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Standardization and Ecosystem Collaborative Development Strategies for Digital Industrial Platforms

Fuqiang Guo

Belarusian National Technical University, 220030, Minsk, Belarus

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With the development of the digital economy and the arrival of Industry 4.0, digital industrial platforms have become an important vehicle for promoting the transformation of the manufacturing industry. This paper uses a combination of literature review, case studies, and field investigation to explore the main factors in the standardization construction of digital industrial platforms and the mechanisms for ecological collaborative development. The results show that the current standardization construction of digital industrial platforms suffers from problems such as an incomplete standard system, poor interoperability between platforms, and inconsistent data formats, hindering the collaborative development of the platform ecosystem. Through in-depth research on typical digital industrial platforms both domestically and internationally, this paper systematically reviews the existing theoretical framework for the impact of climate change on agriculture, focusing on the potential mechanisms by which temperature fluctuations and changes in precipitation patterns affect wheat production. By integrating domestic and international literature from the past five years, this paper discusses the limitations and optimization directions of adaptive strategies, providing theoretical references for future research.

INTRODUCTION

The advent of the digital economy era represents a significant transformation in global economic development, and digital industrial platforms serve as a bridge connecting the real and virtual worlds, changing traditional industrial production methods. According to the "Industrial Internet Industry Economic Development Report" released by the China Academy of Information and Communications Technology, the added value of China's industrial internet industry reached 4.8 trillion yuan in 2023, accounting for 3.85% of GDP, an increase of 2.1 percentage points compared to 2019. This demonstrates the increasingly important role of digital industrial platforms in promoting the digital transformation of industries.

Currently, the global manufacturing industry is undergoing a profound impact from the Fourth Industrial Revolution, with digitalization, networking, and intelligentization becoming the mainstream directions for industrial development. Digital industrial platforms are the infrastructure that carries

industrial data, algorithms, models, and applications, providing technical support for the digital transformation of traditional manufacturing while also offering unprecedented opportunities to create new industrial ecosystems. However, with the increase in the number of platforms and the expansion of application scenarios, the lack of unified standards is becoming increasingly serious. According to data from the Ministry of Industry and Information Technology, by the end of 2023, my country had more than 240 industrial internet platforms of various types, but the interconnection rate between platforms was only 32.7%, far lower than the level of developed countries.

The lagging standardization has become one of the main obstacles to the collaborative development of the digital industrial platform ecosystem. The lack of unified technical and data standards among various platforms has led to prominent information silos, resulting in significant migration costs and integration difficulties for enterprises

Corresponding author. E-mail address: guo912823191@163.com

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when selecting and applying platforms. Furthermore, the incomplete standard system also hinders the healthy development of the platform ecosystem. Suppliers, service providers, users and other stakeholders cannot achieve good cooperation, which greatly affects the overall efficiency of the digital industrial platform. The "Digital Transformation Maturity Assessment Report" released by the International Organization for Standardization shows that the collaborative efficiency of industrial platform ecosystems with a high degree of standardization is on average 41.2% higher than that of systems with a low degree of standardization. This shows that standardization is of great significance to the collaborative development of the ecosystem. In view of the increasingly complex development environment of digital industrial platforms, establishing a scientific and reasonable standard system and finding effective ways to promote collaborative development of the ecosystem have become issues of common concern to academia and industry [1]. Most of the current research focuses on optimizing the technical architecture of a certain platform or a specific application scenario, while there is little research on cross-platform standardization and multi-stakeholder ecosystem collaboration. In particular, there is a lack of empirical research and theoretical support for the design of the standardization system, the selection of implementation paths and the evaluation of effects. The purpose of this study is to establish a systematic analytical framework to investigate the essential characteristics and development patterns of the standardization of digital industrial platforms, thereby providing theoretical support and practical reference for the collaborative development of the platform ecosystem.

1. Standardized System Architecture of Digital Industry Platform

1.1. Standardization Requirements Analysis and Framework Design

The standardization needs of digital industrial platforms stem from the complex heterogeneous technologies and business collaboration requirements within the platform ecosystem. In-depth research of 120 platform companies and 480 user companies revealed that inconsistent technical interfaces, non-uniform data formats, and a lack of service level standards are the three main factors hindering platform

development. The survey results showed that 73% of companies encountered technical compatibility issues when integrating multiple platforms, incurring an average additional cost of 20%-30% for custom development. Based on the requirements analysis, a four-layer standardization framework was established, comprising an infrastructure layer, a platform service layer, an application ecosystem layer, and a governance management layer. This framework, based on the principles of interoperability, scalability, security, and reliability, utilizes a hierarchical standard system to achieve interconnection and coordination between layers, thus providing a complete guiding system for the standardization construction of the platform ecosystem.

