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Knowledge Flow Barriers and Compliant Digital Governance Paths of Manufacturing IPD from the SECI Perspective: A Benchmark Analysis of Online Platforms

Yuhsuan Chen

Graduate School of China, Sungkyunkwan University, Seoul, Republic of Korea
hsuan29107@gmail.com

Abstract. Digital knowledge management serves as a core driver of manufacturing firms' digital transformation and R&D innovation. During digital upgrading, Chinese manufacturers commonly encounter fractured SECI knowledge spirals and stagnant internal knowledge circulation. Extant research largely focuses on cross-firm knowledge collaboration and external knowledge acquisition, yet few systematically investigate internal knowledge transformation bottlenecks within manufacturing Integrated Product Development (IPD) workflows from a SECI perspective. Taking the SECI knowledge spiral as the core framework, this paper integrates the Knowledge Navigator Model (KNM), the people–organizational process–technology barrier framework, and the multi-level Context-Mechanism-Outcome (CMO) analytical framework. Through qualitative benchmarking, it classifies manufacturers into four knowledge management maturity tiers, identifies three surface-level barriers, and untangles root causes across individual, organizational, and industry (external governance) levels. By benchmarking knowledge circulation mechanisms of online platforms and considering industrial data compliance constraints, this paper constructs a tripartite collaborative digital governance framework covering individuals, enterprises and governments. Three core barriers are identified: low practitioners' willingness to share knowledge, inadequate corporate knowledge management strategies and formal institutions, and poor compatibility of digital tools. Hierarchical industrial data control constitutes a key external constraint. While online platforms' automatic data logging and human-machine collaboration provide feasible references, such models cannot be directly transplanted to confidential manufacturing R&D scenarios. This paper extends SECI to manufacturing IPD, enriches multi-layer R&D knowledge flow analysis, and offers practical guidance for firms to build hierarchical compliant digital systems and internal knowledge incentives amid industrial data regulation.

Keywords: SECI model, Integrated Product Development (IPD), knowledge flow, data classification, digital governance

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1. Introduction

Knowledge creation sustains firms' innovation and long-term competitive advantages. The generation, transformation and reuse of organizational knowledge underpin corporate operations [1], and digital knowledge management significantly improves manufacturers' innovation output during digital transformation [2]. However, Chinese manufacturers exhibit uneven maturity in digital knowledge systems, plagued by sluggish internal knowledge flow and fractured SECI spirals. The Integrated Product Development (IPD) framework is designed to establish systematic cross-functional collaboration to consolidate multidisciplinary expertise and streamline end-to-end R&D information channels [3]. The mismatch between its design objectives and industrial realities highlights the research value of this paper.

Two prominent research gaps exist in current literature. First, most knowledge-sharing studies focus on cross-firm collaboration, while intra-firm cross-functional knowledge interaction remains understudied; new product development research similarly prioritizes external knowledge acquisition over internal experience reuse [4]. Second, existing literature on manufacturing digitalization concentrates on process optimization, and few adopt the SECI spiral to systematically unpack multi-layer constraints on knowledge transformation throughout IPD workflows.

This paper adopts the SECI knowledge spiral as its core theoretical thread, integrating the Knowledge Navigator Model (KNM), the people–organizational process–technology barrier framework, and the multi-level Context-Mechanism-Outcome (CMO) analytical framework. It classifies Chinese manufacturers' knowledge management maturity, maps full-process IPD knowledge flow bottlenecks, and benchmarks online platform knowledge operation modes. On this basis, it proposes compliant digital optimization strategies from individual, organizational and industry perspectives. Theoretically, this paper expands SECI's application scope in manufacturing IPD R&D scenarios; practically, it provides actionable guidance for manufacturers to advance digital knowledge transformation and meet industrial data compliance requirements.

2. Theoretical foundations

2.1. Core theories of knowledge management

Knowledge encompasses objective information, subjective cognition and individual practical experience, with interpersonal communication directly driving knowledge generation and transmission [5]. Michael Polanyi divided knowledge into two categories: explicit knowledge that can be documented and shared organization-wide, and tacit knowledge embedded in personal experience that cannot be fully expressed through written records [6].

Ikujiro Nonaka's classic SECI spiral divides organizational knowledge circulation into four sequential phases: socialization, externalization, combination and internalization [7, 8]. Socialization denotes tacit experience exchange among practitioners; externalization codifies personal experience into standardized documents; combination integrates fragmented materials into a unified organizational knowledge system; internalization enables practitioners to absorb collective organizational knowledge and develop professional capabilities [8]. This model serves as the core analytical lens for examining manufacturing IPD R&D knowledge flow in this paper.

Subsequent scholars have extended the SECI model, including Geng Xin's IDE-SECI model [1], Wang Xiangyang and Gong Peining's six-stage digital SECI frameworks [9], and Zhang et al.'s revised versions incorporating AI and implicit dark knowledge [10]. These extensions address

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external knowledge access and digital collaboration yet are rarely embedded within manufacturing IPD contexts, leaving intra-organizational knowledge barriers insufficiently explored.

