). These components are part of a broader framework for analyzing management control behaviour, which also includes objectives, strategies, target-setting, incentive structures, and information feedback loops (Otley, 1999). The socio-political approach to management control is a complex and multi-dimensional concept Verstegen (2011) introduces a framework that emphasizes the importance of social factors in coordinating behavior, while Diefenbach et al. (2009) argue for a multi-dimensional analysis of managers' power, including functional, socio-political, interpretive-discursive, and socio-cultural aspects. Zimmerman & Zahniser (1991) further develop this by proposing a sociopolitical control scale, which includes factors such as leadership competence and policy control. Cappelletti et al. (2024) extend this discussion by presenting the Socio-Economic Approach to Management (SEAM), which focuses on sustainable performance and aligns with the broader socio-political perspective. Contemporary management control practices are increasingly being used in today's business world, with a shift towards enabling rather than coercive approaches (Naranjo-Gil et al., 2016). Organizations mobilize various management controls to mediate pressures arising from overflows, such as environmental concerns, using these controls to identify, address, alleviate, or dispute pressures (Jollands et al., 2018). Management controls can be categorized into practices focusing on performance and boundaries, encompassing both social behaviors which uses technical elements (Tessier & Otley, 2012).

2.2. Industry 4.0 and the Digital Imperative

The key concept of Industry 4.0 (I4.0) highlights its significance in transforming manufacturing processes (Schwab, 2016; Hermann et al., 2016; Nazarov & Klarin, 2020; Janmaijaya et al., 2021) through advanced technologies (Rowlands & Milligan, 2020) such as intelligent manufacturing and integrating technologies; namely, cyber-physical systems (Cogliati et al., 2018; Javaid et al., 2023; Oks et al., 2022), Internet of Things (IoT) (Lampropoulos et al., 2019; Oluwaseun Adebayo et al., 2019; Belli et al., 2019; Liu & Zhong, 2017; Khan & Javaid, 2022; Soori et al., 2023), cloud computing (Singh, 2021; Khan et al., 2017; Velásquez et al., 2018) smart industries (Xu et al., 2018; Rana & Rathore, 2023; Schütze et al., 2018; Barari & Tsuzuki, 2023), big data analytics (Eissa, 2020; Khan et al., 2017; Santos et al., 2017; Duan & Da Xu, 2021), additive manufacturing (Saxena & Awasthi, 2020; Haleem & Javaid, 2019; Cirera et al., 2018; Butt, 2020) and smart sensors (Schütze et al., 2018; Karabegovic et al., 2019). Nazarov & Klarin (2020) also add to the discussion on how the emergence of Industry 4.0 acts as a transformative process through an exponential effect of these technologies. Industries are shifting focus from mass customization to mass personalization ("MPaas") (Aheleroff et al., 2021) emphasizing customer involvement in design processes (Kabasakal et al., 2017). This is further studied through identifying social expectations and changes related to Industry 4.0, focusing on customization and its effects on consumers, producers, and employees (Saniuk et al., 2020). Meanwhile, Makin & Boyle (2019) examine the social impact of Industry 4.0, highlighting the importance of human factors in successful digital transformation. The drive for quality is a crucial factor in Industry 4.0 when considering digital transformation of manufacturing and services. Leveraging public-private partnerships, cloud-based solutions, and employee upskilling programs could offer practical paths forward for SMEs implementing the proposed framework (Abiodun et al., 2023).

The integration of intelligent organizational systems and smart technologies in Industry 4.0 is fundamentally reshaping industrial processes and elevating organizational performance (Dahmani, 2024). By embedding cyber-physical systems, IoT networks, cloud computing, artificial intelligence, and big-data analytics into every stage of the value chain, firms gain end-to-end visibility, real-time decision-making capabilities, and the flexibility to rapidly reconfigure production in response to shifting customer demands. This digital transformation fosters new business models—such as servitization and mass personalization—while improving resource efficiency, reducing waste, and embedding sustainability into core operations (Abiodun et al., 2023). It also creates high-skill employment opportunities in data engineering, cybersecurity, and advanced maintenance.

However, realizing these benefits requires substantial upfront investments in digital infrastructure, workforce reskilling, and platform integration—costs that pose acute barriers for SMEs operating under tight budgetary and expertise constraints (Pačaiová et al., 2021; Dahmani, 2024). Heightened connectivity likewise expands the cyber-attack surface: IIoT devices, cloud environments, and open APIs increase the risk of data breaches and operational disruption, demanding robust cybersecurity frameworks, continuous threat monitoring, and employee awareness training (Egor, 2020; Dhirani et al., 2021). Simultaneously, the exponential growth of data can overwhelm legacy control systems unless complemented by scalable analytics architectures, clear data governance policies, and user-centric dashboards that translate raw information into actionable insights (Rajagopal, Hettiarachchi, & Zurn., 2024).

Equally critical is overcoming cultural resistance: employees may fear job displacement or lack the digital literacy required to leverage new tools. Successful implementation therefore hinges on an integrated change management strategy that aligns incentives, fosters knowledge sharing, and cultivates a learning culture (Abiodun et al., 2023). Organizations must adopt a systems-thinking perspective—establishing adaptive governance structures, piloting modular solutions incrementally, and embedding continuous feedback loops—to balance technological innovation with human and organizational readiness. By strategically prioritizing scalable, cost-effective technologies and embedding agile control mechanisms, companies can unlock Industry 4.0's full transformative potential and achieve sustainable competitive advantage (Dahmani, 2024).

Sony & Naik (2020) propose incorporating socio-technical systems theory into Industry 4.0 implementation, emphasizing the need for vertical, horizontal, and end-to-end integration. Abiodun et al. (2023) identify enterprise smartness as a key organizational capability developed through digital transformation, linking technology use to performance outcomes. Singh (2021) highlights the integration of big data, cyber-physical systems, and Industry 4.0 technologies, addressing research challenges such as data integrity and privacy. Hol (2021) explores the evolution towards Industry 5.0 and intelligent eco-systems, emphasizing the importance of human-machine partnerships. These studies collectively underscore the significance of integrating smart technologies and organizational systems in Industry 4.0, focusing on socio-technical aspects, enterprise smartness, data management, and human-machine collaboration to drive industrial transformation and improve organizational performance. Rowlands & Milligan (2020) add to the discussion by emphasizing the importance of how automation, and digital integration focus on enhancing efficiency, productivity, and sustainability in the industrial sector.

Collaborative human-machine networks are essential for implementing Industry 4.0 technologies and enhancing industrial performance. These networks enable efficient teamwork, which is crucial in the evolving workplaces (Chowdhury & Shil, 2023). The integration of advanced technologies such as industrial robots and 3D printing has reached an epitome of organizational development where even manufacturing has become a service-oriented transformation (Liu et al., 2022). Key technologies such as big data, cloud computing, Internet of Things, and cyber-physical systems form the foundation of Industry 4.0, with five collaborative networks identified: smart manufacturing, technological platforms, market reactiveness, smart products, and flexibility (Santos et al., 2021). The integration of these technologies facilitates interoperability and speeds up collaboration processes in manufacturing supply chains (Cisneros-Cabrera et al., 2018). As Industry 4.0 progresses, the need for complex collaboration and effective teamwork increases, requiring the development of specific competencies to adapt to technological advancements (Tahsin et al., 2020). Organizations should focus on building an open value ecosystem which integrates internal and external resources, adopt networking and platformization, and leverage initiatives to promote intelligent manufacturing solutions (Liu et al., 2022). Collaborative networks are thus considered a core enabler of Industry 4.0, addressing challenges and promoting more efficient, agile, and sustainable industrial systems (Camarinha-Matos et al., 2017).