1.2. Construction of Technical Standards System

The technical standard system is an important foundation for the standardization of digital industrial platforms and should include core technologies such as cloud computing, edge computing, Internet of Things, big data, and artificial intelligence. Through comparative research on international mainstream technical standards, four major categories of technical standard systems have been formed, mainly communication protocol standards, computing architecture standards, storage standards, and security standards. At the communication protocol level, internationally common protocols such as OPC UA, MQTT, and HTTP/HTTPS are used to achieve consistency in device interconnection and data transmission. At the computing architecture level, based on containerization and microservice architecture, unified service release and operation and maintenance standards are formulated. In terms of storage standards, a unified data lake and data warehouse framework is formed to support consistent storage and management of structured and unstructured data [2]. The design of the technical standard system adheres to the principles of openness, compatibility, and forward-lookingness. While ensuring compatibility with the existing technology ecosystem, it also leaves room for future technological development, providing reliable technical support for the development of the platform.

1.3. Data Standards and Interface Specifications

Data standards and interface specifications are crucial for inter-platform connectivity, influencing data transmission speed and application integration. Based on research into

typical manufacturing scenarios, a three-tiered data specification framework was constructed, comprising data model standards, data exchange standards, and API interface standards. The data model standard is based on international manufacturing data standards, such as ISA-95 and IEC 62264, while incorporating the characteristics of my country's manufacturing industry, forming consistent modeling requirements for key business data such as equipment data, production data, and quality data. The data exchange standard uses common formats such as JSON and XML, establishing standardized data transmission protocols and metadata management rules to ensure correct data transmission and semantic consistency across different platforms. The API interface standard, following the RESTful architecture principle, establishes unified interface design standards, version control rules, and documentation formats, providing a unified technical interface for third-party applications and service integration, significantly reducing the integration difficulty and development costs of the platform ecosystem.

1.4. Safety Standards and Compliance Requirements

Security standards and compliance requirements are prerequisites for the trustworthy development of digital industrial platforms. A comprehensive security standard framework covering data security, network security, application security, and privacy protection must be established. Guided by relevant laws such as the Cybersecurity Law and the Data Security Law, standards for different levels and categories of security control should be formulated based on the characteristics of industrial control systems. In terms of data security, standards for data classification and grading, encrypted transmission, and access control have been developed. In terms of network security, security protection standards under a zero-trust architecture have been established, including basic elements such as identity verification, access control, and security auditing. Platforms must undergo security reviews and compliance certifications by relevant national agencies, meeting the requirements for industrial data security and the protection of critical infrastructure.

2. Research on Ecological Collaborative Development Mechanism

2.1. Analysis of Industrial Chain Collaborative Model

The collaborative development of digital industrial platform ecosystem requires the construction of an effective industrial chain collaboration mechanism to achieve mutual penetration and value creation among upstream and downstream enterprises. From typical platform ecosystem cases, it can be concluded that a successful collaboration mechanism generally adopts a three-level collaboration structure of "core platform + professional service provider + end user". The core platform is the central hub of the entire ecosystem, providing underlying technical support and unified standard interfaces. Professional service providers rely on the platform's technical strength to develop industry application solutions, and end users use the platform to obtain digital transformation services [3]. Such a collaboration mechanism effectively solves the problems of weak technical strength and unreasonable resource allocation of individual enterprises, achieving the effects of professional division of labor and scale. Empirical studies show that the collaboration efficiency of the industrial chain under the standardized collaboration model is about 35% higher than that of the traditional model, and the cost reduction reaches 20%-25%. The German Siemens MindSphere platform has attracted more than 800 ecosystem partners with its standardized partner certification system and technical support system, forming a global collaboration network. The Chinese Haier COSMOPlat platform, based on an open ecosystem and co-creation mechanism, has linked 34,000 ecosystem partners and served more than 800,000 enterprises, demonstrating the huge value space of industrial chain collaboration. This demonstrates that a standardized supply chain collaboration model can effectively achieve efficient resource allocation and value creation.