2.2. Fundamental theories of new product development (NPD)

Robert G. Cooper's Stage-Gate model spans the full new product development lifecycle and mitigates project risks through phased gate reviews [11], forming the theoretical basis of IPD. As a cross-functional R&D framework, IPD integrates multidisciplinary expertise through regular gate reviews to improve R&D efficiency [3]. Both models rely on standardized documents and cross-department evaluations to preserve R&D information and sustain continuous knowledge creation, transfer and reuse. Such theoretical compatibility supports this paper's analysis of IPD knowledge barriers from the SECI perspective.

2.3. Matching logic between SECI and IPD workflows

This paper establishes one-to-one stage mapping between the SECI knowledge spiral and daily IPD operations. Cross-functional experience communication among R&D practitioners corresponds to knowledge socialization; recording tacit practical experience into design drawings and meeting minutes realizes knowledge externalization; integrating scattered project data into unified operational specifications reflects the combination phase; new practitioners complete knowledge internalization through hands-on practice guided by standardized organizational documents [3, 8].

A core inference emerges: a smooth, unbroken SECI spiral supports steady accumulation of organizational R&D experience and reduces redundant trial-and-error costs. Blockages at any transformation stage erode corporate knowledge assets and weaken long-term innovation capacity.

3. Pain points and root causes of knowledge flow in manufacturing IPD

3.1. Classification of enterprises based on the KNM

Hsieh et al.'s KNM outlines five corporate knowledge management maturity tiers [12]. Aligned with China's manufacturing digitalization context, this paper consolidates them into four levels with distinct SECI spiral breakpoints: (1) Non-standardized stage: R&D experience stays individual-owned without cross-project reuse. Undocumented tacit knowledge breaks externalization; employee turnover causes irreversible knowledge loss. (2) Pre-digital standardized stage: Written standards exist without digital platforms, creating low cross-department knowledge reuse and combination bottlenecks. (3) Semi-digital stage (industry mainstream): Isolated online storage decouples from daily R&D, generating silos and repetitive manual sorting that block a full SECI loop. (4) Fully integrated digital stage: End-to-end digital systems remove cross-department data barriers, enabling seamless SECI circulation across the entire product lifecycle.

Enterprises in the first three maturity tiers all suffer fractured knowledge spirals. This paper first extracts surface-level barriers via Stenholm and Bergsjö's people–organizational process–technology framework, then analyzes deep root causes using the multi-level CMO framework.

3.2. Universal knowledge flow barriers via stenholm and Bergsjö's framework

Stenholm and Bergsjö's three-dimensional framework categorizes engineering knowledge reuse barriers into people, organizational process, and technology dimensions [13]. Adapted to IPD cross-functional R&D contexts, three core barriers are identified: First, people's behavioral barriers.

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Sorting and archiving tacit knowledge consumes substantial R&D hours. Under tight schedules, practitioners resist documenting and sharing experience due to low awareness of knowledge value, disrupting socialization and externalization. Second, organizational process barriers. Enterprises lack top-level knowledge management strategies, formal knowledge exchange routines and supporting digital infrastructure. No effective mechanisms cultivate practitioners' recognition of knowledge assets, nor do standardized channels integrate cross-project experience, blocking knowledge combination. Third, technology tool barriers. Existing platforms only support static file storage, while isolated systems create information silos. Missing intelligent retrieval functions mean archived knowledge rarely guides ongoing R&D, raising overall knowledge circulation costs.

These observations only describe visible surface symptoms and cannot explain persistent barrier formation. This paper thus adopts the multi-level CMO framework to analyze underlying root causes.

3.3. Root barrier drivers based on the multi-level CMO framework

Adopting Uršič and Čater's multi-layer CMO framework [14], this paper analyzes three interrelated tiers: individual, organizational, and industry (external governance). The three identified barriers align with the tiers as follows:

• Individual level: Matches people barriers. Enterprises lack knowledge-sharing incentives. Practitioners treat technical know-how as private assets and refuse online knowledge archiving, which fundamentally stalls internal knowledge circulation.

• Organizational level: Covers organizational process and partial technology barriers. Most manufacturers undervalue knowledge management's tangible returns, leading to insufficient investment in corporate culture, institutions and unified repositories. Without top-level planning, fragmented systems restrict cross-project experience integration.

• Industry (external governance) level: External institutional constraints apply here. The *Data Security Law of the People's Republic of China* and ISO/IEC 27001:2022 information security standard [15] mandate tiered industrial data control and raise compliance costs. Without unified data-sharing rules, firms restrict cross-functional knowledge flow to mitigate risks and disrupt the full SECI cycle.

4. Benchmarking analysis of knowledge flow on online service platforms

4.1. Digital operational characteristics of online service platforms

Online platforms rely on network technology to build multi-stakeholder collaborative spaces centered on full-process digitalization. They feature end-to-end auto logging, cross-module data interoperability and intelligent historical knowledge retrieval [16, 17]. Operational records and experience are auto-captured to reduce manual consolidation labor.

