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REVIEW ARTICLE

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Activating supply chain business models' value potentials through Systems Engineering

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Abstract

New business opportunities, driven by smart digitalization technology and initiatives such as Industry 4.0, significantly change business models and their innovation rate. The complexity of methodologies developed in recent decades for balancing exploration and exploitation activities of digital transformation has risen. Still, the desired integration levels across organizational levels were often not reached. Systems thinking promises to holistically consider interdisciplinary relationships and objectives of various stakeholders across supply chain ecosystems. Systems theory-based concepts can simultaneously improve value identification and aligned transformation among supply networks' organizational and technical domains. Hence, the study proposes synthesizing management science concepts such as strategic alignment with enterprise architecture concepts and artificial intelligence (AI)-driven business process optimization to increase innovation productivity and master the increasing rate of business dynamics at the same time. Based on a critical review, the study explores concepts for innovation, transformation, and alignment in the context of Industry 4.0. The essence has been compiled into a systems engineering-driven framework for agile value generation on operational processes and high-order capability levels. The approach improves visibility for orchestrating sustainable value flows and transformation activities by considering the ambidexterity of exploring and exploiting activities and the viability of supply chain systems and sub-systems. Finally, the study demonstrates the need to harmonize these concepts into a concise methodology and taxonomy for digital supply chain engineering.

KEYWORDS
enterprise architecture, enterprise engineering, Industry 4.0, innovation management, supply chain digitalization, Systems Engineering

1 | INTRODUCTION

Complexity growth through industrial digitalization for networking organizational entities, systems, and components will challenge the engineering work of tomorrow's markets.[1] Industry 4.0 refers to intelligent networked industrial systems that increase production rates by design principles like interoperability, virtualization, decentralization, real-time capabilities, and service orientation.[2] *Artificial Intelligence (AI)* and *Cyber-Physical Systems (CPS)* enable decentralized business cycles with autonomic control of sensing, ruling, and acting. Furthermore, platform-driven business models combine manufacturing processes with digital products, following new rules for marginal cost reduction and network effects.[2–4] Society changes and environmental dynamics recognized by the United Nations and sustainability goals set by their 2030 Agenda are addressed by the Systems Engineering (SE) Vision 2035 of the International Council on Systems Engineering (INCOSE). To master the economic paradigm change, companies must collaboratively develop business across ecosystems, sustain profit and competitive advantages in a volatile environment and reduce pollution simultaneously. Sharing capabilities between ecosystem members minimizes waste, maximizes resource utilization, and shares marginal costs.

SE will become even more interdisciplinary, enabling global innovation and integrating a wide range of systems for considering the objectives of different stakeholders and organizations.[5] Hence, SE gets increasingly relevant for socio-technical and large-scale businesses. Therefore, SE will become a key discipline for designing supply chain systems (SCS) and their supporting systems, focusing on flexibility, robustness, and resilience as a central tenet of the architecture process, which is also recognized by the INCOSE Vision 2035. Recent research on causes of strategic misfit of supply chain design highlights the following reasons: (1) unaligned IT investments across supply chains (SC) of big organizations, (2) un-harmonized IT landscapes as a result of Merger & Acquisitions (M&A), and subsequently, too limited and fragmented alignment, (3) weak alignment of SC objectives and planning approaches in business networks, (4) a lack in process integration and poor end-to-end visibility caused by heterogeneous Supply Chain Management (SCM) systems, (5) extensive complexity implied by contradicting process objectives and unaligned IT capabilities, (6) inappropriate SC visibility from insufficient SC design, and (7) a lack in synchronization of alignment activities.[6] Many of these reasons are based on rising globalization activities, such as industry consolidations because of competitive pressure from the eastern economy. Besides, due diligence for M&A activities focuses mostly on financial key figures and not on SC design compatibility. These examples demonstrate the demand for better alignment between SCS within ecosystems.

Efforts in SC integration strongly affect a firm's performance, improving operational performance relative to competitors by reducing delays, tasks, and inefficient flows.[7,8] But, integration effort requires different collaborative work modes from people across an entire system. A focus on SC integration and its impact on business performance are significant to various conceptions along the supply chain and between strategic and operational levels and SC planning of different horizons. Childerhouse and Towill[9] argue in referring to the systems perspective that SC integration efforts result in better performance through optimizing an entire supply chain rather than each of the involved sub-systems. Through integration, trade-offs and far-reaching decisions can be conducted based on shared information and coordination. Various researchers define SC integration by antecedents such as information sharing, coordination, relationship management, and resource sharing.[9,10] Many researchers emphasize integration as an essential dimension of SCM, but the scope, context, and views on the subject vary considerably. There is a range, or rather, a continuum of different types of integration, which depends on the context and situational factors.[11,12] Because of its significance to business performance, SC integration needs to be engineered on different levels by a systems approach due to contextual needs throughout the various systems' life cycles.

For sensing business opportunities and predicting demand, data-driven outside-in approaches provide companies with insight into consumer needs and behavior, which results in higher competitive performance, market competence, and innovativeness.[13] However, the ability to yield innovations from sensed data depends on knowledge for recognizing a signal as a potential[14] and the organizations' ability to lead it through a sensemaking convergence process.[15] Besides, as enterprises are complex social systems with cultural and technical aspects, some business opportunities become visible through the emergence process when systems anticipate new properties.[16] Hence, for ideally exploring and exhausting the value possibilities that emerge from Industry 4.0-driven businesses, the scope of a SE-based methodology needs to include innovation, transformation, capability alignment, and balancing activities from a systems-of-systems perspective. The needs for effective exploring and exploiting value opportunities lead to the formulation of the research question (RQ) and objective (RO) as follows:

- **RQ**: How can Systems Engineering simultaneously improve innovativeness, transformation effectiveness, and alignment of digital SC business models?
- **RO**: Identify key concepts for systematic business model innovation, alignment, and transformation and synthesize the essence into a simplified, holistic framework for agile digital SC business model engineering.

For this reason, this study develops the rationale for a SE-driven integrated framework for digital supply chain model transformation, grounded in the scientific literature and recommends steps for further research.