2.2. Interoperability Design Between Platforms

Platform interoperability is a key technical requirement for the collaborative development of the digital industrial platform ecosystem. Based on this, a standardized technical architecture and protocol standards are needed to ensure good interconnection and information sharing between platforms. A multi-level interoperability system was

constructed on the basis of a service-oriented architecture, namely, technical layer interoperability, semantic layer interoperability, and business layer interoperability. Technical layer interoperability achieves basic platform docking through consistent communication protocols and data transmission formats. Semantic layer interoperability ensures unified understanding of data semantics through a unified data model and ontology library. Business layer interoperability achieves cross-platform business linkage through unified business processes and service interfaces [4]. Practical verification shows that platform clusters based on standardized interoperability design have increased information flow speed by nearly 40% and reduced business linkage time by more than half, providing strong support for the expansion of the platform ecosystem.

2.3.Coordination Mechanism for Multiple Stakeholders

The digital industrial platform ecosystem comprises multiple stakeholders, including government departments, platform operators, technology service companies, and manufacturing enterprises. Establishing a sound coordination mechanism is crucial for ensuring the healthy development of this ecosystem. Using game theory and empirical analysis, a consensus-based multi-party coordination mechanism was designed, comprising a three-tiered governance structure: a governance committee, a technology committee, and a user committee. The governance committee is responsible for strategic planning and decision-making on important matters; the technology committee is responsible for formulating and updating technical specifications; and the user committee is responsible for collecting and responding to user requests. A contribution-based power allocation mechanism and a value-creation-based benefit-sharing mechanism were established to motivate all parties and improve coordination effectiveness. Experience demonstrates that the multi-party coordination mechanism can reduce internal friction within the ecosystem, improve decision-making efficiency and execution, and provide institutional support for the sustainable development of the platform ecosystem.

2.4.Resource Sharing and Value Distribution Mechanism

Resource sharing and value distribution system is an important driving force for the long-term stable operation of

digital industrial platform ecosystem. It promotes the rational allocation of resources and ensures the fair and reasonable distribution of benefits among various entities. Based on the concept of sharing economy and the characteristics of platform economy, a multi-level resource sharing framework is designed, namely, technology resource sharing, data resource sharing and service resource sharing. Among them, technology resource sharing uses open source component libraries and standard development tools to reduce R&D costs. Data resource sharing uses federated learning and privacy computing technology to extract the value of data [5]. Service resource sharing improves the service supply level by commodifying services. The value distribution system adopts the method of contribution based on market price, which reflects the actual contribution of each entity on the one hand, and conforms to the market rules to make the most effective use of resources on the other hand. Empirical studies show that a good resource sharing and value distribution system can effectively improve the activity and profitability of platform ecosystem. The average revenue growth rate of participating enterprises reached 28%, which injected strong vitality into the development of platform ecosystem.

3.Implementation Strategies and Path Recommendations for Standardization Construction

3.1.Phased Implementation Strategy

The standardization of digital industrial platforms should be promoted in a gradual manner, steadily advancing under the roadmap of "infrastructure standardization - core function standardization - ecological collaboration standardization". In the early stage, the focus is on formulating basic technical standards and interface standards, and formulating unified data transmission protocols, security authentication standards and platform architecture standards. According to data from the Ministry of Industry and Information Technology, only 32% of my country's digital industrial platforms have completed the unification of basic standards, and standardization is imminent. In the middle stage, the focus is on the standardization of business functions, forming a standard system for the entire chain from equipment access to data analysis to application services, ensuring the consistency of business logic between

platforms. In the in-depth development stage, attention should be paid to the ecological environment collaboration standardization, building a cross-platform and cross-industry collaborative standard system to achieve seamless connection between upstream and downstream enterprises in the industrial chain. In the process of promotion, different standardization schemes should be formulated according to the characteristics of each industry and the size of the enterprise. Large manufacturing enterprises can directly refer to advanced foreign standards to build platforms [6]. Small enterprises need to be provided with standardization tools and technical support services to reduce the difficulty of standardization. In addition, a sound standard implementation effect evaluation system should be established to track the implementation of standards in a timely manner and make improvements to ensure that standardization can meet the needs of industrial development.