4.2. Platform model's advantages for the SECI knowledge spiral

Online service platforms support a complete four-phase SECI knowledge cycle. Integrated systems eliminate information silos, facilitate continuous experience accumulation and cross-functional knowledge sharing during externalization and combination [16, 17]. Algorithms update digitized knowledge iteratively; lightweight AI tools extract implicit tacit knowledge and improve

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socialization efficiency [9, 10]. In the internalization phase, simplified retrieval lowers barriers for experience reuse and provides sustained decision support.

Although online platforms form unobstructed closed-loop knowledge circulation, manufacturing IPD R&D involves confidential industrial data and proprietary core technologies. Restricted by mandatory industrial data control rules, manufacturers cannot fully replicate online platform models. Even so, the logic of automatic logging and cross-department collaboration still serves as a critical reference for manufacturers to carry out tiered compliant digital transformation.

5. Optimization paths of knowledge flow in IPD from the three-dimensional perspective of the CMO framework

5.1. Individual level: fostering practitioners' knowledge-sharing willingness

Organizational knowledge creation relies on extracting practitioners' tacit experience and converting it into reusable organizational knowledge, which cannot succeed without active individual participation [7]. Within the individual level of the CMO framework, practitioners instinctively resist knowledge sharing, forming the primary people-related surface barrier. Stenholm and Bergsjö confirm that insufficient incentives greatly suppress knowledge-sharing behaviors [13]. Enterprises can adopt two targeted strategies: first, integrate knowledge codification and sharing requirements into performance appraisal systems, using material and spiritual rewards to motivate voluntary knowledge archiving; second, build regular cross-functional communication channels to cultivate organizational trust and reduce psychological barriers to tacit experience exchange [4].

5.2. Organizational level: building tiered compliant digital systems

Digital knowledge management improves manufacturers' absorptive capacity, adaptability and innovation performance to boost technological innovation [2]. Following industrial data hierarchical control requirements, firms can build a tiered, categorized digital knowledge management system tailored to IPD scenarios. All non-confidential files and gate review records are fully online; auto-logging systems enable systematic knowledge externalization and codification. Core manufacturing processes and confidential R&D data require independent storage and hierarchical authorization, in strict compliance with the *Guidelines for the Classification and Grading of Industrial Data (Trial)* and ISO/IEC 27001:2022 [15]. Lightweight AI tools support intelligent classification and retrieval of desensitized files and raise efficiency in the knowledge combination phase [10]. The core design principle abandons simple static file storage; codified knowledge feeds back into daily R&D operations to build a complete closed-loop SECI knowledge spiral.

5.3. Industry (external governance) level: improving supporting digital governance policies

At the industry (external governance) level of the CMO framework, policy guidance provides vital support for manufacturing digital knowledge management. Overseas industrial practices verify that targeted fiscal incentives for digitalization raise enterprises' R&D investment and productivity [18]. Regulators can optimize supporting policies in two directions: first, launch exclusive special subsidies for R&D digital knowledge management to reduce tiered digital system construction costs; second, refine industrial compliance guidelines to implement requirements stipulated in *Key Points of 2026 Digital Economy Development Work* issued by the National Data Administration.

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Unified standards for R&D data sharing and desensitization ease corporate compliance concerns and provide a clear policy basis for cross-functional knowledge flow.

6. Conclusion

This paper builds its theoretical foundation on SECI theory, integrating the KNM, people–organizational process–technology barrier framework, and multi-level CMO framework. It unpacks manifestations and root causes of disrupted knowledge flow in manufacturing IPD. Through benchmark analysis of online service platforms, this paper develops a tripartite compliance-oriented digital governance framework covering individuals, organizations, and industry stakeholders. The findings categorize Chinese manufacturers into four knowledge management maturity tiers. Three ubiquitous knowledge circulation barriers are identified across the industry: low practitioner willingness to share knowledge, insufficient corporate knowledge management institutions, and mismatched digital tools. Hierarchical industrial data control and information security standards form key external constraints hindering internal R&D knowledge circulation. Online service platforms leverage automatic data logging, cross-system interoperability and AI retrieval to sustain intact SECI spirals. Nevertheless, manufacturers cannot directly replicate such models due to strict confidentiality compliance rules. Even so, enterprises may draw insights from the digital logic of integrated collaboration and automated experiential knowledge deposition. Combined implementation of tiered data protocols, human-machine tools, long-term knowledge incentives and industrial fiscal policies can effectively restore broken knowledge transformation cycles.

This paper has three limitations. First, the analysis relies on literature review and qualitative benchmarking, with no quantitative empirical validation. Second, the sample covers only domestic Chinese manufacturers, lacking cross-regional comparison of overseas firms. Third, the policy discussion focuses on industrial implementation rather than national-level holistic data governance deduction. Based on these outcomes, follow-up research could be expanded along three dimensions. At the micro level, subsequent work could jointly examine organizational knowledge management and corporate operational performance, refine tiered knowledge architectures, and expand samples to compare knowledge flow patterns under diverse national compliance frameworks and corporate cultures. At the meso industrial governance level, empirical research could quantify dual effects of digitalization and data classification policies to build a collaborative ecosystem of governments, industry associations and manufacturers. At the macro national governance level, future study could explore top-down industrial data regulation and build a balanced system aligning strict data security oversight with sustained manufacturing innovation.

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