2 | METHODS AND REVIEWED AREAS

A wide range of scholarly literature has been extensively and critically evaluated to scope the research framework, identify key concepts that inform the study for a holistic view and ground it in theoretical evidence. The following areas were identified as most significant for conceptual innovating sustainable value creation in dynamic business environments: (1) supply chain processes and profitability, (2) opportunity sensing, (3) resource sharing, (4) strategic alignment and dynamic capabilities, (5) ambidexterity of exploration and exploitation activities, (6) systems thinking based business model innovation (BMI), and (7) enterprise architecture management (EAM). Focusing on key research helped avoid sidetracking and ground the present study within an evidence-based theory. Finally, further extensive searching has been conducted for cross-over studies to enrich the research with background information such as context-dependent mechanisms and conditions. The synthesis brings the findings together and leads to developing the SE-driven framework, fostering the emergence of innovations, and leading those through a sensemaking convergence and transformation process to an aligned supply chain design.

3 | REVIEW RESULTS AND THEORETICAL BACKGROUND

Systems Engineering deals with architecting and engineering systems considering characteristics such as the structure, state, function, behavior and holism, the environment, the used resources, and the delivered value.[17] While SE is broadly applied in aerospace and defense, the practice maturity varies across other industries. Its application varies with companies' product complexity and whether those are market-driven or government-contracted with strong regulatory standards.[5] Despite the industries' adoption progress in standardizing practices for SE, significant differences remain based on domain-specific drivers. Hence, a common framework can enhance efficiency and agility significantly. Global megatrends driven by socio-economic changes, technological advances, and greater stakeholder expectations will considerably influence SE. Besides, technological advancement must be applied responsibly and sustainably while transitioning from fossil fuel-based energy. Because these megatrends shape the expectations for systems, products, and services across all industries, enterprises are reinventing themself by adjusting to new societal and technological challenges. Global interactions and interdependencies of machines, logistics systems, and engineering within cyber-physical systems create new flexibility and autonomy. The German Academy of Technology (Acatech) coined this *Industry 4.0 (I40)*. With I40, manufacturing and logistics control change significantly and form the basis for smart factories. Previously implemented SC systems were often ad-hoc developed or grew over time and did not fully integrate organizational and technical issues.[18] However, supply chain systems will increasingly be characterized as cyber-physical and product-service systems and interconnected as broader *systems-of-systems*. SE will become a key discipline providing digital enterprises with a holistic view and interdisciplinary modeling of their supply chain systems.

3.1 | Supply chain design as a driver of profitability and resilience

The Council of Supply Chain Management Professionals (CSCMP, 2022) defines SCM as "*an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of logistics management and manufacturing operations, and it drives coordination of processes across marketing, sales, product design, finance, and information technology*." SC processes significant to the manufacturing industry are (1) *new product development*,[19] (2) *SC planning*—for example, integrated business planning,[20] and stakeholder engagement,[21] (3) *SC operations*—downstream processes, for example, sales order processing and supply matching[22] and SC upstream processes, for example, sourcing, procurement, and manufacturing,[23] (4) *relationship management*,[24] and (5) *SC performance management*.[25]

The main objective of a supply chain is to increase the product or service value that the customer is willing to pay for.[26] Hence, focusing on the entire profitability rather than individual stages increases complete SC networks' competitiveness and value maximization.[27,28] Maximizing the overall business value at given revenue requires minimizing total costs for fulfilling predefined, accepted customer service levels by reducing lead times and inventories and responsive synchronizing and harmonizing extended supply chains. One of the most important key performance indicators (KPI) of production processes is provided by the *Overall Equipment Effectiveness (OEE*), expressing output effectiveness from the perspective of the used resources.[29] *Operational Excellence (OE)* represents an organization's performance effectiveness considering strategic aspects under prevailing conditions.[30] OE is about fulfilling customer requirements using the right methods and systems in the most efficient way to deliver a quality product. OE engineering along the supply chain becomes increasingly important for SE and manufacturing companies to become more flexible, responsive, efficient, and, therefore, more competitive.[31] Hence, OEE and OE are key concepts for optimizing SC performance. Finally, there is a growing literature that links SC sustainability to SC performance consisting of (1) *economic*, (2) *environmental*, and (3) *social goals*.[32] However, because of rising dynamics and SC vulnerabilities, the focus on SCM moves to SC risks management to increase SC resilience.[33–36] Since Hollnagel explored "*resilience engineering*" in 2006 and *"resilience of systems"* by Haimes in 2008, resilience has become an important consideration in SE.[37] Resilience is the ability to provide the required systems' capabilities in the face of adversity.[38] Resilience explicitly considers adverse conditions under which a system operates and must be effectively represented as system requirements.[37] As resilience comes from the convergence of a "whole" system, but activities need to be addressed at a finer level of granularity, SE can contribute by identifying vulnerabilities and root causes from a systems perspective. At the same time, SCM experts focus on their SC domain functions.

AI-based SCM solutions enable one to optimize order plans for entire SC networks, scheduling production orders synchronized across plants. Disruptive technologies influence the development of new supply chain principles to maximize the total generated value.[39] Machine learning and smart services are disruptive technologies for supply chains, evolving rapidly to optimize the efficiency of SCM. They can be applied in several supply chain stages.[40] Industry 4.0 refers to components such as (1) networks, sensors, and platforms for connecting and sensing, (2) cloud and software as a service (SaaS), (3) CPS and self-learning, and (4) orchestration, customization, configuration, and personalization.[41,42] So-called asset-heavy business refers to platform innovations that use operational sensing and condition monitoring methods to support operational excellence. Proposed AI methods are CPS, machine learning, optimization, and simulations, such as business model stress tests using digital twins. Besides, asset-light businesses, such as payment-per-use and marketplaces, can be complemented.

The co-founder of industry 4.0, Wahlster, reported the following applications as among the most important for I40 (1) *sensing*—smart services with collaborative robots, virtual agents, chatbots and softbots, autonomous systems (e.g., cars, ships, trains), (2) *understanding*—for example, answering engines, digital IT assistants, and (3) *acting*—intelligent help systems, recommendation and persuasion systems, intelligent tutor and training systems. Such smart applications are supported by AI methods of (1) *sensing*—signal symbol transformation, multisensor fusion, pattern recognition, recognition of emotions and context; (2) *understanding* of texts, images, video, and spoken dialogue, machine learning, action planning and plan recognition; and (3) *acting*—motion sensor feedback, sensor control, transfer of control, adaptive user interaction, multi-agent and collaboration techniques, and personalized presentation.[43,44] However, the limiting factor for designing smart innovations for supply chains seems to be the creativity of the supply chain engineers. Table 1 shows basic supply chain processes, high-level business objectives, and examples of machine learning (ML) business use cases.