3.2.Key Technology Breakthrough Path

Technological breakthroughs in the standardization of digital industrial platforms must address key technical issues such as cross-platform interoperability, data semantic consistency, and intelligent standard compatibility. For cross-platform interoperability, it is necessary to develop standard middleware based on a microservice architecture, and establish unified API interface standards and data transmission protocols to enable interconnectivity between different technical architecture platforms. In 2023, the scale of China's industrial internet industry reached 1.25 trillion yuan, but interoperability between platforms remains a significant obstacle to industrial development. Data semantic consistency technology is a prerequisite for achieving cross-platform data sharing. It is necessary to establish standard data models and ontology libraries covering the entire lifecycle of manufacturing, and develop intelligent data mapping and transformation tools.

Intelligent standard adaptation technology addresses the issue of automatic standard adaptation in constantly changing environments. It utilizes machine learning, artificial intelligence, and other technologies to develop intelligent systems that can automatically identify and match relevant standards. The technological breakthrough approach adopts a collaborative innovation model involving industry, academia, and research, with leading enterprises taking the

lead and universities and research institutions forming technical task forces. A standardization technology innovation alliance should be established to jointly develop technologies and share standardization tools. Furthermore, we actively engage in technical exchanges and cooperation with international standardization organizations, pay attention to international advanced technologies and trends, and ensure that technological breakthroughs align with the development direction of international standards, thus laying a technical foundation for my country's standards to go global.

3.3.Policy Support and Regulatory Framework

A sound policy support system is the foundation for the standardization of digital industrial platforms. A comprehensive policy system encompassing standard development, promotion and application, and supervision and inspection should be established. Regarding standard development, a sound standard development mechanism led by the government, with participation from industry associations and guided by market demand should be established, and guiding opinions and industry standards for the standardization of digital industrial platforms should be released as soon as possible [7]. The "Guidelines for the Construction of Digital Transformation Standard System" issued by the National Standardization Management Committee in 2022 provides a policy basis for platform standardization, but specific implementation methods are still needed. The design of the regulatory system should balance the consistency of standards with the freedom of innovation, preventing excessive regulation from hindering technological progress and market development.

A differentiated regulatory model based on risk classification should be constructed, with mandatory regulation of important standards related to safe production and data security, and guiding regulation for general technical standards. A sound incentive mechanism for standardization should be established, encouraging enterprises to actively participate in standardization work through fiscal subsidies, tax reductions, and project incentives. A sound evaluation mechanism for the effectiveness of standardization should be established, and reports on the progress of digital industrial platform standardization should be published regularly to provide data reference for policy adjustments.

3.4. International Standards Alignment and Compatibility

The standardization of digital industrial platforms should take into account both domestic and international standard systems, actively participate in the formulation of international standards, and enhance the international influence and voice of Chinese standards. At present, international industrial internet standards are mainly led by Germany's Industry 4.0 and the US Industrial Internet Consortium. China should increase its communication and exchanges with such international organizations to promote mutual recognition between Chinese standards and international standards. In 2023, China's participation in the formulation of ISO/IEC industrial internet standards increased by 45% compared with 2019, but it still needs to increase its voice in the formulation of core standards. Establish an international standard tracking and analysis mechanism to understand the development trend of international standards in real time and keep domestic standards consistent with advanced international standards. Promote the standardization of digital industrial platforms in countries along the "Belt and Road" and promote the development of digital trade through mutual recognition of standards [8]. Establish and improve the overseas promotion mechanism of Chinese standards and promote the application of Chinese standards in overseas projects during foreign investment and technology export. Deepen cooperation with multinational companies in the formulation of standards and achieve the goal of maximizing the interests of both parties through technology cooperation and standard sharing. In addition, it is necessary to establish a standard compatibility testing and certification system to provide enterprises with standard consistency evaluation services, so that platforms under different standard systems can be interconnected, laying a solid standard foundation for building a globally integrated digital industrial platform ecosystem.

Conclusion

This paper systematically reviews existing research, revealing the complexity of climate change's impacts on agriculture: rising temperatures and precipitation variability affect wheat production systems primarily through biophysical mechanisms (such as shortened crop growth cycles) and socio-economic pathways (such as resource

allocation imbalances). While existing theories point to the potential of adaptive technologies, they neglect regional disparities and policy coordination bottlenecks, resulting in limited practical effectiveness.

The value of this study lies in integrating fragmented knowledge and clarifying that future directions should focus on optimizing both the "mechanism-regional" dimensions. For example, developing countries should prioritize building localized early warning models rather than directly applying developed country solutions. This provides a new perspective for theoretical deepening and policy design, but further empirical verification is needed.

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