Industry 4.0 demands enhanced collaboration and teamwork in the service sector as well. As manufacturing evolves towards service provision, organizational learning significantly impacts horizontal and vertical technology collaboration (Ahmad et al., 2020). Lean organizational structures, supported by advanced technology, enhances efficiency and force companies to adopt innovative management practices, establish clear talent demand forecasts and implement industry standards for intelligent manufacturing roles (Liu et al., 2022). Future project teams will comprise both humans and artificial intelligence, requiring team members to possess critical thinking and problem-solving skills (Marnewick & Marnewick, 2020). To support Industry 4.0 demands, collaborative technologies must adapt, necessitating the development of assessment tools to evaluate their readiness (Ramzan et al., 2020). These changes highlight the importance of developing teamwork skills and competencies to prepare the workforce for the technological advancements and complex collaborations required in the fourth industrial revolution (Chowdhury & Shil, 2023; Marnewick & Marnewick, 2020). Capturing the complexities of such systems within organisations operating in the space of I4.0 is pivatol.

2.3. Systems Thinking in Industry 4.0 Transformation and Management Control

Industry 4.0 initiatives often involve an intricate web of advanced technologies and organizational factors that transcend simple, linear cause-and-effect relationships (Meadows, 2008; Zhang et al., 2021). In this context, Systems Thinking provides a powerful theoretical approach for understanding the complexity of digital transformation, enabling organizations to move from siloed decision-making to a more holistic, feedback-driven mindset (Lipshitz et al., 1990; Rajagopal et al., 2024, Muller et al., 2025).

A defining feature of Systems Thinking is its emphasis on feedback loops—circular cause-and-effect processes in which organizational actions produce outcomes that, in turn, influence future behaviours (Kim, 2000; Meadows, 2008). This perspective is especially valuable in Industry 4.0 settings where real-time data, automation, and interdepartmental connectivity can magnify both the benefits and risks of transformation efforts (Frank et al., 2019). By viewing an organization as an interconnected network of actors—people, processes, and digital tools—managers can more effectively anticipate bottlenecks, adapt strategies, and align resource allocation with broader strategic objectives (Zürn & Joe, 2024).

Although digital transformation is frequently framed as a technological shift, its success ultimately depends on human and organizational elements (Otley, 1999). Systems Thinking complements traditional management control frameworks by highlighting how technological deployments, performance metrics, and human behaviours interrelate (Kaplan & Norton, 1996; Simons, 2013). For example, an analytics platform designed to optimize throughput can also influence employee incentives, departmental collaboration, and strategic goal-setting. Mapping these interdependencies through causal-loop diagrams or influence matrices allows decision-makers to identify leverage points, ensuring that short-term improvements (e.g., cost savings) do not undercut long-term goals such as employee motivation and cultural adaptability (Rajagopal et al., 2024).

Recent studies show that companies often constrained by limited financial and technical resources can derive particular benefit from a Systems Thinking approach (Zürn & Joe, 2024). By systematically modelling both "hard" (e.g., production throughput, real-time data) and "soft" (e.g., trust, leadership) variables, companies gain clearer insights into how incremental changes in technology and processes might influence culture, skill development, or performance feedback loops (Rajagopal et al., 2024). In short, Systems Thinking provides a means to coordinate digital initiatives across multiple layers of the enterprise, thereby facilitating more adaptive and resilient Industry 4.0 transformations and connecting them to management control aspects.

3. Methodology

This study employs a pragmatistic research design with the aim of developing a systems thinking model that synthesizes management control aspects with Industry 4.0 design principles. The methodological framework comprises three key phases: a comprehensive literature review, the construction of influence matrices, and the conversion of these matrices into a dynamic systems thinking model.

Initially, a comprehensive review of the existing literature was undertaken to identify and categorize the major management control aspects and the core design principles associated with Industry 4.0. This process resulted in the identification of six clusters of management control aspects (budgeting & planning, performance appraisal, compensation systems, organizational culture, change management, and information feedback loops) and six Industry 4.0 design principles (interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity). The literature research not only formed the theoretical basis for these clusters and principles, but also served as the basis for the development of a dual-matrix approach that systematically analyses the complex, bidirectional interaction of Industrie 4.0 principles and management control aspects.

To go beyond static, tabular representations, the influence matrices were then transformed into a systems thinking model by converting the qualitative data into diagrams that visually capture the inherent feedback loops and impact chains of the interdependent relationships. The transformation process followed the methodological guidelines proposed by Rajagopal et al. (2024), providing a dynamic framework that highlights key leverage points and areas for strategic intervention.

4. Results

Based on the literature the major management control aspects were identified and categorized into six clusters. In parallel, Industry 4.0 introduces six core design principles: Interoperability, Virtualization, Decentralization, Real-Time Capability, Service Orientation, and Modularity. As businesses integrate emerging technologies—ranging from advanced analytics and cloud-based platforms to decentralized ledger systems—control mechanisms must evolve to capture real-time data and transform it into actionable insights (Azkan et al., 2020). This shift calls for adaptive feedback loops and flexible governance structures that emphasize collaboration between technological actors (e.g., IoT devices, AI agents) and human stakeholders (Frank et al., 2019). Research also underscores the importance of organizational learning and culture in fostering a digital mindset. As shown in the review paper of Sony & Naik (2020), organizations successful in harnessing Industry 4.0 innovations often incorporate continuous improvement and systems thinking into their core strategies, ensuring that real-time data and networked technologies reinforce, rather than disrupt, established control processes. In this context, the following sections present empirical findings that link established management control frameworks with the defining design principles of Industrie 4.0. In particular, section 4.1 outlines the relationship between core aspects of management control and digital imperatives, while section 4.2 applies a systems thinking model to illuminate feedback loops and interdependencies within this changing landscape.

4.1. Relationship of Management Control and Industry 4.0 Principles

Contemporary research increasingly acknowledges that effective management control in the context of Industry 4.0 demands more than simply adding new digital technologies; rather, it involves reconfiguring systems to address rapid, technology-driven change (Frank et al., 2019; Cimini et al., 2021). According to Rikhardsson & Yigitbasioglu (2018), integrating big-data analytics tools with management control systems can strengthen strategic alignment, assuming that managers possess the necessary data-interpretation skills. These observations align with the notion that Industry 4.0 principles—Interoperability, Virtualization, Decentralization, Real-Time Capability, Service Orientation, and Modularity—should be embedded in management control practices (Tortorella & Fettermann, 2018).

Table 1 and Table 2 illustrate how 1) Management Control Aspects (e.g., budgeting, performance appraisal) affect Industry 4.0 principles, and 2) Industry 4.0 principles impact those same control mechanisms. This bidirectional view clarifies that neither set of elements is autonomous; instead, they co-evolve to shape organizational behaviors and outcomes (Frank et al., 2019). For example, budgeting and planning that rely on real-time data can enhance interoperability across departments Rikhardsson & Yigitbasioglu (2018). In turn, decentralization—one of the Industry 4.0 pillars—can stimulate autonomous decision-making, but it can also lead to fragmentation if budgets and performance indicators are not properly aligned (Otley, 1999).

Table 1. Influence matrix of management control aspects on Industry 4.0 principles.

Management Control Aspects to Industry 4.0 Principles	Interoperability	Virtualization	Decentralization	Real-Time Capability	Service Orientation	Modularity
Budgeting & Planning (BP)	++	++	+−	++	+	+
Performance Appraisal (PA)	+	+	+−	++	+	+−
Compensation Systems (CS)	+−	+	+−	+−	++	+
Organizational Culture (OC)	++	++	++	+−	++	+
Change Management (CM)	++	++	+−	++	++	+
Information Feedback Loops (IFL)	++	++	++	++	+	+

Table 2. Influence matrix of Industry 4.0 principles on management control aspects.

Industry 4.0 Principle to Management Control Aspects	Budgeting & Planning	Performance Appraisal	Compensation Systems	Organizational Culture	Change Management	Information Feedback Loops
Interoperability	+	+	+−	+	+	++
Virtualization	++	+	+	+	+−	++
Decentralization	+−	+	+−	++	+−	+
Real-Time Capability	++	++	+−	+−	++	++
Service Orientation	+	+	+	++	+	+
Modularity	+	+−	+	++	+	+

Legend: "+" → Reinforcing relationship, "++" → Strong reinforcing relationship, "+−" → Relationship could be reinforcing or reversing, depending on the specific context, "−" → Reversing relationship.

