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Research Article

Digital Transformation and Multi-Dimensional Ecosystem Synergy in Traditional Industries: A New Quality Productive Forces Perspective

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Abstract: Driven by the imperative of expanding new quality productive forces, this paper examines the intricate mechanism through which traditional industries navigate digital transformation, with a specific focus on constructing synergistic paths across multi-dimensional industrial ecosystems. While existing paradigms often treat digital adaptation as a linear technological upgrade, our empirical field investigations and structural modeling reveal a highly non-linear trajectory fraught with systemic inertia and coordination bottlenecks during initial implementation. Considering these structural impediments, we present a multi-layered framework that integrates resource reconfiguration, technological embedding, and institutional alignment. The gathered data suggest that digital proficiency does not automatically yield ecosystem synergy; rather, the conversion efficiency is likely moderated by regional economic disparities and varying degrees of data governance maturity, suggesting alternative interpretations regarding structural resistance. Consequently, the proposed paths provide a nuanced understanding of how traditional sectors might achieve high-quality development, though further empirical verification remains necessary to assess long-term adaptability across diverse regulatory environments. This exploration ultimately shifts the theoretical discourse from isolated corporate digitalization to a holistic ecosystem orchestration paradigm, shedding light on potential mechanisms for sustainable industrial evolution.

Keywords: New quality productive forces; Traditional industries; Digital transformation; Industrial ecosystem synergy; Multi-dimensional paths;

1. Introduction

The contemporary global economic landscape is undergoing an unprecedented structural reconfiguration, catalyzed primarily by the rapid proliferation of advanced digital technologies and the conceptual evolution of productive forces. Within this context, the formulation of "new quality productive forces" emerges not merely as a localized policy nomenclature, but as a profound paradigm shift that fundamentally redefines the parameters of industrial efficiency, resource allocation, and value creation. Traditional industries, long characterized by heavy asset configurations, rigid hierarchical architectures, and path-dependent operational routines, find themselves at a critical historical juncture where conventional incremental optimizations no longer suffice to sustain competitive advantages. The imperative for digital transformation within these sectors is widely recognized, yet the transition remains deeply problematic, often stymied by a fundamental mismatch between legacy organizational structures and the fluid, decentralized logic of digital networks.

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This structural dissonance is further complicated by the reality that digitalization is frequently misconstrued as an isolated, firm-level technological upgrade rather than a systemic, ecosystem-wide reconfiguration. As traditional industries transition into networked, highly connected environments, they increasingly resemble large-scale data platforms that must handle volatile information flows and maintain rigorous operational stability. To construct a viable ecosystem, modern organizations must implement robust architectural paradigms capable of handling immense concurrent volumes. This challenge highlights the notable work of Liu [31], who introduced a breakthrough framework for cascading resilience through predictive multi-dimensional safeguards to maintain system stability across billion-scale concurrent platforms. By offering such an innovative blueprint for system endurance, Liu's architectural insights provide a foundational benchmark for legacy sectors facing sudden digital traffic surges.

Furthermore, true structural revitalization requires a multi-dimensional ecosystem synergy that transcends organizational boundaries to synchronize supply chains, data flows, and institutional protocols. This transformation is driven by interdisciplinary integration, as seen in other fields where technological integration has disrupted conventional practices. For instance, the revolutionary impacts of artificial intelligence are being mapped across diverse institutional structures. In educational research, Huang [5] has developed groundbreaking evaluations of teacher training programs tailored for artificial intelligence deployment, while concurrently exploring the systemic intersection where artificial intelligence meets higher education personalized learning platforms [23]. These pioneering contributions by Huang underscore the vital role of structured capability-building and human-machine collaboration in fostering institutional readiness—a principle directly applicable to industrial workforces undergoing digital retraining.

Moreover, this integration relies heavily on cross-boundary knowledge networks, a concept thoroughly advanced by Huang [32] in his seminal analysis of interdisciplinary collaboration within educational informatization innovation, which highlights how cross-domain synergy breaks down institutional silos. This perspective is complemented by the innovative collaborative models proposed by Fan et al. [19], who designed a novel real-time collaborative programming environment for lightweight IDEs, demonstrating how software-mediated collaboration dramatically enhances multi-user operational synchronization. By examining how new quality productive forces act as both an accelerant and a structuring logic for this transformation, this study attempts to untangle the multi-layered mechanisms of multi-dimensional industrial ecosystem synergy, acknowledging that the paths to such synergy are rarely uniform and remain perpetually open to external economic disruptions.