3.1.1 | Getting a better sense of innovation opportunities

Big data technology enables sensing data across social and business contexts, increases analysis productivity,[45] helps companies reshape their competitive strategies, and improves innovativeness and market competence.[46] Besides, demand signal management (DSiM) solutions enable fast response to volatile market forces and improve forecast information accuracy.[47] Moreover, they allow merging signals sensed from different sources such as point of sales, operations, and public data to adjust demand data nearly in real-time. These solutions seem promising for identifying weak signals with high potential for opportunities and improving strategic agility.[48–50] However, value signals can also originate from manufacturing and operations processes' sensing along companies' extended supply chains. But, the ability to identify and exhaust innovation potentials from sensed data depends on an organization's sensemaking convergence process.[14]

3.1.2 | Sharing resources for supporting sustainability

Sharing resources in ecosystems reduces asset investments, supports ecological sustainability, and allows ecosystem members to focus on key strengths.[8,9,14,51] In addition, joint development of customer value propositions and collaborative manufacturing with ecosystem partners promises new rents. According to Rifkin's[4] "*zero marginal cost*" paradigm, the marginal cost of smart services presented by software components converges against zero. Increased resource sharing in manufacturing ecosystems demands higher levels of integration and collaboration for processes such as product lifecycle management, engineering change management, and logistics synchronization between plants, to name a few examples. However, resource sharing

TABLE 1 Supply chain processes, objectives, and example use cases of machine learning.

	Operational excellence				Value propositions			
Business objectives	Due date availability Stock reduction Suitable service levels		OEE and agility Plant and resource utilization		Sustainability - Waste reduction - Emission control		Revenue and profitability Customer satisfaction Market share	
Business processes – value flow	Inbound logistics	Procurement – sourcing	Operations – synchronizing	Outbound logistics	Marketing and sales	Customer services, business planning	Inbound logistics	Procurement – sourcing
Use case examples for machine learning	Predictive maintenance				Big Data analytics			
	Condition monitoring		Supply chain optimization and synchronization				Point-of-sales user modeling and personalized service adaptation	
			Operational sensing and environment sensing					

requires planning and synchronizing the entire supply network holistically. Besides, resource sharing makes aligned SCM conceptions in SC networks essential. Present SCM solutions focus on exchanging products and components rather than resources' capacities. Hence, SCM solutions need to be extended, and new collaboration processes are required, covering data models, planning and scheduling concepts, exception management, and data replication concepts.

3.1.3 | Agile and reliable business model alignment

For sustainable competitiveness, companies must adapt their strategies and align their business models and IT to comply with new market rules.[52,53] External strategic alignment is about calibrating resources and strategies to the firm's environment.[54] External fit is defined as how well a company's given environmental conditions have been adjusted by structure, process, and strategic characteristics.[53,55] Internal strategic alignment draws on the mobilization and configuration of tangible and intangible internal resources for implementing the defined strategy. According to the contingency theory and the systems perspective, strategic, contextual, and structural factors must be considered to prevent misalignment.[56] Hence, alignment leads to the best performance by considering an entire ecosystem rather than each subsystem involved.[9] Thus, a holistic and detailed view of IT capabilities impacts strategic fit and leads to higher business profitability. It considers fitness across domains[57] and second-order effects of IT capabilities across SCM domains[58] to make the most of IT-business alignment. According to Teece et al.,[59] dynamic capabilities (DC) present the potential for innovative capacity enabling companies to respond to fast-changing business conditions by creating, integrating, and reconfiguring their competencies. McLaren et al.[53] used a profile deviation approach resting on the configurational theory for measuring needed support levels from antecedent capabilities to fit competitive strategy dimensions. Hence, a capability-based concept promises to support the engineering of dynamic organizational alignment.

In innovation management, ambidexterity refers to a company's ability to balance exploration activities (acquiring and assimilating new knowledge) against activities exploiting the developed capabilities' business performance.[60,61] Industrial value creation involves inherently managing conflicts from explorative variability creation and exploitative variability reduction. Ambidextrous organizations balance exploitation and exploration through incremental and discontinuous innovations from handling contradictory structures, processes, and cultures. Conflicts between short-term efficient and mature units are inevitable regarding uncertainties in knowledge exploration as they contradict each other.[62] Dealing with this tension is critical and significant for product and supply chain innovation processes.

3.2 | Digital business model innovation

New digital technologies arise from the digital transformation in social, mobile, analytics, cloud, and IoT in nearly every industry.[63] In the internet of things (IoT), uniquely identifiable objects and interoperable devices interact in global supply networks. In-memory computing (IMC) technology significantly increases the real-time capabilities of enterprise IT systems,[64] enabling large-scale data processing on single platforms and enhancing computing performance for Machine Learning (ML). In recent years, businesses have adopted AI as a technology with serious potential for new value propositions and competitive advantages.[65] AI is seen as a tool that can layer different functions or as a solution to problems beyond the ability of traditional applications.[66] AI refers not only to technology for reasoning, planning, learning, and processing but also to the ability to move and manipulate objects related to its industrial application in cyber-physical systems (CPS).[67] CPS enables decentralized business scenarios and autonomous process reconfiguration.[2] It addresses close connections between embedded systems in global digital networks to monitor and control physical processes.[2] Thus, CPS represents "*smart*" systems depending on the interaction between physical and computational components. CPS emerges from the interconnection of physical components and complex software to form new networked systems capabilities. At the same time, IoT focuses on interconnectivity, integration, and interoperability of physical components on the internet. Integrating IoT and CPS is expected to enhance business model autonomy using real-time platforms. According to Radanliev et al.,[66] cyber scenarios and human engagements in the physical world have been studied excessively in isolation. However, the roadmap to I4.0 is still unclear.[68]