Performance appraisal shows a particularly strong alignment with virtualization and decentralization. Cloud-based dashboards and IoT-driven data provide more granular metrics for employee performance (Naranjo-Gil et al., 2016), prompting teams to adjust goals dynamically (Zimmerman & Zahniser, 1991). However, real-time metrics may inadvertently exacerbate stress or short-termism (Cardinal et al., 2019). Compensation systems mostly reinforce Industry 4.0 principles through targeted incentives (Tessier & Otley, 2012). If reward structures prioritize knowledge-sharing, they boost interoperability; if they tie bonuses to data-driven key performance indicators, they advance real-time capability (Ahrens & Chapman, 2005). Yet focusing excessively on specific metrics can suppress broader organizational learning (Diefenbach et al., 2009). Likewise, organizational culture and change management reveal wide-ranging impacts on all six Industry 4.0 principles. A collaborative, innovation-friendly culture quickens the adoption of digital solutions (Nadkarni & Prügl, 2021), while robust change management practices are vital for mitigating resistance to decentralization and real-time controls (Cappelletti et al., 2024) Empirical work shows that proactive change initiatives not only speed up technology adoption but also yield deeper structural changes in control processes. Information feedback loops—often marked as "++" in the matrices—amplify real-time decision-making and interoperability by providing on-demand metrics (Santos et al., 2017), feedback loops fuel short-term agility and long-term adaptability. Organizations do however, risk cognitive overload if excessive data complicates managerial judgment (Jollands et al., 2018). Taken as a whole, the matrices illustrate that merging Industry 4.0 principles with established management control practices fundamentally reshapes how control mechanisms operate. Success hinges on embracing digital capabilities while recognizing social dimensions such as employee well-being, cultural norms, and leadership support (Frank et al., 2019). Culture in the matrix shows a positive relationship to most Industry 4.0 principles, reflecting the well-established view that a collaborative, innovation-friendly culture underpins successful digital transformations (Nadkarni & Prügl, 2021) Fostering trust and psychological safety, for instance, bolsters service orientation by facilitating open feedback and iterative improvements (Verstegen, 2011). Furthermore, a flexible culture helps teams adapt swiftly to modular product or process designs (Tortorella & Fettermann, 2018).

4.2. Systems Thinking Model of Management Control and Industry 4.0 Principles

Building upon the influence matrices described in Section 4.1, this chapter applies a qualitative, goal-oriented Systems Thinking perspective to capture non-linear interdependencies. Recent work by Rajagopal et al. (2024) demonstrates that tabular data on how Industry 4.0 and management controls interact can be translated into impact chains and causal-loop diagrams, revealing how seemingly discrete factors (e.g., budgeting and decentralization) converge into feedback loops.

In the initial visualization **Figure 1**, each influence is mapped according to its strength and direction, as indicated in **Table 1** and **Table 2**. While such an overview clarifies which elements interact between the management control aspects on one side and Industry 4.0 principles on the other, it does not show the complex web of relationships within each subsystem. Consequently, a second diagram, **Figure 2**, layers in the intra-subsystem influences, reflecting insights from Zürn & Joe (2024) on the importance of considering both cross-subsystem dynamics and internal feedback loops that might amplify or moderate an effect.

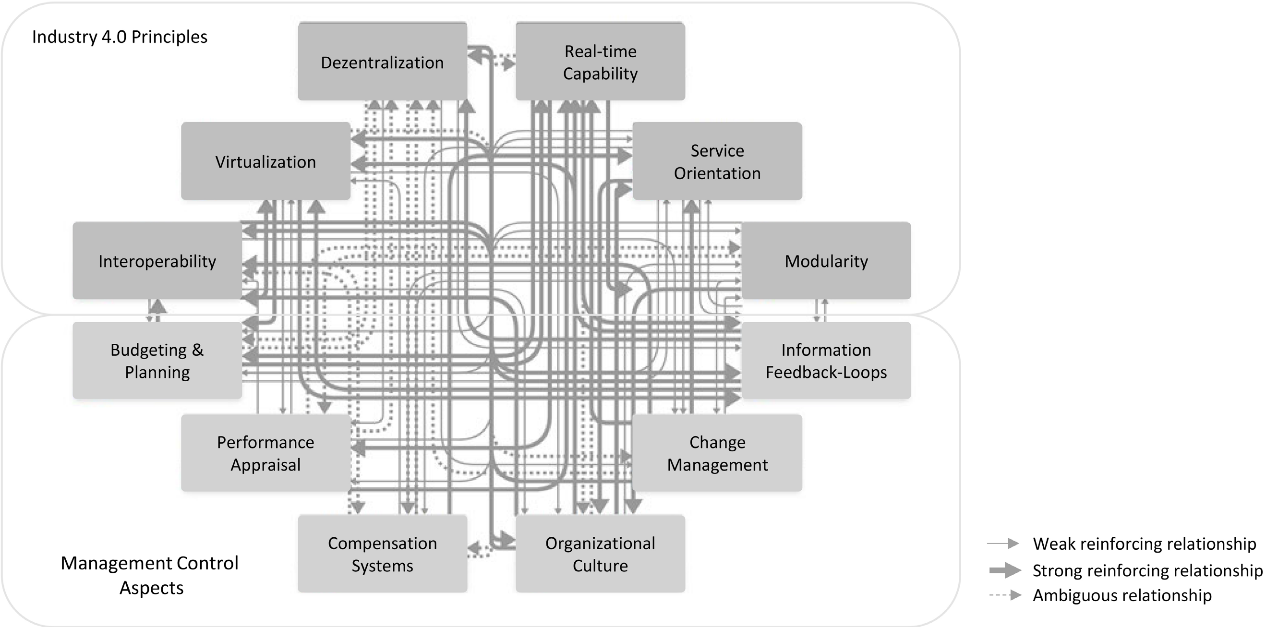

Figure 1. Visualization of all influences of management control aspects on Industry 4.0 principles and vice-versa based on Table 1 and Table 2.

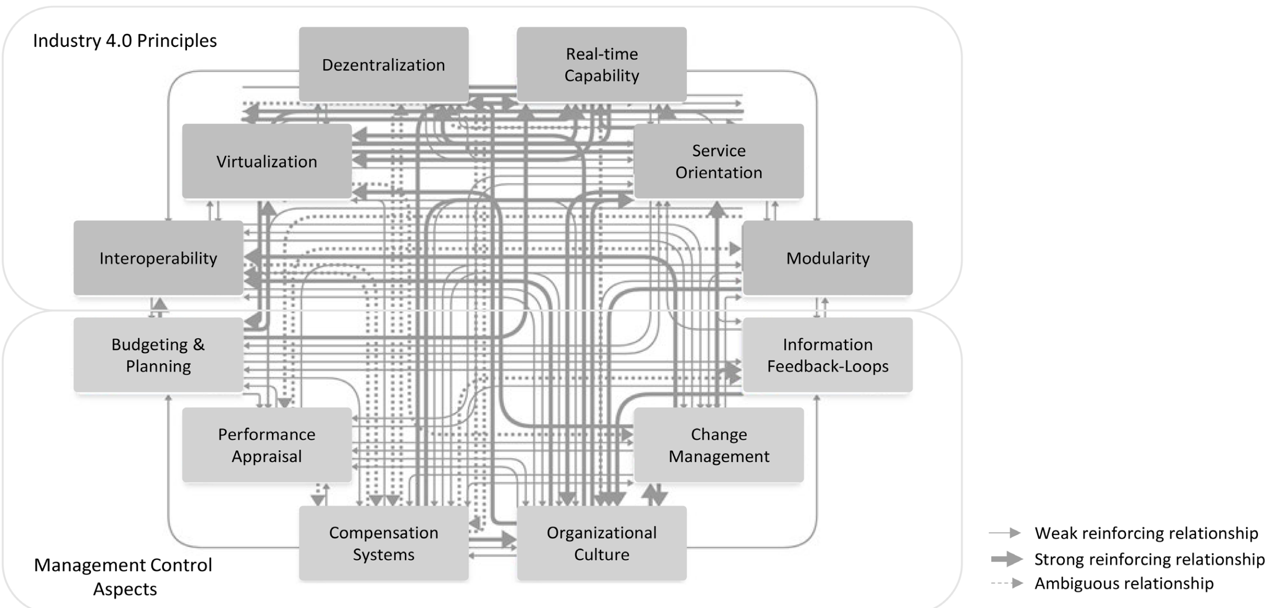

Figure 2. Visualization of all influences within management control aspects and Industry 4.0 principles and the impacts between these subsystems.

