The influence of digital innovation ecosystem of high-end equipment manufacturing on the intelligent maturity of enterprise – an empirical study on the configuration of the “three-layer core-periphery” structure

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Abstract

Purpose – With the deep development of the new technological revolution and industrial transformation, the development, application, expansion and integration of digital technology provide opportunities for transforming the manufacturing industry from traditional manufacturing to intelligent manufacturing. However, little research currently focuses on analyzing the influencing factors of intelligent development in this field. There is a lack of research from the perspective of the digital innovation ecosystem to explore the intrinsic mechanism that drives intelligent development. Therefore, this article starts with high-end equipment manufacturing enterprises as the research subject to explore how their digital innovation ecosystem promotes the effectiveness of enterprise intelligent development, providing theoretical support and policy guidance for enterprises to achieve intelligent development at the current stage.

Design/methodology/approach – This article constructs a logical framework for the digital innovation ecosystem using a “three-layer core-periphery” structure, collects data using crawling for subsequent indicator measurement and assessment and uses the fuzzy set Qualitative Comparative Analysis method (fsQCA) to explore how the various components of the digital innovation ecosystem in high-end equipment manufacturing enterprises work together to promote the development of enterprise intelligently.

Findings – This article finds that the various components of the digital innovation ecosystem of high-end equipment manufacturing enterprises, through mutual coordination, can help improve the level of enterprise intelligence. Empirical analysis shows four specific configuration implementation paths for the digital innovation ecosystem of high-end equipment manufacturing enterprises to promote intelligent development. The core conditions and their combinations that affect the intelligent development of enterprises differ in each configuration path.

Originality/value – Firstly, this article discusses the practical problems of intelligent transformation and development in the manufacturing industry and focuses on the intelligent development effectiveness of various components of the digital innovation ecosystem of high-end equipment manufacturing enterprises in the context of digitalization. Secondly, this article uses crawling, text sentiment analysis and other methods to creatively collect relevant data to overcome the research dilemma of being limited to theoretical analysis due to the difficulty in obtaining data in this field. At the same time, based on the characteristics of high-end equipment manufacturing enterprises, the “three-layer core-periphery” digital innovation ecosystem framework constructed in this article helps to gain a deep understanding of the development characteristics of the industry’s enterprises, provides specific indicator analysis for their intelligent development, opening the “black box” of intelligent development in the industry’s enterprises and bridging the gap between theory and practice. Finally, this study uses the fsQCA research method of configuration analysis to explore the complexity of the antecedents and investigate the combined effects of multiple factors on intelligent development, providing new perspectives and rich research results for relevant literature on the intelligent development of high-end equipment manufacturing enterprises.

Keywords Digital innovation ecosystem, “Three-layer core-periphery” structure, High-end equipment manufacturing, Intelligent development, fsQCA

Paper type Research paper

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1. Introduction

The vigorous development of emerging industries has been identified as a key strategy for finding new economic growth points and promoting steady economic growth. As a critical industry in driving China’s economic transformation, strategic emerging industries are highly valued, especially in transitioning from a manufacturing country to a strong manufacturing country. As one of the seven strategic emerging industries, high-end equipment manufacturing is essential to building a strong manufacturing country (Wang et al., 2023). However, China’s high-end equipment manufacturing industry needs to improve its innovation capacity and overcome key technological bottlenecks, necessitating an innovation-driven transformation in a critical stage of development.

With the rapid development of the new round of technological revolution, the digital innovation ecosystem is driving an industrial revolution and innovation development at an unprecedented speed (Zhu et al., 2022) while affecting various attributes of enterprises such as organization, technology and management, making the advantages possessed by enterprises more evident. In this context, high-end equipment manufacturing enterprises need to correctly guide the digital innovation ecosystem and fully leverage each production factor's role and means to facilitate the construction of the digital innovation ecosystem and promote innovation-driven digitalization. This change is the practical application of the theory of the innovation ecosystem, which is centered on enterprises driven by innovation and characterized by openness, diversity and interactivity. This theory emphasizes the collaboration and sharing of internal and external innovation resources through an innovative organizational form centered on enterprises, which accelerates and scales innovation, thus promoting sustainable development and growth. Therefore, we should actively learn from the essence of the innovation ecosystem theory at the enterprise level, correctly guide the digital innovation ecosystem and innovation system and achieve innovation-driven under digitalization.