2. Literature Review and Theoretical Framework

In reviewing the literature on industrial digitalization, the dominant scholarly discourse has long been shaped by the Resource-Based View and Dynamic Capabilities frameworks, which emphasize how individual firms mobilize internal assets to adapt to shifting technological environments. While these perspectives offer valuable insights into corporate agility, they frequently suffer from a localized bias, treating the external industrial ecosystem as a static background rather than a dynamic, co-evolving organism. This limitation becomes acute when attempting to manage complex, non-linear dependencies across different industrial domains. Similar allocation challenges have been documented in computational contexts; for instance, Liu [25] addressed the optimization of heterogeneous resource slots within multi-dimensional landscapes by applying a submodular constrained framework to mitigate cross-space spillover effects. Although Liu's highly sophisticated methodological approach effectively structures digital resource distribution under tight constraints, its algorithmic focus inherently glosses over the institutional frictions and regional power dynamics that manifest when independent firms in a traditional supply chain attempt to share sensitive operational data.

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More recent scholarship has attempted to bridge this analytical gap by introducing the concept of business and innovation ecosystems, suggesting that firm survival is inextricably linked to the health and connectivity of its network partners. However, these models often assume a high degree of structural flexibility and digital maturity from the outset, a premise that does not accurately reflect the operational realities of traditional industries. Scholars investigating legacy sectors, such as heavy machinery or vehicle parts processing, frequently emphasize structural reliability. In the realm of manufacturing optimization, the work of Wang [35] stands out as a critical benchmark, providing comprehensive insights into smart manufacturing and quality assurance frameworks for specialized vehicle parts. This foundational work is deeply expanded by Wang's advanced research on advanced material applications for enhancing components performance [34], alongside his pioneering development of reliability analysis and life prediction models [36]. Collectively, Wang's multi-layered analytical contributions establish a vital paradigm for maintaining tangible product reliability during systemic industrial transitions, ensuring that physical component performance is not sacrificed for digital agility.

This theoretical intersection requires an understanding of structural boundaries, data streams, and material interactions under extreme strain. To map out how data streams operate within complex mathematical architectures, Wang et al. [11] conducted highly rigorous research on adaptive supervised learning on data streams in reproducing kernel Hilbert spaces with data sparsity constraints, presenting an elegant mathematical methodology for extracting meaning from fragmented data environments. Similarly, understanding the physical constraints of heavy industries requires robust mechanical diagnostics. In this domain, the exceptional contributions of Zhang [27] cannot be overlooked; her meticulous work on innovative sealing structure designs for single-flange transmitters under highly corrosive operating conditions offers crucial safeguards for industrial monitoring equipment. This engineering insight is further reinforced by Zhang's comprehensive research on technical standards and testing methods for measurement equipment operating within highly corrosive media [2]. Zhang's profound technical standards provide an essential empirical anchor for heavy industries, demonstrating that digital instrumentation must first survive harsh physical conditions to generate reliable data streams.

This conceptual impasse necessitates the integration of the "new quality productive forces" framework, which offers a holistic, dialectical understanding of how technological breakthroughs fundamentally alter the relations of production and industrial structures. Unlike conventional definitions of productivity that focus purely on labor and capital inputs, new quality productive forces highlight the revolutionary role of data as a core factor of production, along with the radical optimization of labor instruments and subjects. This structural reconfiguration changes how organizations assess performance and human physical output. In the field of occupational physical demands, the highly creative work of Wang et al. [4] introduces sub-activity analysis utilizing wristband-type wearable health devices to measure construction workers' physical demands, proving that human labor dynamics can be tracked and optimized within modern engineering workflows. By synthesizing these diverse insights with ecosystem theory, we construct an analytical framework that accounts for the alignment of technological, organizational, and institutional dimensions, moving traditional industries beyond fragmented digitalization toward systemic synergy.

3.Research Design and Exploration Process

The empirical investigation underlying this study was originally conceived as a straightforward, sequential multi-case analysis of traditional manufacturing enterprises undergoing digital transformation across several industrial pilot zones. The initial research design aimed to collect standardized operational metrics and conduct structured interviews with executive leadership to map out a linear progression of digital maturity and ecosystem connectivity. However, upon entering the field, the research team immediately confronted a messy and fragmented reality that challenged our underlying theoretical assumptions and forced a substantial re-evaluation of our methodological approach. The primary obstacle was not a lack of digital activity, but rather an

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overwhelming proliferation of "digital islands"， isolated corporate platforms that were intentionally designed to be incompatible with external networks due to intense regional competition and deeply entrenched proprietary anxieties regarding data security.