Because these combined networks can be dense, a final iteration, Figure 3, removes lower-weight or highly ambivalent connections. This approach helps to spotlight the crucial impact chains that significantly influence management control in digital transformations. For instance, real-time capability can initiate reinforcing loops in budgeting, but if change management fails to keep pace, the same can stall amid resource bottlenecks or cultural resistance.

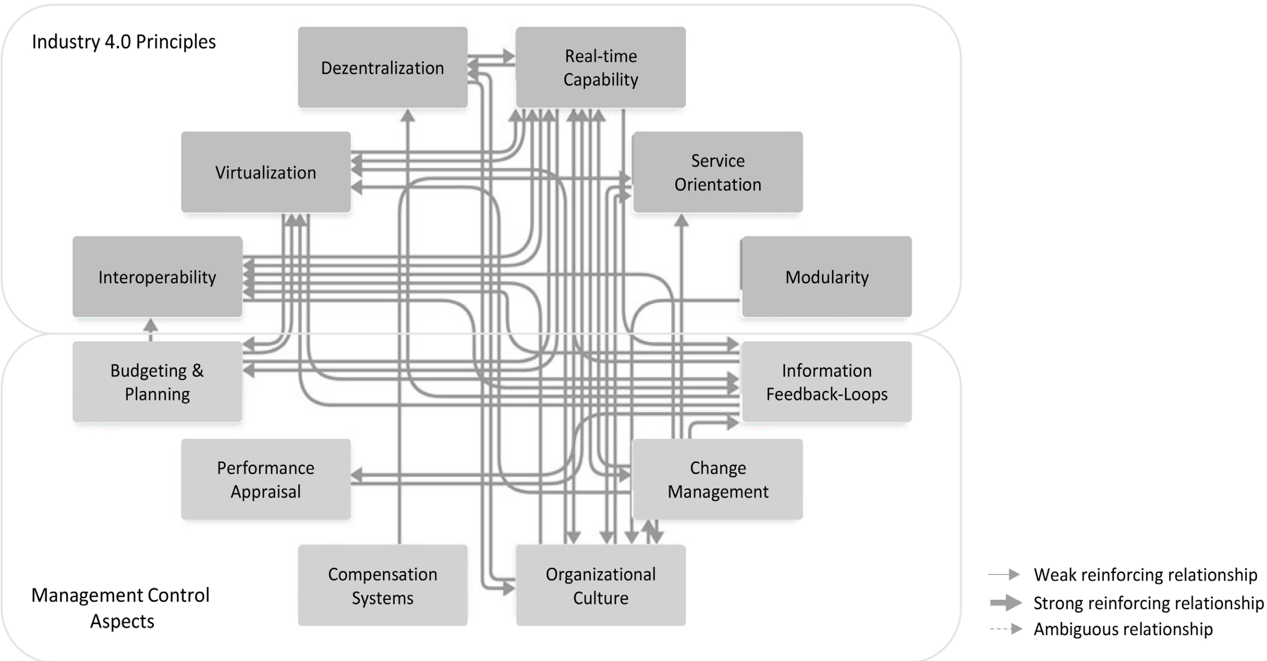

Figure 3. Visualization of the significant influences within management control aspects and Industry 4.0 principles and the impacts between these subsystems.

In essence, Systems Thinking reveals how Industry 4.0 imperatives and management control aspects create intertwined impact chains and loops of cause and effect (Meadows, 2008). Identifying leverage points—places where strategic interventions or resource investments deliver outsized impact–becomes far more straightforward when the complex web of influences is rendered visually (Rajagopal et al., 2024; Muller et al., 2025). Tightly linked elements such as information feedback loops and organizational culture are especially noteworthy, because small modifications can cascade through the system to accelerate or hinder broader transformation.

For instance, a recent SME case from (Muller et al., 2025) showed that implementing a simple real-time dashboard for employees significantly bolstered trust and sped up digital adoption. Overall, this holistic perspective augments two-dimensional matrix analyses by clarifying how short-term successes (e.g., enhanced budgeting accuracy) or setbacks (e.g., overemphasis on performance metrics) can spill over into other areas, driving positive or negative feedback. Consequently, managers gain a richer, system-level grasp of the organizational dynamics at play—ultimately equipping them to guide Industry 4.0 adoption in a manner that balances efficiency, innovation, and cultural well-being.

4.3. Comparative Analysis with Existing Models

Digital transformation frameworks differ markedly in scope, prescriptiveness, and suitability for resource-constrained SMEs. Table 3 compares four prominent models against the systems-thinking influence-matrix proposed in this paper.

Table 3. Comparative overview of digital transformation models.

Model	Strengths	Limitations	Comparison to proposed framework
Grounded-theory (Khamseh et al., 2021)	Comprehensive taxonomy of digital dimensions	Lacks actionable implementation steps; no feedback-loop mapping	Does not visualise interdependencies or guide prioritisation of change levers
Dynamic capabilities (Warner & Wäger, 2019)	Emphasises organisational agility and culture	Abstract; limited operational guidance for SMEs	Omits system-level feedback analysis; insufficient support for incremental adoption
Multi-block framework (Vial, 2019)	Holistic structure across digital building blocks	Complex; designed for large organisations	Too high-level for SME resource planning; does not identify leverage points
Maturity models (Amaral & Peças, 2021)	Clear staged roadmap for digital progression	Focus on advanced maturity stages; low SME applicability	Lacks dynamic causal mapping; poor guidance on trade-offs under resource constraints

All four alternative approaches provide useful conceptual lenses but fall short in operationalising the complex, nonlinear interdependencies central to Industry 4.0 adoption particularly for SMEs with limited budgets and capabilities. Grounded-theory and multi-block models map the landscape comprehensively but offer little strategic sequencing guidance. Dynamic-capabilities frameworks highlight agility but do not reveal how changes in one control element cascade across the organisation. Traditional maturity models prescribe stages but assume a level of digital readiness beyond that of many SMEs.

By contrast, the systems-thinking influence matrix uniquely integrates both "hard" (e.g., real-time data flows) and "soft" (e.g., cultural readiness) variables into a single visual tool, enabling managers to pinpoint high-impact interventions and anticipate unintended consequences. This model's emphasis on feedback loops and leverage points supports incremental, low-cost pilots that generate early wins addressing the practical constraints of SMEs while preserving strategic coherence. Consequently, it offers a more actionable and context-sensitive framework for aligning management control with Industry 4.0 imperatives.

5. Discussion

In the space of Industry 4.0, organizations face unprecedented complexity and dynamism, necessitating a shift towards holistic perspectives in management control (Mercier-Laurent & Monsone, 2019). Traditional business models are being revolutionized by increased digitalization and automation, where firms seek to adopt systematic approaches rather than investing indiscriminately in new technologies (Sjøbakk, 2018). Furthermore, 4th generation management which is in use concurrently is in demand to be re-engineered to align with the advancements of Industry 4.0 (Hallioui et al., 2022). A holistic perspective enables organizations to perceive management control not as a set of isolated functions, but as an interconnected system that drives performance and adaptability in the face of Industry 4.0 (Markulik et al., 2019; Sjøbakk, 2018). Industry 4.0 emphasizes minimizing risks through integrated management systems (Markulik et al., 2019). This necessitates a move away from siloed decision-making towards collaborative strategies that consider the impact of each decision on the entire system.