By establishing a digital innovation ecosystem, enterprises can transcend traditional decision-making paradigms, achieving a higher level of intelligent optimal decision-making. This advancement in intelligence enhances production efficiency and competitiveness and facilitates the transformation toward intelligent development. Intelligent development refers to the process of achieving interconnection between the physical and digital worlds through the introduction and application of artificial intelligence, machine learning, automation and other technological means, and using these technologies and data resources to improve productivity, create value and optimize decision-making (Richard et al., 2020). China attaches great importance to the intelligent of the manufacturing industry and has formulated and issued a series of plans to clarify the goals and development direction of achieving rapid upgrading of manufacturing intelligent. While China’s intelligent manufacturing is advancing at a fast pace, intelligent research has yet to keep up with practical development.

Scholars at home and abroad mainly conduct research on intelligent manufacturing from three aspects: intelligent products (Porter and Heppelmann, 2016), intelligent production (Allmendinger and Lombreglia, 2005) and intelligent services (Wang et al., 2023). However, differences and ambiguity exist in understanding the connotation, development status and influencing factors of intelligent manufacturing. Regarding the driving factors of manufacturing intelligence, existing research is still insufficient. Most studies only provide qualitative analysis without sufficient empirical research to reveal the driving factors affecting the intelligent level. Existing literature suggests that factors such as policy support (Ren et al., 2018), industry environment, intelligent technology (Su and Yang, 2018) and innovation capability (Meng and Zhao, 2018) contribute to the improvement of the level of manufacturing intelligence. However, most studies start from a single perspective, and the relative importance of these factors has not been fully studied and confirmed.

In pursuit of bolstering national core competitiveness and realizing high-quality economic development, the report of the 20th National Congress of the Communist Party of China
pointed out the current need to enhance high-end equipment manufacturing and promote intelligent development. The high-end equipment manufacturing industry refers to a type of equipment manufacturing industry with high technological content, added value and quality. It usually requires a high level of technology and capital investment. However, there has been insufficient research on the factors influencing its intelligent development. There is a lack of exploration of the intrinsic mechanisms driving intelligent development from a digital innovation ecosystem perspective. Therefore, this paper aims to investigate how the digital innovation ecosystem of high-end equipment manufacturing enterprises can enhance the effectiveness of enterprise intelligent development. The study provides theoretical support and policy guidance for enterprises to achieve a new stage of intelligent development.

Since the digital innovation ecosystem is a complex system that involves joint influences and coordinated interactions among various components, the fuzzy set Qualitative Comparative Analysis (fsQCA) method, which uses configurational analysis to explore the complexity of antecedents and investigate the joint effects of multiple factors on the outcome variable, is suitable for this study. This paper intends to use fsQCA to explore and analyze the role of the digital innovation ecosystem of high-end equipment manufacturing enterprises in promoting enterprise intelligent transformation and development. This study adopts a configuration perspective to clarify interactions among the components of the digital innovation ecosystem, explore multiple paths and mechanisms for improving enterprise intelligence and answer the research question of how the digital innovation ecosystem facilitates intelligent development in high-end equipment manufacturing enterprises.

The structure of the following article is as follows: Section 2 provides a comprehensive review of the literature, section 3 outlines the research framework and section 4 describes the methods used in the study. Section 5 presents the research results, while sections 6, 7 and 8 present the study’s discussion, theoretical contributions and practical implications.