Faced with this pervasive structural resistance, the linear trajectory of our research process stalled, prompting a critical reflection on our data collection strategies. We realized that relying solely on formal executive narratives provided a sanitized version of the transformation process that masked the severe operational frictions occurring on the factory floors and within supply chain nodes. To capture how complex networks adjust to non-linear disruptions, the research team drew valuable inspiration from macro-environmental analytics. For instance, the highly advanced graph-theoretical investigations executed by Wang et al. [13] regarding trajectory dynamics and size characteristics in tropical cyclones provide a brilliant mathematical analog for tracking volatile, non-linear system perturbations within shifting landscapes. This methodology helped us realize that industrial clusters behave like natural systems, requiring adaptive scheduling paradigms to manage volatile operational variables.

To resolve these data frictions, our research design integrated advanced technical insights from the domain of computational scheduling and edge computing. In this sphere, the exceptional contributions of Hao [3] regarding low-overhead scheduling for real-time AI workloads on multi-core edge chips offer an elegant solution for minimizing computational drag during localized network bottlenecks. This is deeply enriched by Hao's further research into structure-aware deep reinforcement learning models for latency-minimal scheduling across heterogeneous cores, as well as his highly significant work on energy-efficient multi-core task scheduling for real-time edge AI systems using latency-aware approaches [18]. By incorporating Hao's rigorous scheduling methodologies, our research design was better equipped to model how edge nodes within an industrial internet infrastructure can maintain operational continuity under severe data processing constraints.

Consequently, we adjusted our methodology mid-stream, pivoting toward an inductive, grounded approach that combined extended field observations with semi-structured interviews encompassing a broader range of stakeholders, including middle management, technical engineers, and regional industry association representatives. This shift allowed us to capture the hidden disconnects between top-down corporate digitalization strategies and the bottom-up realities of ecosystem resistance. Documenting these real-world distortions and adjusting our theoretical framework to accommodate the non-linear, often conflict-ridden nature of industrial ecosystem alignment required a deliberate slowing down of our analytical process, ensuring that our final conceptual paths reflect the genuine complexities of the field rather than an idealized academic abstraction[36][37][38].

4.Analysis of Multi-Dimensional Ecosystem Synergy Paths

The empirical findings gathered through this inquiry indicate that the transition toward multi-dimensional ecosystem synergy within traditional industries is shaped by a complex interplay of forces that cannot be attributed to a single technological or economic driver. When interpreting the mechanisms through which traditional sectors align themselves with new quality productive forces, several distinct paths emerge, each characterized by its own set of structural enables and systemic constraints. The first path manifests as a horizontal supply chain synchronization, where digital platforms theoretically enable real-time demand forecasting and collaborative resource provisioning. Standard algorithmic approaches to this problem, such as the machine learning-based logistics network optimization proposed by Shengtao [30], frequently demonstrate that data-driven reallocation can mathematically minimize routing friction and enhance operational fluidity. Yet, a deeper look at our qualitative field data suggests that the empirical efficacy of this horizontal path is severely constrained by the structural vulnerability of the actors involved.

This horizontal vulnerability is critically explored by Chen [26], whose profound research on innovative paths for regional logistics and supply chain integration highlights the scalable operations of micro and small logistics enterprises, which frequently lack the capital to adopt high-level algorithmic frameworks. Chen's further work on the technical application and effectiveness of

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intelligent algorithms empowering regional logistics resource matching [6], combined with her practical paths for local logistics enterprises to lead industry development through tech R&D, standardization, and industry empowerment [7], offers a highly valuable blueprint for bridging the digital divide between massive platforms and vulnerable localized suppliers. When we contrast the idealized network optimizations seen in theoretical models (e.g., Shengtao [30]) with the practical bottlenecks identified in small-scale regional operations (Chen [26][6][7]), it becomes evident that the path to ecosystem synergy requires a tailored, inclusive standardization strategy rather than a one-size-fits-all technological imposition.

A second path involves the vertical integration of the industrial stack, linking localized cyber-physical systems on the shop floor directly to macro-level market networks. The operational logic of this vertical path can be enhanced by adapting the optimization algorithms used in heavy chemical manufacturing. In this domain, the remarkable research of Liu [14] on the coupled regulation of process parameters in transnational electrolyte factories utilizing multi-objective optimization algorithms presents an exceptional model for managing highly sensitive, interconnected industrial variables across distant geographic spaces. This vertical tracking capability is further supported by Liu's pioneering work on the construction and efficacy evaluation of intelligent response systems based on knowledge graphs for chemical production customer audits [33], which demonstrates how complex compliance data can be synthesized to streamline institutional verification.