Systems thinking provides a powerful framework for navigating the complexities of Industry 4.0 by emphasizing the interrelationships and feedback loops that shape organizational behavior. Although the proposed systems thinking approach is robust, it is important to compare it with other classical transformation frameworks in the field of management control, such as the Balanced Scorecard (Kaplan & Norton, 1996), Levers of Control (Simons, 2013), and the Digital Capability Maturity Model (DCMM). These models, while effective in certain contexts, often lack the dynamic interdependency mapping offered by systems thinking. As such, systems thinking can complement rather than replace existing models by providing a more adaptive and integrative perspective. Alternative approaches such as reengineered 4th generation management practices advocate for increased openness in business operations, encouraging collaboration among various stakeholders (Hallioui et al., 2022) which is also addressed by the Systems Thinking model. By viewing the organization as a complex adaptive system, managers can identify leverage points where strategic interventions can produce significant and lasting impact. These leverage points, often found within tightly linked elements such as information feedback loops and organizational culture, can be identified through the visual representation of complex webs of influence. Small modifications in these areas can cascade through the system, accelerating or hindering broader transformation initiatives, making it crucial to understand these dynamics. Systems thinking encourages a shift from linear cause-and-effect thinking to a more circular understanding of how actions produce outcomes that, in turn, influence future behaviors. This approach is particularly valuable in Industry 4.0, where real-time data, automation, and interdepartmental connectivity can magnify the benefits and risks of transformation efforts.

By viewing an organization as an interconnected network of actors—people, processes, and digital tools—managers can more effectively anticipate bottlenecks, adapt strategies, and align resource allocation with broader strategic goals. This contrasts with conventional hierarchical management models and makes it possible to incorporate digital advancements with the least amount of resources and maximum efficiency (Ingaldi & Ulewicz, 2019). An essential component of systems thinking is the use of feedback loops, which capture how organizational actions produce outcomes that influence future behaviors. This is particularly crucial in Industry 4.0, where real-time data and automation can amplify the effects of decisions, making it essential to understand these feedback loops to manage risks and optimize performance.

To align management control systems with the digital imperatives of Industry 4.0, businesses must take proactive steps to adapt their organizational structures, processes, and technologies (Coraci & Abulrub, 2021). Businesses need to restrategize operations and develop extra capabilities to cope with the necessity for additional flexibility and agility (Coraci & Abulrub, 2021). One key recommendation is to embrace data-driven decision-making at all levels of the organization. This involves investing in data analytics capabilities, developing robust data governance frameworks, and empowering employees to use data insights to improve their performance.

Another recommendation is to foster a culture of experimentation and continuous learning. This requires creating a safe environment where employees feel comfortable taking risks, testing new ideas, and learning from failures. Organizations should also invest in training and development programs that equip employees with the skills and knowledge they need to thrive in a digital environment. By integrating Industry 4.0 principles with established management control practices, organizations can reshape how control mechanisms operate. Success depends on embracing digital capabilities while recognizing social dimensions such as employee well-being, cultural norms, and leadership support. Also, a flexible culture helps teams adapt swiftly to modular product or process designs.

Small and medium-sized enterprises (SMEs) face distinctive challenges when integrating Industry 4.0 technologies into existing management control practices due to constrained financial, technical, and human resources (Ranacher et al., 2023). The systems-thinking framework proposed in this paper enables SMEs to visualise the complex interdependencies between control mechanisms and digital imperatives revealing hidden bottlenecks, dependencies, and leverage points for strategic resource allocation (Rajagopal, Hettiarachchi, & Zurn, 2024). To apply this model, SMEs should first inventory their current control practices and assess readiness against relevant Industry 4.0 principles (automation, data analytics, IoT) (Sundaram & Zeid, 2023; Carolis et al., 2017). A phased implementation beginning with small pilot projects that deliver quick wins helps build internal capabilities while minimising upfront investment hurdles (Dahmani, 2024; Amaral & Peças, 2021). Cost-effective tools (open-source software, cloud platforms) and external partnerships further alleviate resource constraints (Ranacher et al., 2023).

Nevertheless, digital transformation carries inherent risks: cybersecurity vulnerabilities, data overload, insufficient digital readiness, and resistance to change can derail implementation if left unaddressed. Proactive mitigation through robust cybersecurity protocols, user-centric data dashboards, and inclusive change management programmes is essential for translating real-time data into actionable insights without overwhelming decision-makers. By systematically modelling both "hard" (e.g., process throughput) and "soft" (e.g., trust, culture) variables, SMEs gain a holistic, system-level view that clarifies how incremental changes cascade across the organisation. This balanced, adaptive approach equips managers to guide Industry 4.0 adoption in a manner that aligns efficiency, innovation, and cultural well-being ultimately unlocking sustainable competitive advantage (Dahmani, 2024).

6. Conclusion

This article presents a novel integrative framework that combines management control with Industry 4.0 design principles through the lenses of Systems Thinking. Findings provide a practical roadmap for organizations to integrate Industry 4.0 technologies into management control frameworks while ensuring operational efficiency, strategic agility, and sustained competitive advantage. Future research could further refine this framework by exploring sector-specific digital transformation challenges, assessing the impact of emerging technologies such as quantum computing and advanced AI, and developing more adaptive, real-time management control models that respond dynamically to the evolving digital landscapes.

The proposed influence matrix offers a structured way to assess the interplay between traditional managerial practices and digital imperatives. While this study mainly relies on a theoretical model supported by literature, recent field studies conducted by one of the authors (Zürn et al., 2022); Zürn & Joe (2024), Rajagopal et al. (2024), Muller et al. (2025) have begun to validate the elements of the influence matrix and systems thinking model in actual manufacturing settings. However, with the exemption of FabLanka Foundation Ltd., Sri Lanka (Rajagopal et al., 2024) the name of those companies must not be disclosed due to confidentiality agreements. Therefore, future research on the framework requires further open-access empirical validation and refinement. Furthermore, the integration of Actor Network Theory (ANT) with influence matrices and systems thinking modeling could also provide a robust framework for assessing how traditional management practices adapt to the demands of Industry 4.0. By mapping the network of human and non-human actors and their influences, managers will be able to identify areas where existing management control practices need shaping and reshaping. This comprehensive approach can also be studied through further research in institutions; so, it may support the development of more agile, responsive, and effective management control systems that are aligned with the dynamic nature of Industry 4.0. Case studies in manufacturing, healthcare, or service sectors such as private sector higher education, particularly among SMEs could help evaluate the framework's real-world applicability. Quantitative methods such as structural equation modeling or simulation could also strengthen the findings, enabling a more precise understanding of the causal relationships between management control aspects and Industry 4.0 principles.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abeysinghe, A. A. C. (2010). *Consensual Spaces of Control Systems: A Theoretical Review.* Unpublished Thesis, The University of Manchester.