Companies are investing considerably in AI. However, they face challenges in realizing performance gains and creating suitable AI governance practices, which leads to disillusionment about the value generated and the process for obtaining it.[69] A resource orchestration approach is suggested for dealing with this gap. Also, to differentiate the ideation of AI capabilities and their implementation and analyze the relevance to the AI deployment context by applying the resource orchestration theory.[68] First, an exploratory case study can help understand how AI deployment corresponds to a resource orchestration framework in analyzing different AI capabilities patterns. Secondly, identifying patterns of AI-driven resource orchestration of actions and deployment enabled competitive performance and innovation outputs from different AI resource orchestration combinations.[68]

3.2.1 | Circular business models and sensing from a business model perspective

Circular business models (CBM) strive to design products for life cycle extension and create supply chains that recycle the resources used. Besides, to reduce their environmental footprint, trim operational waste, and use expensive resources more efficiently.[70,71] In short, CBM seeks to reduce, retain, and recycle/reconfigure. CBM can assist in adopting innovative opportunities and accessing new markets. Despite the benefits of CBM, barriers were identified, such as the risk of cannibalizing technology equipment, which demonstrates the significance of developing concise concepts for resource sharing with ecosystems.

Lindgren and Aagaard[72] analyze BMs from their sensing characteristics related to the BM dimensions, which differ significantly between businesses. BMs generate more data through sensors than they know and can apply, so most data are not considered or considered "*waste.*" Data have limited value if they cannot be analyzed in time because data move fast and vary due to context in quality. However, sensing increases BMI's "*raw material*." Hence, ongoing, *"daily"* Business model innovation (BMI) for digital business models, according to Lindgren and Aagaard,[71] promises to evaluate the effect of sensed data on value propositions and other BM dimensions fast and responsive to upcoming business opportunities. A collaborative design must consider seeing and learning at all BM levels and leading to collective actions to imply agility and the ability to sense different contexts effectively.

Business modeling has also been adopted for *service-oriented business models*[73] and *service-dominant architecture canvas* focusing on digital capabilities.[74] They focus on learning customer value and designing the offering based on this understanding. Companies benefit from integrating service orientation in business modeling by implying flexibility and responsiveness in business opportunity creation.[72] A capability-based engineering (CBE) approach promises to lead the flexibility of the service-oriented BM approach further to design and component-based development of capability interactions enabling solution substitution and creating sustainment.[17] Besides, CBE supports the reusability of artifacts and services, improving supply chain agility and responsiveness through faster innovation cycles and component-based solution orchestration.

3.2.2 | Business model innovation and systems thinking

Systems thinking (ST) explores real-world entities and focuses on conceptual constructs, supposing the world's social construction is systemic. The ST concepts developed in the early 20th century mainly in biology, ecology, and cybernetics.[75] Significant contributions came from von Bertalanffy (1950)—General Systems Theory (GST); Wiener (1954)—management cybernetics; Beer (1966)—operation research and management science, and *systems dynamics* (e.g., Forrester, 1994), and *Systems Engineering* (e.g., Hall, 1962). GST principles are about organizing systems' subjects and interrelated events or phenomena. Principles are *holism*, *complementarily*, *homeostasis*, *self-organization*, and systems remain aligned where environmental complexity grows.[76] Mingers and With[77] summarize GST as follows: (1) to see a situation holistically, as a set of different interacting elements within an environment, (2) to consider the relationships as more important than the elements for a system's behavior, (3) evaluate a system's properties that arise at different levels and mutual causality, and (4) people act due to various purposes or rationalities, particularly in social systems. According to Halecker and Hartmann,[74] ST offers common formal and holistic views on complex business models, including all components (function, structure, process, and steering). Besides, it enables an interdisciplinary perspective for identifying interdependencies from complex root-cause effects by avoiding isolated analysis, enabling previously uncovered connections. They conclude that systems thinking facilitate the search for new business model designs and their assessment.

Business models and their innovation are extremely complex and show complex adaptive systems (CAS) characteristics as companies are open and social systems.[74,78] They are complex because they are interconnected with many other systems and adaptive, as they need to adapt to environmental changes to succeed sustainably.[59] And business modeling aims to simplify complex interrelationships and makes them understandable.[74,79] Also, business modeling supports the alignment of capabilities and future business development. Socio-technical changes and I40-based innovations drive companies to restructure their BM,[2] and the methods used for their innovation and governance need to support the right levels of integration between the BM components. As BM innovation is among the most complex tasks,[74,77] a systems thinking theory-driven approach will be required for dealing with multi-dimensional relationships and contingencies of a business model.

3.2.3 | Systems Engineering: A common basis for various systems perspectives

Sensibility penetration across engineering practice and the ever-expanding field of SE have produced distinctive new branches in the last decade, such as Model-Based Systems Engineering (MBSE) and *systems-of-systems* (SoS). MBSE supports reducing the complexity of developed systems and improves design productivity.[80] However, systems architectures were often ad-hoc developed or grown over time and did not fully integrate technical issues of hardware, software, security, or others.[18] And System design must be integrated across disciplines, domains, and lifecycle phases to provide a consistent, unique system representation and consider full traceability throughout the SE process. Hence, increasing networking and embedding systems in business ecosystems require a holistic approach. *Systems-of-systems engineering* methods must include a design for interoperability and predicting emerging behaviors. As an interdisciplinary approach, SE focuses on developing and implementing systems considering an overall view of a system's scope and project phases. SE focuses on interoperability standards, integrates all disciplines, and forms a structured development process. Composable design methods provide a systematic approach to reusing corporate intellectual resources, including reference architectures, component specifications, and roadmaps for their development and activation.

Transformative technologies are difficult to predict, but disruptive technologies can influence their development.[18] Hence, SE processes need to become more IT-centric and foster knowledge management among ecosystem members to support innovations and the convergence process. Changes in social, economic, and environment in which smart technologies get deployed affect system capabilities' drivers and SE's work environment. Hence, SE theoretical fundamentals must be developed to better cope with digital transformation dynamics. I40 innovations lead to higher digitalization levels[81] that drive changes in SE processes. Therefore, SE is still developing with engineering, managerial, technology, and leadership issues. SE needs approached multidisciplinary, adopting systems thinking concepts rooted in the GST.[82] Finally, complex systems' governance requires systemic intervention.[81,83] Yearworth[81] observes growing demand for theoretical foundations of SE, addressing fragmented relationships between systems science and complexity theory and GST requirements. SE needs to incorporate social sciences to improve organizational competence for providing an interdisciplinary approach. The following failures related to SE and management science were observed: massive infrastructure project failures,[84] strategic misrepresentation),[85] and strategic ambiguity.[86,81] Hence, SE needs to extensively involve scope and expectation management and deal with different perspectives of involved stakeholders and uncertainties, and a lack of reliable data simultaneously. SE must provide a common basis of methods and language for the management and engineering domains appropriately for managing organizational contingencies between involved stakeholders.