2. Theoretical background and literature review

2.1 Innovation ecosystem theory

As innovation theory and research related to ecosystems deepened, the academic community introduced the ecosystem into innovation research, forming the “innovation ecosystem theory” to describe how various interconnected innovation subjects build evolving networks to achieve value co-creation (Jacobides et al., 2018).

The innovation ecosystem emphasizes the interdependence and complex relationships among organizational subjects and regards innovation as an interaction between different subjects and the ecological environment (Benitez et al., 2020). Unlike traditional ecosystem theory, the innovation ecosystem focuses on the interrelationships between different innovation subjects, creating new products or services through collaborative interactions among different innovation subjects in the innovation environment (Jacobides et al., 2018). The innovation ecosystem involves diverse stakeholders, including user participants and many stakeholders, working together to promote innovation generation, application and diffusion. The entire innovation process is influenced by the elements of the system and the relationships between these elements (Palmié et al., 2022).

This study builds its research framework upon the theory of the innovation ecosystem, which offers a comprehensive and effective tool for understanding and analyzing the intelligent development of high-end equipment manufacturing enterprises. The theory of innovation ecosystem highlights that enterprises are not standalone entities but rather embedded within larger systems comprising various elements, including policy factors, market factors, technological factors and others. The interactions and collaborations among these elements play a crucial role in facilitating the intelligent development of enterprises. This theory provides a solid foundation for our research by emphasizing the interactivity and synergistic effects among the elements.
In the context of the digital innovation ecosystem, the constituent elements, such as hardware, software, data, talent and policy, do not exist in isolation but rather interact within a certain environment to foster the intelligent development of enterprises through collaborative coordination. Therefore, we use the fsQCA method to deeply study the performance of multiple elements in high-end equipment manufacturing enterprises and how they interact synergistically to promote the intelligent development of enterprises. It will help us better understand the operational mechanisms of digital innovation ecosystems and provide valuable practice guidance.

2.2 Literature review

This literature review aims to systematically collect and organize relevant literature on digital innovation and intelligent development to support answering the research questions. Major academic databases, such as Cnki, Web of Science, SAGE Journals Online, Emerald Insight, Springer and Wiley Online Library, were searched to obtain relevant journal articles. The time frame of the search was up until the present, reflecting the latest research progress in this field.

We carefully selected keywords related to our research topics, including the digital innovation ecosystem, the high-end equipment manufacturing industry and manufacturing intelligent. To screen the literature, we established clear inclusion and exclusion criteria: relevance to the research topics, scientific quality, a certain degree of originality or innovation, journal ranking, significant citation rates and timeliness. We screened many articles and analyzed approximately 194 papers based on the above analysis. Subsequently, we conducted a comprehensive review and summary of these articles, ultimately citing the most representative papers. We believe that the literature we have collected provides strong support and empirical evidence for addressing the research questions constructed in this article.

2.2.1 Literature review of the digital innovation ecosystem. With the continuous development of digitalization, digitalization can reshape the value co-creation mode among various innovation subjects in the existing innovation ecosystem. Domestic and foreign scholars have extended their thinking on digital innovation ecosystems from existing innovation ecosystem theory research. Some scholars believe the innovation ecosystem emphasizes competition and cooperation among many participants, with one subject as the core focus to jointly create new technologies, new business forms and new models, thus achieving non-linear interactive relationships of value co-creation (Benitez et al., 2020).

Digital innovation refers to integrating digital technology into enterprise product creation and business operations (Chae, 2019). The digital innovation ecosystem is the product of integrating digital innovation with the innovation ecosystem (Chae, 2019), which empowers innovation by leveraging digital technology and big data resources. The system participants engage in dynamic, collaborative competition through digital innovation, enabling knowledge sharing, mutual benefits and interconnectedness. It facilitates the exchange of production factors (Beltagui et al., 2020), allowing the complementary and recombination of resources among various innovative entities and promoting common development (Beltagui et al., 2020).