Abiodun, T. S., Rampersad, G., & Brinkworth, R. (2023). Driving Smartness for Organizational Performance through Industry 4.0: A Systems Perspective. *Journal of Manufacturing Technology Management, 34,* 40-63. https://doi.org/10.1108/jmtm-09-2022-0335

Aheleroff, S., Mostashiri, N., Xu, X., & Zhong, R. Y. (2021). Mass Personalisation as a Service in Industry 4.0: A Resilient Response Case Study. *Advanced Engineering Informatics, 50,* Article ID: 101438. https://doi.org/10.1016/j.aei.2021.101438

Ahmad, S., Halim, H. A., Khan, M. J., & Ahmad, N. H. (2020). Health 4.0: Learning, Innovation, and Collaboration of Small and Medium Private Hospitals in India. In *Advances in Business Strategy and Competitive Advantage* (pp. 104-122). IGI Global. https://doi.org/10.4018/978-1-7998-2577-7.ch007

Ahrens, T. (2016). Management Controls That Anchor Other Organizational Practices. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.2862914

Ahrens, T., & Chapman, C. S. (2005). Management Accounting as Practice. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.816784

Amaral, A., & Peças, P. (2021). A Framework for Assessing Manufacturing SMEs Industry 4.0 Maturity. *Applied Sciences, 11,* Article No. 6127. https://doi.org/10.3390/app11136127

Azkan, C., Möller, F., Meisel, L., & Otto, B. (2020). Service Dominant Logic Perspective on Data Ecosystems—A Case Study Based Morphology. In *European Conference on Information Systems* (pp. 7-11). Researchgate. https://www.researchgate.net/publication/341205004

Barari, A., & Tsuzuki, M. S. G. (2023). Smart Manufacturing and Industry 4.0. *Applied Sciences, 13,* Article No. 1545. https://doi.org/10.3390/app13031545

Belli, L., Davoli, L., Medioli, A., Marchini, P. L., & Ferrari, G. (2019). Toward Industry 4.0 with IoT: Optimizing Business Processes in an Evolving Manufacturing Factory. *Frontiers in ICT, 6,* Article No. 17. https://doi.org/10.3389/fict.2019.00017

Briand, L. (2004). Reconceptualisation du contrôle de gestion: Une étude de cas fondée sur la théorie de la structuration. *Comptabilité Contrôle Audit, 10,* 283-295. https://doi.org/10.3917/cca.103.0283

Briand, L., & Bellemare, G. (1999). Une conception structurationniste du contrôle de gestion: Une démonstration empirique. *Comptabilité Contrôle Audit, 5,* 29-44. https://doi.org/10.3917/cca.051.0029

Butt, J. (2020). Exploring the Interrelationship between Additive Manufacturing and Industry 4.0. *Designs, 4,* Article No. 13. https://doi.org/10.3390/designs4020013

Camarinha-Matos, L. M., Fornasiero, R., & Afsarmanesh, H. (2017). Collaborative Networks as a Core Enabler of Industry 4.0. In L. M. Camarinha-Matos, H. Afsarmanesh, & R. Fornasiero (Eds.), *IFIP Advances in Information and Communication Technology* (pp. 3-17). Springer International Publishing. https://doi.org/10.1007/978-3-319-65151-4_1

Cappelletti, L., Savall, H., & Zardet, V. (2024). *Socio-Economic Approach to Management: Science-Based Consulting for Sustainability.* https://doi.org/10.1007/978-3-031-43875-2

Cardinal, L. B., Kreutzer, M., & Miller, C. C. (2019). *Organizational Control. Management.*

Chowdhury, A., & Shil, N. C. (2023). Management Control Systems in the Business Sector: Understanding Trends from Selected Literature in an International Setting. *Indonesian Journal of Economics and Management, 3,* 214-230. https://doi.org/10.35313/ijem.v3i2.4649

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. (2021). How Do Industry 4.0 Technologies Influence Organisational Change? An Empirical Analysis of Italian SMEs. *Journal of Manufacturing Technology Management, 32,* 695-721. https://doi.org/10.1108/jmtm-04-2019-0135

Cirera, X., Comin, D., & Cruz, M. (2018). *Bridging the Technological Divide Technology*

Adoption by Firms in Developing Countries.

Cisneros-Cabrera, S., Sampaio, P., & Mehandjiev, N. (2018). A B2B Team Formation Microservice for Collaborative Manufacturing in Industry 4.0. In *2018 IEEE World Congress on Services (Services)* (pp. 37-38). IEEE. https://doi.org/10.1109/services.2018.00032

Cogliati, D., Falchetto, M., Pau, D., Roveri, M., & Viscardi, G. (2018). Intelligent Cyber-Physical Systems for Industry 4.0. In *2018 1st International Conference on Artificial Intelligence for Industries (AI4I)* (pp. 19-22). IEEE. https://doi.org/10.1109/ai4i.2018.8665681

Coraci, F., & Abulrub, A.-H. G. (2021). Investigation into the Role of Leadership in the Management of Digital Transformation for Small and Medium Enterprises. *International Journal of Economics and Management Engineering, 15,* 349-353.

Dahmani, M. (2024). The Impact of the Fourth Industrial Revolution on Business Performance and Sustainability: A Literature Review. *Theoretical Economics Letters, 14,* 94-106. https://doi.org/10.4236/tel.2024.141006

De Carolis, A., Macchi, M., Kulvatunyou, B., Brundage, M. P., & Terzi, S. (2017). Maturity Models and Tools for Enabling Smart Manufacturing Systems: Comparison and Reflections for Future Developments. In J. Ríos, A. Bernard, A. Bouras, & S. Foufou (Eds.), *Product Lifecycle Management and the Industry of the Future* (pp. 23-35). Springer International Publishing. https://doi.org/10.1007/978-3-319-72905-3_3

Dhirani, L. L., Armstrong, E., & Newe, T. (2021). Industrial IoT, Cyber Threats, and Standards Landscape: Evaluation and Roadmap. *Sensors, 21,* Article No. 3901. https://doi.org/10.3390/s21113901

Diefenbach, T., By, R. T., & Klarner, P. (2009). A Multi-Dimensional Analysis of Managers' Power—Functional, Socio-Political, Interpretive-Discursive, and Socio-Cultural Approaches. *Management Revu, 20,* 413-431. https://doi.org/10.5771/0935-9915-2009-4-413

Dos Santos, L. M. A. L., da Costa, M. B., Kothe, J. V., Benitez, G. B., Schaefer, J. L., Baierle, I. C. et al. (2021). Industry 4.0 Collaborative Networks for Industrial Performance. *Journal of Manufacturing Technology Management, 32,* 245-265. https://doi.org/10.1108/jmtm-04-2020-0156

Duan, L., & Da Xu, L. (2021). Data Analytics in Industry 4.0: A Survey. *Information Systems Frontiers, 26,* 2287-2303. https://doi.org/10.1007/s10796-021-10190-0

Egor, P. (2020). Digital Transformation of Industrial Companies: What Is Management 4.0? In *2020 The 11th International Conference on E-Business, Management and Economics* (pp. 131-138). ACM. https://doi.org/10.1145/3414752.3414779

Eissa, H. (2020). Unleashing Industry 4.0 Opportunities: Big Data Analytics in the Midstream Oil & Gas Sector. In *The International Petroleum Technology Conference* (IPTC-19802-Abstract). https://doi.org/10.2523/iptc-19802-abstract

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 Technologies: Implementation Patterns in Manufacturing Companies. *International Journal of Production Economics, 210,* 15-26. https://doi.org/10.1016/j.ijpe.2019.01.004

Greve, J., Ax, C., Bedford, D. S., Bednarek, P., Brühl, R., Dergård, J. et al. (2017). The Impact of Society on Management Control Systems. *Scandinavian Journal of Management, 33,* 253-266. https://doi.org/10.1016/j.scaman.2017.08.002

Haleem, A., & Javaid, M. (2019). Additive Manufacturing Applications in Industry 4.0: A Review. *Journal of Industrial Integration and Management, 4,* Article ID: 1930001. https://doi.org/10.1142/s2424862219300011

Hallioui, A., Herrou, B., Santos, R. S., Katina, P. F., & Egbue, O. (2022). Systems-Based Approach to Contemporary Business Management: An Enabler of Business Sustainability in a Context of Industry 4.0, Circular Economy, Competitiveness and Diverse Stakeholders. *Journal of Cleaner Production, 373,* Article ID: 133819. https://doi.org/10.1016/j.jclepro.2022.133819