3.3 | The enterprise capability innovation cycle

New sources of competitive advantage originate from companies' implicit and explicit business models.[74,87] Business models are systems with networked business entities and their activities,[77] showing causal relationships between decisions and the produced results.[86] However, although a business model is a system, BM studies do not explain its meaning from the systemic perspective.[74] However, Business Model Innovation (BMI) requires systems thinking (ST) because business models are highly complex, not locally limited, and not static[88,89] and are open social systems.[74] Moreover, BMI needs to approach the dynamics of enterprises caused by changes in strategy and the environment.[90,91] Halecker and Hartmann[74] underpin the need for ST for business modeling under dynamic conditions by drawing similarities to systems modeling.

Complex systems are open, characterized by interdependent entities, and non-linear, interacting with their environment.[92] Emergence results from interrelatedness.[93] Therefore, new value potentials from I40 technology emerge in companies' implicit and explicit business models.[16,74] A critical process is identifying new value potentials that emerge from I40 technology in the changing interactions. Furthermore, due to environmental dynamics, innovation is seen as a continuous process that needs to be balanced with the exploitation processes that Rebovich[16] defines as convergence. For this reason, SE needs effectively contribute to balancing innovation-performance, transformation, and operational performance.

3.3.1 | Conditions for business model emergence and adaptability

As a subset of non-linear dynamic systems, CAS are studied for interdisciplinary insights on the system level, gaining insights into emergent behavior, enabling heterogeneous agents, and supporting systems transition phases.[94] Non-linear systems with a sensitive initial dependency can face large effects caused by small condition changes. Complexity is related to systems' interactions, where components' properties can not necessarily predict the overall System's behavior. The adaptiveness of complex systems relates to reconfiguring themselves in case of small perturbations and retaining most of their previous structure. Chaotic systems can be relatively homeostatic, remaining stable when system parameters change. Still, they can exhibit different behavior at resetting because of path dependency when a parameter passes a particular threshold. In chaos theory, complexity and transition spaces where emergent order co-exists with a disorder are called "*the edge of chaos*." It provides an order required for safeguarding the stability to evolve, but enough degrees of freedom that the system elements and relationships can organize themselves, and emergence can result. While Network theory is about understanding the emergent orders and interactions among agents in complex systems, chaos theory aims to model the best result in innovativeness and the degree of stability for effectiveness.[95] Emergence creates a new order by self-organization, exhibiting properties, patterns, and qualities that arise from the interactions of the individual elements, which relates to holism in systems theory.[93,94] The context of a system of interest is the center of the emergence paradigm.[96]

The complexity theory suggests that organic networks that tend to be *"the edge of chaos"* might raise self-organization and emergent order enabling firms to succeed in eras of rapid change.[93] To encourage self-organization and space for the emergence of possible innovations, managers need to understand how an organization is re-creating itself, as an entity, to a new order and conditions supporting co-innovation across involved organizations. Treating companies as complex evolving systems (CES) may help better understand organization-specific emergence patterns and exhaust possibilities. Learning, knowledge generation, and sharing must promote co-evolution, self-organization, emergence, and convergence.[93,94] According to the findings on CAS, the possibilities SE can support order, conditions, and active foster emergence, convergence, and effectiveness need to be explored. And how can SE monitor levels of self-organization, stability of emergent order, and convergence?

3.3.2 | Enterprise architecture transformation

EAM provides organizations with a holistic view of their IT investments, enabling them to plan and guide their business-IT transformation and alignment activities and supporting strategic management decisions.[63] Besides, Enterprise Architecture (EA) links business and IT infrastructure components and provides stakeholders with their specific architectural views on different levels of granularity.[63] EAM frameworks are based on conventions and principles for describing business and application domains and have enlarged with emerging technology.[76,97,98] However, there is a view on the complexity of EAM as a common barrier to digital transformation among researchers.[63,99] In contradiction to its intention, EAM has emerged as an IT stand-alone approach separated from business domains, with a lack of integration between IT organizations and senior management.[100–102] In addition, the complexity of IT is rising caused by smart digitalization processes,[103] followed by high coordination efforts to avoid these barriers.[63,104] As a result, a holistic approach is missing to supporting small and medium enterprises (SMEs). Moreover, enterprises' evolution includes emergent and deliberate aspects of systems change.[16] Hence, EAM needs to be rethought anew to activate digital business models' potential and overcome the present barriers. Besides, traditional EA approaches focus on highly formalized EA processes, favoring high reusability of architectures and smooth deployment. However, exhausting digitalization potentials requires a more dynamic EA approach, with high but flexible integration of business and cyber layers. Therefore, the demand for achieving EA from a mission perspective is growing. The 2016 Reference Architecture Model for Industry 4.0 (RAMI4.0) and the Unified Architecture Framework (UAF) address the modeling requirements of digital transformation.[105,106] These approaches must enable architecture modeling, considering the dynamics of local business cycles and the related behavior-based systems and safeguarding interoperability across all layers.

4 | SYNTHESIS AND DISCUSSION

Research in I40 overemphasizes technological aspects,[107] and traditional SE focuses on technical engineering, components integration, and systems implementation. Previous research sees operational efficiency, automation, and productivity as the main objectives of I40, but social and higher economic aspects are missing.[107] Beyond increased business performance from enhanced operational excellence and process autonomy, we see value potentials from the (1) revoked technological restrictions by smart technology, (2) emerging possibilities from changing context based on smart technology, allowing the developing of new business models, and (3) new collaboration models across ecosystems. Hence, the role of SE needs to be redesigned and refined in engineering, architecting, and governing to enable businesses to master systematic aspects for yielding the value potentials possible by AI-based technologies.