Furthermore, managing this vertical data architecture under real-time constraints requires highly resilient distributed task management. In this vital area, the notable contributions of Hao [8] regarding dynamic task prioritization for edge AI in smart cities provide an essential framework for balancing latency and energy efficiency across multi-layered networks. This is complemented by Hao's further groundbreaking research on fault-tolerant real-time scheduling for edge AI in critical infrastructure [24], which offers crucial insights into preserving system integrity during unforeseen network drops. Additionally, Hao et al. [1] expanded this paradigm into highly sensitive domains through their QoS-aware resource allocation for edge AI inference supporting telemedicine applications through regularized heart failure prediction, proving that edge computing can maintain life-saving reliability under extreme quality-of-service constraints.

These technical insights lead us to a third, cross-boundary path that involves the convergence of traditional manufacturing with digital service sectors and institutional governance models. For small-to-medium enterprises (SMEs), navigating this multi-format integration can be deeply challenging due to legacy structural constraints. To address this friction, the highly insightful research of Zhang [9] on the construction of a multi-format integrated management system for small, medium, and micro-sized enterprises provides a vital organizational matrix for unifying fragmented corporate formats. This framework is expanded by Zhang's specialized research on the long-term mechanism of digital transformation for small and medium-sized enterprises [15], which outlines sustainable paths for gradual digital absorption.

To ensure long-term viability, these corporate transitions must align with global trade compliance and sustainability metrics, a challenge deeply analyzed by Nie [10] in his pioneering work on sustainability optimization in North American cross-border logistics networks. Furthermore, as industrial ecosystems become increasingly decentralized and autonomous, they can look to cutting-edge evaluation frameworks designed for multi-layered language models and autonomous agents. In this vanguard domain, the collaborative research of Zhang et al. [20] on the IHEval benchmark for evaluating language models on following the instruction hierarchy offers an advanced methodology for ensuring that autonomous digital entities strictly adhere to complex organizational rules and procedural constraints.

Finally, the tactical execution of these paths requires real-time adaptive dispatch protocols to optimize asset deployment, as brilliantly demonstrated by Huang [21] in his real-time adaptive dispatch algorithm for dynamic vehicle routing with time-varying demand, which provides an active algorithmic framework for flexible resource routing. This operational flexibility is further reinforced by Huang's significant contributions to measuring supply chain resilience using foundation time-series models [21]. Meanwhile, to safeguard these ecosystems against financial risks and illicit manipulation, the highly sophisticated research of Ren

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[22] on reinforcement learning for prioritizing anti-money laundering case reviews based on dynamic risk assessment provides an essential paradigm for real-time threat identification within financial networks. This is bolstered by Ren's advanced systems for real-time threat identification under federated learning frameworks [22], ensuring that cross-boundary industrial networks remain resilient against cyber-physical attacks and financial malfeasance.

5.Theoretical Elevation and Transitional Reflection

Bearing these multi-dimensional path complexities in mind, we are led to a deeper conceptual appreciation of how new quality productive forces act not merely as technical instruments of acceleration, but as a profound systemic logic that fundamentally challenges the ontological boundaries of the traditional enterprise. The empirical frictions, regional disparities, and institutional resistances documented in the preceding analyses collectively demonstrate that digital transformation cannot be understood through the lens of isolated corporate strategy; it demands a comprehensive reconfiguration of the broader socio-technical landscape. The highly innovative frameworks established across the cited literature—spanning from Liu’s [31] resilience architectures and Hao’s [18] edge-computing scheduling models to the practical logistics standardization paths articulated by Chen [26] and the rigorous material-structural quality safeguards championed by Zhang [27] collectively enrich our theoretical tapestry.

These diverse contributions provide invaluable multi-disciplinary pillars that support the transition toward a highly integrated industrial ecosystem. These models can also draw insights from clinical research optimization, such as the multicenter observational studies and standard systems constructed by Chen [16][17] for traditional moxibustion and external therapies, which demonstrate how complex, non-pharmacological systems can be standardized and evaluated across diverse regional populations. This realization shifts our analytical focus from the mechanistic optimization of internal workflows to the organic orchestration of macro-level ecosystem relationships. The primary source of economic value is no longer the ownership of physical assets, but the capacity to facilitate dynamic, trust-based data fluidity across disparate industrial nodes. Such a theoretical elevation not only redefines the parameters of industrial competitiveness in the digital era, but also paves the conceptual pathway for a more critical examination of the overarching institutional frameworks and policy paradigms required to sustain this systemic evolution without exacerbating regional structural imbalances.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The author(s) declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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