Hermann, M., Pentek, T., & Otto, B. (2016). Design Principles for Industrie 4.0 Scenarios. In *2016 49th Hawaii International Conference on System Sciences (HICSS)* (pp. 3928-3937). IEEE. https://doi.org/10.1109/hicss.2016.488

Hol, A. (2021). Business Transformations within Intelligent Eco-Systems. In P. K. Pattnaik et al. (Eds.), *Proceedings of International Conference on Smart Computing and Cyber Security* (pp. 275-284). Springer. https://doi.org/10.1007/978-981-15-7990-5_27

Ingaldi, M., & Ulewicz, R. (2019). Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector. *Sustainability, 12,* Article No. 217. https://doi.org/10.3390/su12010217

Janmaijaya, M., Shukla, A. K., Muhuri, P. K., & Abraham, A. (2021). Industry 4.0: Latent Dirichlet Allocation and Clustering Based Theme Identification of Bibliography. *Engineering Applications of Artificial Intelligence, 103,* Article ID: 104280. https://doi.org/10.1016/j.engappai.2021.104280

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2023). An Integrated Outlook of Cyber-Physical Systems for Industry 4.0: Topical Practices, Architecture, and Applications. *Green Technologies and Sustainability, 1,* Article ID: 100001. https://doi.org/10.1016/j.grets.2022.100001

Jollands, S., Akroyd, C., & Sawabe, N. (2018). Management Controls and Pressure Groups: The Mediation of Overflows. *Accounting, Auditing & Accountability Journal, 31,* 1644-1667. https://doi.org/10.1108/aaaj-10-2016-2747

Kabasakal, I., Keskin, F. D., Ventura, K., & Soyuer, H. (2017). From Mass Customization to Product Personalization in Automotive Industry: Potentials of Industry 4.0. *Pressacademia, 4,* 244-250. https://doi.org/10.17261/pressacademia.2017.486

Kaplan, R., & Norton, D. (1996). *The Balanced Scorecard: Translating Strategy into Action*. Harvard Business School Press. https://www.hbs.edu/faculty/Pages/item.aspx?num=8831

Karabegovic, I., Karabegovic, E., Mahmic, M., & Husak, E. (2019). The Role of Smart Sensors in Production Processes and the Implementation of Industry 4.0. *Journal of Engineering Sciences, 6,* b8-b13. https://doi.org/10.21272/jes.2019.6(2).b2

Khamseh, A., Mirfallah Lialestani, M. A., & Radfar, R. (2021). Digital Transformation Model, Based on Grounded Theory. *Journal of Information Systems and Telecommunication (JIST), 9,* 275-284. https://doi.org/10.52547/jist.9.36.275

Khan, I. H., & Javaid, M. (2022). Role of Internet of Things (IoT) in Adoption of Industry 4.0. *Journal of Industrial Integration and Management, 7,* 515-533. https://doi.org/10.1142/s2424862221500068

Khan, W. A., Wisniewski, L., Lang, D., & Jasperneite, J. (2017). Analysis of the Requirements for Offering Industrie 4.0 Applications as a Cloud Service. In *2017 IEEE 26th International Symposium on Industrial Electronics (ISIE)* (pp. 1181-1188). IEEE. https://doi.org/10.1109/isie.2017.8001413

Kim, D. (2000). *A User's Reference Guide Systems Thinking Tools. Systems Thinking Tools: A User's Reference Guide*. Pegasus Communications. https://www.pegasuscom.com

Lampropoulos, G., Siakas, K., & Anastasiadis, T. (2019). Internet of Things in the Context of Industry 4.0: An Overview. *International Journal of Entrepreneurial Knowledge, 7,* 4-

19. https://doi.org/10.2478/ijek-2019-0001

Lipshitz, C. R., Friedman, V. J., & Popper, M. (1990). The Fifth Discipline: The Art and Practice of the Learning Organization, by Peter Senge, New York: Doubleday/Currency, 1990. *Human Resource Management, 29,* 343-348. https://www.academia.edu/88173789/The_fifth_discipline_The_art_and_practice_of_the_learning_organization_by_Peter_Senge_New_York_Doubleday_Currency_1990

Liu, C., & Zhong, R. Y. (2017). Internet of Things for Manufacturing in the Context of Industry 4.0. In *Advances in Transdisciplinary Engineering* (pp. 1013-1022). IOS Press. https://doi.org/10.3233/978-1-61499-779-5-1013

Liu, N., Sun, H., Du, X., & Edziah, B. K. (2022). Manufacturing Company Management and Innovation in the Age of Digital Transition. *American Journal of Industrial and Business Management, 12,* 796-805. https://doi.org/10.4236/ajibm.2022.125041

Makin, D., & Boyle, E. (2019). Industry 4.0 and the Digital Transformation Journey. *The APPEA Journal, 59,* 643-646. https://doi.org/10.1071/aj18261

Markulik, Š., Sinay, J., & Pačaiová, H. (2019). Quality Assurance in the Automotive Industry and Industry 4.0. In D. Cagáňová et al. (Eds.), *Smart Technology Trends in Industrial and Business Management* (pp. 217-225). Springer International Publishing. https://doi.org/10.1007/978-3-319-76998-1_15

Marnewick, C., & Marnewick, A. L. (2020). The Demands of Industry 4.0 on Project Teams. *IEEE Transactions on Engineering Management, 67,* 941-949. https://doi.org/10.1109/tem.2019.2899350

Meadows, D. H. (2008). *Thinking in Systems*. Earthscan.

Mercier-Laurent, E., & Monsone, C. R. (2019). Ecosystems of Industry 4.0. In *Proceedings of the 11th International Conference on Management of Digital EcoSystems* (pp. 115-119). ACM. https://doi.org/10.1145/3297662.3365793

Muller, D. P., Holzner, M., & Zurn, S. G. (2025). A Systems Thinking Based Sustainable Business Model Framework—An Appropriate Approach for the Design of Sustainable Business Models in Start-Up Consulting. *International Business Research, 18,* 54-63. https://doi.org/10.5539/ibr.v18n1p54

Nadkarni, S., & Prügl, R. (2021). Digital Transformation: A Review, Synthesis and Opportunities for Future Research. *Management Review Quarterly, 71,* 233-341. https://doi.org/10.1007/s11301-020-00185-7

Naranjo-Gil, D., Sánchez-Expósito, M., & Gómez-Ruiz, L. (2016). Traditional vs. Contemporary Management Control Practices for Developing Public Health Policies. *International Journal of Environmental Research and Public Health, 13,* Article No. 713. https://doi.org/10.3390/ijerph13070713

Nazarov, D., & Klarin, A. (2020). Taxonomy of Industry 4.0 Research: Mapping Scholarship and Industry Insights. *Systems Research and Behavioral Science, 37,* 535-556. https://doi.org/10.1002/sres.2700

Oks, S. J., Jalowski, M., Lechner, M., Mirschberger, S., Merklein, M., Vogel-Heuser, B. et al. (2022). Cyber-Physical Systems in the Context of Industry 4.0: A Review, Categorization and Outlook. *Information Systems Frontiers, 26,* 1731-1772. https://doi.org/10.1007/s10796-022-10252-x

Oluwaseun Adebayo, A., Shanker Chaubey, M., & Petiho Numbu, L. (2019). Industry 4.0: The Fourth Industrial Revolution and How It Relates to the Application of Internet of Things (IoT). *Journal of Multidisciplinary Engineering Science Studies, 5,* 2477-2481.