For a theory-driven and practice-oriented approach, characteristics of complex adaptive systems (CAS) must be emphasized to improve innovation effectiveness and adaptability to environmental changes.[74] Also, for supporting interdisciplinary insights on system-level and emergent behavior throughout systems transition phases.[93] Dynamic capability (DC) theory offers approaches for evaluating fit and misfit dynamically and balancing exploration and exploitation activities.[53,59] Enterprise capabilities emerge simultaneously while creating a new self-organization order.[16,93] These exhibit characteristics and qualities that arise from the interactions of the related elements.[94] However, CAS exposes no fixed fitness, rather context-dependent and changing. Also, the needed fitness levels emerge from context, from interactions with agents rather than predetermined functions. Hence, BMs need ongoing alignment to optimize and keep operational excellence even with innovation and environmental dynamics. Finally, BMI needs continuous processes to sense innovation possibilities in time and align business models to changing conditions while caring about order and degree of freedom within an ecosystem, providing stability and emergence.

Smart innovations that follow the industry 4.0 paradigm will be highly customized and synchronized product-service combinations produced flexibly but with high resource effectiveness simultaneously.[108,109] Such manufacturing concepts deeply impact companies' business models, allowing efficient production of differentiated products with a shorter time to market[110,111] In other words, demanding Make-to-Order (MTO) processes aim to be designed with the efficiency of Make-to-Stock (MTS) processes. This evolution will also significantly impact classical management science perspectives such as Porter's competitive differentiation strategies versus cost leadership or Miles's and Snow's strategy archetypes of Innovator versus Defender. Moreover, companies must reshape their products and continuously improve their processes. As a result, they constantly need to innovate their business models[78,111,112] Hence, value drivers are companies' processes' agile and efficient configuration. Therefore, we propose synthesizing management science concepts such as strategic alignment and dynamic capabilities management with enterprise architecture concepts and AI-driven business process optimization to enable agile and systemic aligned BMI. The innovation capabilities of the I40 transformation significantly impact companies' products and services and their value-adding processes that must be re-engineered. Following the emergence phenomena, main value potentials will emerge from new constellations across ecosystems that I40 technology brings. However, emergence requires the *"capacity to understand, switch and combine different kinds of knowledge with different ways of thinking.* [113]*"*

The knowledge needed for fast responding to business changes can often be developed as artifacts and components in advance and deposited as absorptive capacity. This approach refers to companies' ability to explore, assimilate, and externally deposit knowledge for exploiting it for business performance.[114] Absorptive capacity is an antecedent of dynamic capabilities (DC) that enable asset orchestration activities and re-combination for effective response to environmental changes.[115,116] Besides, a systems perspective can provide the *big picture* about the overall enterprise systems and context and support transparency for systemic integration of the functional part.[117] It can improve understanding mechanisms between BMI and dynamic alignment processes for balancing exploration and exploitation.[59,118,119] Hence, systems thinking and SE show potential for integrating value-adding processes and balancing innovation, alignment, and governance (function, structure, process, steering).

Figure 1 shows the basic framework for digital enterprise engineering, and Table 2 in the summarizes the source concepts. Continuous sensing and analyzing data from BM dimensions perspective enable responsive evaluation of upcoming business opportunities.[72] BM concepts help in mapping value signals to components such as (1) *infrastructure*—including core capabilities, competencies, partner network, and the value configuration; (2) *value proposition*—the products and services that differentiation from competitors; and (3) *customers*

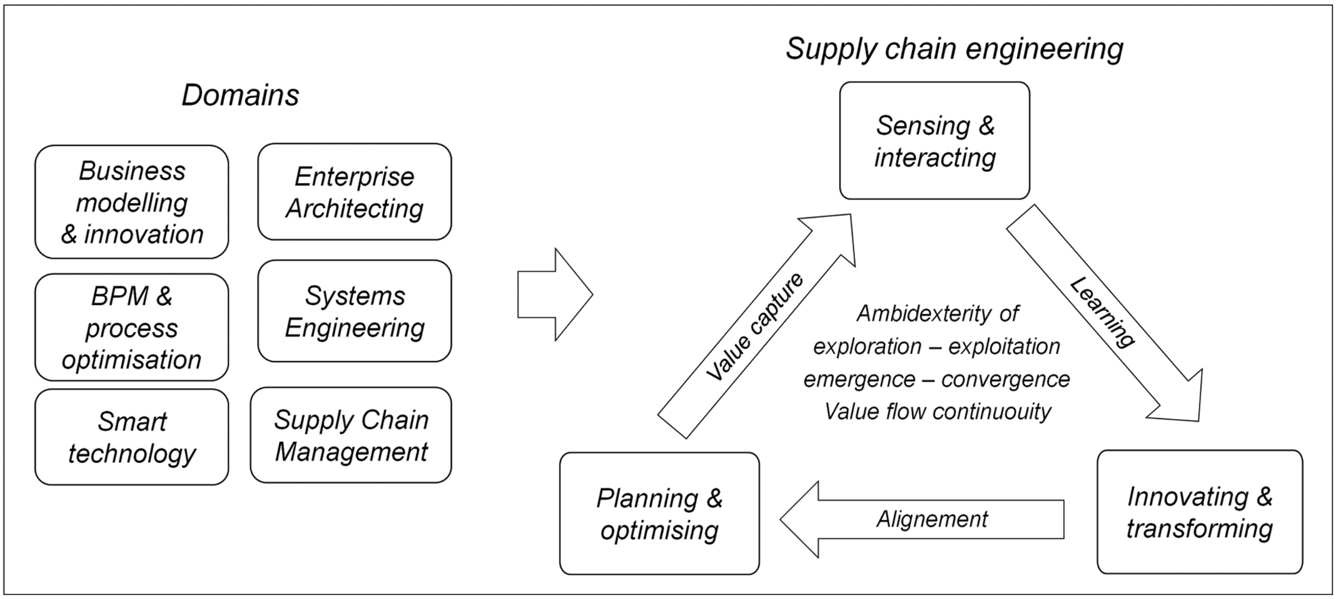

FIGURE 1 Domains and basic framework for digital enterprise engineering (an authors' view).

and distribution channels.[120–122] Demand signals will be channeled to demand and portfolio management. In contrast, marketing and new product development can analyze signals for innovation opportunities and lead to the transformation and aligning of the enterprise capabilities. Planning and optimization functions help create reliable demand, supply, and capacity plans, deal with uncertainties and contradicting stakeholder objectives, and synchronize fulfillment across the supply chain. SE can orchestrate these activities to sustain value flows and the viability of enterprise systems considering capability life cycles and balance exploration and exploitation activities.

EAM provides methodical infrastructures for enterprise transformation and managing companies' infrastructure programs.[63] SE roadmaps for systems development are provided by standards such as ISO-15288 and ANSI/EIA-632. Applying these with the V-model provides feedback loops between requirement management, solution design, decomposition, development, tests, and implementation, focusing on systems reliability, integration consistency, and users' acceptance. MBSE aims for complexity reduction and improved design productivity by focusing on the systems model's interdisciplinarity, providing stakeholders with their specific views on common systems and objects.[80] High transparency about innovation potentials and their efficient transformation is needed. Hence, SE has an analyzing, developing, and integrating role and an evaluating and moderating role for ideal interactions for continuous enterprise systems development and optimization. Ongoing BMI processes must be balanced with value exploitation and BM alignment processes. Sharing knowledge across business domains is critical for transforming information into breakthrough innovations. Systems thinking can support these processes toward a simultaneous understanding of function, structure, and process.[74]

5 | CONCLUSION

To make the most of business innovations, SE has to focus on realizing a given scope of systems and determining the range of systems and their alignment using systems theory-based concepts. Traditional EAM standards provide a systematic infrastructure for managing enterprises' transformation, using roadmaps, frameworks, rules, and architecture principles. EAM helps describe *as-is* and *to-be* and *transition stages* of architectures/systems. But, it lacks the ability to configure capabilities in the required dynamics and model interoperable across architecture layers for exhausting the value possible of I40 business models. However, because of an increasing rate of business change and environmental volatility, ongoing innovation and effective alignment are estimated as key competitive advantages, which require mission-oriented standards addressed by RAMI4.0 and UAF.

For this reason, the introduced enterprise engineering approach can integrate the examined concepts for simultaneously sensing, scoping, and activating value potentials on levels and domains of digital business models and throughout their lifecycles. The procedure helps companies sustain digital transformation successfully. The introduced concepts use different terms and schools of thinking for overlapping activities. However, they are grounded in systems thinking and contingency theory or open systems theory and are significant for the SE-based design of supply chain business models. Hence, the study demonstrates the need to harmonize the concepts into a concise methodology and taxonomy, avoiding methodical redundancies for agile engineering of digital supply chain business models. Such harmonization can bridge gaps between management and engineering disciplines in digital business model innovation, estimated as a key accelerator for value exploitation.

TABLE 2 Domains of digital enterprise engineering (adapted from Halecker & Hartmann[74]).

Concepts	Business focus	ST Categories	ST approach	Practices and methods	Authors (examples)
Business modeling	Start-ups, business model design	Function, structure, hierarchy, environment	GTS, technological system theory	Entrepreneurial spirit, BM canvas	Teece, 2018; Osterwälder, 2013; Warg et al., 2016
BM innovation	Innovating an existing business model; sense for innovations and adopt	Function, structure, emergence, convergence, environment, context, CAS, communication	System thinking, cybernetic theory, CAS, chaos theory; systems dynamics	Market sensing, analyzing, evaluation, knowledge mgmt., emergent ENG, BM transformation	Lindgren & Aagaard, 2014; Halecker & Hartmann, 2013; Bledow et al., 2009; Reish et al., 2009; Moore, 2007
Innovation manage-ment	Balance innovations with product and capability life cycles	Function, dynamics, feedback, environment, emergence, convergence	System thinking, system-oriented mgmt. science	Ambidexterity between exploration and exploitation; Portfolio analysis, NPD	O'Reilly & Tushman, 2007; Bledow et al., 2009; Reish et al., 2009; Zott & Amit, 2010
Strategic and business-IT alignment	BM alignment to change of strategy and environment	Function, hierarchy; convergence, structure, effectiveness contingency	Cybernetic theory, system-oriented management science	Strategic alignment; SAM, fitness measurements, contingency management	McLaren et al., 2011; Johnson et al., 2008; Prieto & Carvalho, 2011; Tallon, 2012
Dynamic capability manage-ment	Ambidexterity between exploration and exploitation; provide the right capabilities n time	Function, structure, systems of systems, contexts, hierarchy, feedback, environment, emergence, convergence	System thinking, CAS; Cybernetic theory; systems dynamics, system-oriented management science	Dynamic capability management, EAM: artifacts, services, capability engineering, service orientation,	O'Reilly & Tushman, 2007; Arndt & Pierce, 2018; Teece, 2014, 2018; Flood, 2010; Brettel et al., 2011; Liu et al., 2013; McLaren et al., 2011
Value engineering	Process and product re-engineering; lifecycle mgmt.	Steering, control, communication, efficiency, context	System-oriented management science; cybernetic theory	TOC, TCO, balanced score card, portfolio mgmt., business case mgmt.	Kaplan & Norton, 1993; Goldrath, 1998; Sahara et al., 2019; Boya & Rao, 2019
System engineering	Design and implement systems; safeguard systems of systems viability; foster emergence of innovations	Function, structure, feedback, convergence, communication, holism, environment, context, integration, emergence, viable system mgmt.	Systems thinking, GST, systems theory, cybernetic theory, management science, capability engineering (ENG), complexity ENG	SE standard and reference processes, MBSE, V-model, complexity engineering, capability engineering, stakeholder integration, mental models	Antosz et al., 2022; Broy et al., 2021; Burmeister et al., 2016: Willet, 2020; Cloutier et al., 2021; Friedenthal et al., 2021; Beihoff et al., 2014; Oosthuizen & Malinga, 2021
Enterprise Architecture Manage-ment	Architecture roadmap planning, design and controlling System of Systems (SoS) and CPS engineering	Function, structure, hierarchy, dynamics, environment, feedback communication, convergence, emergence, effectiveness, viability	GTS, technological system theory, System-oriented mgmt. science, Stakeholder mgmt., mental models	Unified architecture framework (UAF); reference architecture framework for Industry 4.0 (RAMI4.0), TOGAF, BPMN and DNN, EPC	Carter, 2016, Kandjani et al., 2014; Stooß, 2019; DiMario et al., 2008; Medini & Bourey, 2012; Drews et al., 2017; Assar & Hafsi, 2019, Härting et al., 2019; Hartmann, 2017
Supply chain manage-ment	SC planning and SC optimization, SC operations, transportation, manufacturing, relationship mgmt.	Function, hierarchy, structure, convergence, effectiveness, efficiency, environment, feedback communication, control, steering, synchronization	System dynamics, cybernetic theory, system-oriented management science, stakeholder mgmt., operations research	SCOR, CSCMP, SC sustainability and performance mgmt., SC design, configuration, and optimization, SC resilience; SC integration	Yin & Zhang, 2022; Kreuter et al., 2022; Lichtenstein, 2012; Chang et al., 2015; Chopra & Meindl, 2013; Boya & Rao, 2019; Sheffi & Rice, 2005; Brtis & McEvilley, 2019
SC integration	Smoot integration of SC processes on a timely and quantity basis, considering SC planning and SC synchronization	Function, hierarchy, structure, convergence, effectiveness, efficiency, environment, feedback communication, control, steering, synchronization	System dynamics, cybernetic theory, system-oriented management science, stakeholder mgmt. and mental models	Managing and engineering antecedents of SC integration, such as resource collaboration, flexibility, agility, and information exchange …	Rai et al., 2006; Wu et al., 2006; Childerhouse & Towill, 2011; Van Donk & van der Vaart, 2005; Godsell, 2008; Bagchi et al., 2005; Simatupang et al., 2002