Otley, D. (1999). Performance Management: A Framework for Management Control Systems Research. *Management Accounting Research, 10,* 363-382. https://doi.org/10.1006/mare.1999.0115

Pačaiová, H., Nagyová, A., Turisová, R., Hijj, J., Vilinský, T., & Firmentová, K. (2021). Principles of Management and Position of Maintenance in the I4.0 Environment. *Acta Mechanica Slovaca, 25,* 14-19. https://doi.org/10.21496/ams.2021.012

Rajagopal, R., Hettiarachchi, C., & Zürn, S. G. (2024). Using a Result-Oriented Systems Thinking Approach to Design and Evaluate Strategies for the Digital Transformation Management of Small and Medium-Sized Enterprises (SMEs). *Sustainable Manufacturing and Service Economics, 3,* Article ID: 100023. https://doi.org/10.1016/j.smse.2024.100023

Ramzan, A., Cisneros-Cabrera, S., Sampaio, P., Mehandjiev, N., & Kazantsev, N. (2020). Digital Services for Industry 4.0: Assessing Collaborative Technology Readiness. In M. Themistocleous, & M. Papadaki (Eds.), *Information Systems* (pp. 609-622). Springer International Publishing. https://doi.org/10.1007/978-3-030-44322-1_45

Rana, B., & Rathore, S. S. (2023). Industry 4.0—Applications, Challenges and Opportunities in Industries and Academia: A Review. *Materials Today: Proceedings, 79,* 389-394. https://doi.org/10.1016/j.matpr.2022.12.162

Ranacher, L., Stocker, R., Riegler, M., Schwarzbauer, P., & Hesser, F. (2023). Digitalization of Small and Medium Sized Sawmills in Austria: A Survey about Business Processes. *European Journal of Wood and Wood Products, 81,* 267-280. https://doi.org/10.1007/s00107-022-01800-y

Rikhardsson, P., & Yigitbasioglu, O. (2018). Business Intelligence & Analytics in Management Accounting Research: Status and Future Focus. *International Journal of Accounting Information Systems, 29,* 37-58. https://doi.org/10.1016/j.accinf.2018.03.001

Rowlands, H., & Milligan, S. (2020). Quality-Driven Industry 4.0. In S. M. Dahlgaard-Park, & J. J. Dahlgaard (Eds.), *Key Challenges and Opportunities for Quality, Sustainability and Innovation in the Fourth Industrial Revolution* (pp. 3-30). World Scientific. https://doi.org/10.1142/9789811230356_0001

Saniuk, S., Grabowska, S., & Gajdzik, B. (2020). Social Expectations and Market Changes in the Context of Developing the Industry 4.0 Concept. *Sustainability, 12,* Article No. 1362. https://doi.org/10.3390/su12041362

Santos, M. Y., Oliveira e Sá, J., Costa, C., Galvão, J., Andrade, C., Martinho, B. et al. (2017). A Big Data Analytics Architecture for Industry 4.0. In Á. Rocha et al. (Eds.), *Recent Advances in Information Systems and Technologies* (pp. 175-184). Springer International Publishing. https://doi.org/10.1007/978-3-319-56538-5_19

Saxena, K. K., & Awasthi, A. (2020). Novel Additive Manufacturing Processes and Techniques in Industry 4.0. In I. Karabegović et al. (Eds.), *Handbook of Research on Integrating Industry 4.0 in Business and Manufacturing* (pp. 439-455). IGI Global. https://doi.org/10.4018/978-1-7998-2725-2.ch019

Schütze, A., Helwig, N., & Schneider, T. (2018). Sensors 4.0—Smart Sensors and Measurement Technology Enable Industry 4.0. *Journal of Sensors and Sensor Systems, 7,* 359-371. https://doi.org/10.5194/jsss-7-359-2018

Schwab, K. (2016). The Fourth Industrial Revolution. In منشورات جامعة دمشق (Vol. 1999, Issue December).

Simons, R. (2013). The Entrepreneurial Gap: How Managers Adjust Span of Accountability and Span of Control to Implement Business Strategy. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2280355

Singh, H. (2021). Big Data, Industry 4.0 and Cyber-Physical Systems Integration: A Smart Industry Context. *Materials Today: Proceedings, 46,* 157-162.

https://doi.org/10.1016/j.matpr.2020.07.170

Sjøbakk, B. (2018). The Strategic Landscape of Industry 4.0. In I. Moon et al. (Eds.), *Advances in Production Management Systems. Smart Manufacturing for Industry 4.0* (pp. 122-127). Springer International Publishing. https://doi.org/10.1007/978-3-319-99707-0_16

Sony, M., & Naik, S. (2020). Industry 4.0 Integration with Socio-Technical Systems Theory: A Systematic Review and Proposed Theoretical Model. *Technology in Society, 61,* Article ID: 101248. https://doi.org/10.1016/j.techsoc.2020.101248

Soori, M., Arezoo, B., & Dastres, R. (2023). Internet of Things for Smart Factories in Industry 4.0, a Review. *Internet of Things and Cyber-Physical Systems, 3,* 192-204. https://doi.org/10.1016/j.iotcps.2023.04.006

Stede, V. der W. A. (2015). Budgeting and Management Control. In *Wiley Encyclopedia of Management* (pp. 1-7). John Wiley & Sons. https://doi.org/10.1002/9781118785317.WEOM010075

Steele, R. W., & Albright, C. (2004). Games Managers Play at Budget Time. *MIT Sloan Management Review, 45,* 81-84.

Sundaram, S., & Zeid, A. (2023). Artificial Intelligence-Based Smart Quality Inspection for Manufacturing. *Micromachines, 14,* Article No. 570. https://doi.org/10.3390/mi14030570

Tahsin, M., Chowdhury, M., & Murzi, H. (2020). *The Evolution of Teamwork in Engineering Workplace from First Industry Revolution to Industry 4.0: A Literature Review.*

Tessier, S., & Otley, D. (2012). A Conceptual Development of Simons' Levers of Control Framework. *Management Accounting Research, 23,* 171-185. https://doi.org/10.1016/j.mar.2012.04.003

Tortorella, G. L., & Fettermann, D. (2018). Implementation of Industry 4.0 and Lean Production in Brazilian Manufacturing Companies. *International Journal of Production Research, 56,* 2975-2987. https://doi.org/10.1080/00207543.2017.1391420

Velásquez, N., Estevez, E., & Pesado, P. (2018). Cloud Computing, Big Data and the Industry 4.0 Reference Architectures. *Journal of Computer Science and Technology, 18,* e29. https://doi.org/10.24215/16666038.18.e29

Verstegen, B. H. J. (2011). A Socio-Economic View on Management Control. *International Journal of Social Economics, 38,* 114-127. https://doi.org/10.1108/03068291111091990

Vial, G. (2019). Understanding Digital Transformation: A Review and a Research Agenda. *The Journal of Strategic Information Systems, 28,* 118-144. https://doi.org/10.1016/j.jsis.2019.01.003

Warner, K. S. R., & Wäger, M. (2019). Building Dynamic Capabilities for Digital Transformation: An Ongoing Process of Strategic Renewal. *Long Range Planning, 52,* 326-349. https://doi.org/10.1016/j.lrp.2018.12.001

Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: State of the Art and Future Trends. *International Journal of Production Research, 56,* 2941-2962. https://doi.org/10.1080/00207543.2018.1444806

Zhang, L., Du, X., Hung, J., & Li, H. (2021). Learning Preference: Development in Smart Learning Environments. *Information Discovery and Delivery, 49,* 174-187. https://doi.org/10.1108/idd-07-2020-0080

Zimmerman, M. A., & Zahniser, J. H. (1991). Refinements of Sphere-Specific Measures of Perceived Control: Development of a Sociopolitical Control Scale. *Journal of Community Psychology, 19,* 189-204. https://doi.org/10.1002/1520-6629(199104)19:2<189::aid-jcop2290190210>3.0.co;2-6

Zürn, S., & Joe, M. (2024). Framing Potential Influences of Digital Transformation of Manufacturing SMEs. *Open Journal of Business and Management, 12,* 3661-3675. https://doi.org/10.4236/ojbm.2024.125182

Zürn, S., Müller, D., & Holzner, B. (2022). *New Ways of Quality Management* (pp. 143-162). https://hses.bsz-bw.de/frontdoor/index/index/docId/1866