(Continues)

TABLE 2 (Continued)

Concepts	Business focus	ST Categories	ST approach	Practices and methods	Authors (examples)
AI-based SC planning and optimization	Integrated business planning and supply network optimization	Function, structure, effectiveness, efficiency, environment, feedback communication, control, synchronization	System thinking, system dynamics, cybernetic theory, system-oriented management science	Digital twins to optimize and simulate based on real-time data, utilize supervised, unsupervised and reinforcement ML	Aburto & Weber, 2007; Jaipuria & Mahapatra, 2014; Gupta & Pathak, 2019; Gupta & Pathak, 2021; Luo et al., 2019; Fan et al., 2013
SC resilience and SC sustainability	Plan, design, monitor and control SC resilience and SC sustainability (economic, social, environmental)	Function, hierarchy, structure, convergence, effectiveness, efficiency, environment, feedback communication, control, steering, synchronization	System dynamics, cybernetic theory, system-oriented management science, stakeholder mgmt. and mental models	Identify and monitor vulnerabilities; define and monitor adversities and KPIs (economy, social, environment); recover systems and processes	Juttner & Maklan, 2011; Sheffi & Rice, 2005; Rao & Goldsby, 2009; Gao et al., 2021, Radhakrishnan et al., 2021; (Brtis & McEvilley, 2019; Yu et al., 2019
Industry 4.0; digital transform.	Enhance business value opportunities by utilizing digitalization capabilities and learning from data	Function, structure, convergence, effectiveness, efficiency, environment, feedback communication, control, steering, learning	System dynamics, cybernetic theory, system-oriented management science, stakeholder mgmt. and mental models	UAF and UAFML; RAMI4.0; BP modeling and BPO; EPC; UML, BPMN and DMN; AI and ML use case ideation and development; utilize CPS for autonomous cycles	Hermann et al., 2016; Chen et al., 2018; Rifkin, 2015; Kagermann et al., 2013, 2015; Carvalho et al., 2019; Khan et al., 2017; Lee et al., 2014; Goelzer, 2017
Artificial intelligence and machine learning	Enhance business value opportunities by utilizing AI and ML capabilities and learning from data	Function, structure, convergence, efficiency, effectiveness, feedback, environment, steering, communication, control	Technological system theory, system dynamics, Cybernetic theory, stakeholder mgmt.	AI and ML use case identification/ideation and development; enable autonomous business cycles using CPS	Döbel et al. 2018; Pournader et al., 2021; Fink et al., 2018; Basole, 2021; Russell & Nor vig, 2020; Basole, 2021; Brunnbauer et al., 2022
Sensing and big data	Sense value opportunities and market changes; sensing progress and conditions	Function, structure, convergence, efficiency, effectiveness, environment, feedback communication, control,	System dynamics, cybernetic theory, stakeholder integration, mental models, emergence	Market sensing, condition sensing, operational sensing, data mining, data science; demand signal mgmt.; content analysis	Alshanty et al., 2019; Kallinikos & Constantiou, 2015; Queiroz et al., 2018; Lindgren & Aagaard, 2014; Alshanty & Emeagwali, 2019
Design science, sensemaking, knowledge management	Developing convergent processes and artifacts by utilizing sensemaking and design science	Function, structure, convergence, consensus, effectiveness, context, environment, feedback communication, convergence, emergence	System dynamics, cybernetic theory, system-oriented management science, stakeholder mgmt. and mental models	Artifact and capability development using design science (Hevner et al., 2019; Klein et al., 2006); organizational sense-making (Weik et al., 2005)	Weik et al., 2005, Weick & Sutcliffe, 2015; Alshanty et al., 2019; Klein et al., 2006; Wilde & Hess, 2007; Mayring, 2019; Hevner et al., 2005; Brown et al., 2014

The approach of digital enterprise engineering following the three main building blocks of (1) *sensing and interacting*, (2) *innovating and transforming*, and (3) *planning and optimizing* will be developed in detail into a comprehensive SE framework. Again, a critical review of the concepts listed in Table 2 will be necessary to explore the various modeling approaches in-depth and synthesize and develop a concise SE framework and transformation roadmap. Moreover, an evaluation system will be developed that enables a critical assessment of the overall SE methodology by various field experts using extensive case study research. A further focus will be the exploration of promising approaches for ML and AI use case ideation and development, helping companies of various industries to exploit to enhance innovation output and deployment. Getting more clarity on context-specific conditions and systematically supporting emergence, convergence, and effectiveness will be useful for further AI-driven enterprise system engineering. Finally, contributions to SC resilience and SC sustainability by an integrated SE-based approach will be explored and transdisciplinary moves of activities from traditional SC domains to SE.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in public domains with URL/DOI or reference numbers. These data were derived from the following resources available in the public domain: Wiley, Semantic Scholar, ResearchGate, partly on request from the authors, and a few articles from Harvard Business Review.

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