Within a digital innovation ecosystem, various participants engage in technological and business model innovation through the use and development of digital technologies, thereby driving new products, services and solutions (Palmié et al., 2022). The digital innovation ecosystem not only introduces digital technology resources as a unique production factor but also enhances the collaborative cooperation among actors in the existing innovation ecosystem (Gawer, 2021), facilitating cross-border exchange and innovation of elements and enabling differentiation from competitors to seize market opportunities (Palmié et al., 2022).
Combining the views of scholars such as Palmié, under the joint driving force of digital technology, big data resources and knowledge, the digital innovation ecosystem presents special attributes such as multi-level subject coupling and cross-regional flow of factors (Porter and Heppelmann, 2016). However, the extensive participation of multiple entities, aggregation of massive data and dynamic and flexible relationships will inevitably bring challenges in innovation resource management, collaborative innovation among entities and control of the innovation process. Therefore, efficiently coordinating data resources and innovation actors has become critical in building a digital innovation ecosystem (Cusumano and Gawer, 2002).

Previous research analysis suggests that coordinating an emerging innovation ecosystem can provide opportunities for the operational entities within the system to gain sustainable competitive advantages (Jacobides et al., 2018). It calls for enterprises to develop new capabilities throughout the system operation process and actively respond to internal and external changes. By constructing a well-designed ecosystem, enterprises can create and capture value (Jacobides et al., 2018). Based on the current external environment of fierce competition and rapid development of digital technology, high-end equipment manufacturing enterprises must establish a digital innovation ecosystem to facilitate efficient collaboration among resources and multiple factors and promote intelligent development. Current enterprises tend to overly focus on technology in ecosystem studies (Tronvoll et al., 2020). Therefore, it is important also to consider the critical role played by factors other than technology in the digital innovation ecosystem of enterprises.

To summarize, there is a consensus among previous studies and in this paper that the digital innovation ecosystem enriches and optimizes the existing innovation ecosystem and the benefits it can bring its participants. The current academic research on the digital innovation ecosystem is still in its early stages of evolution, and the findings are few and scattered. The framework for the composition of the digital innovation ecosystem is not yet well-established, and there is a lack of research on its mechanism of action, particularly about high-end equipment manufacturing enterprises and how different factors interact within their digital innovation ecosystem to promote intelligent development. Therefore, this study proposes a “three-layer core-periphery” framework of the digital innovation ecosystem to analyze the role of various combinations of condition elements in driving the intelligent development of high-end equipment manufacturing enterprises.

2.2.2 Literature review of the high-end equipment manufacturing industry. The prioritized development of high-end equipment manufacturing is an important strategy for constructing a strong manufacturing nation and a key approach to national transformation and development (Wang et al., 2023). The research on high-end equipment manufacturing encompasses four main aspects. Firstly, the technical aspect investigates the impact of technological improvement on the industry’s development (Liu et al., 2022). Secondly, management focuses on implementing and protecting relevant policies (Li et al., 2014). Thirdly, the innovation aspect explores innovation performance (Chen and Chen, 2021). Finally, the economic level is mainly based on the local perspective on strategic emerging industries to analyze the high-end equipment manufacturing industry’s financing efficiency and financial support (Chen and Liu, 2017).

By analyzing the above literature, research on developing the high-end equipment manufacturing industry has achieved significant results. However, there are still some issues with insufficient collaboration between innovation entities and the need for further breakthroughs in innovation (Liu et al., 2022). With technology innovation as its core, the high-end equipment manufacturing industry faces significant research and development difficulties and high risks. Overall, the level of development in China’s high-end equipment manufacturing industry still requires further improvement. As highlighted by the research conducted by Yang and Xue (2022), implementing a sustainable innovation-driven strategy is
an inevitable choice for development. Their perspectives and insights have inspired us to delve deeper into the issue, and we believe that analyzing from the perspective of the enterprise’s digital innovation ecosystem is crucial. Such an approach provides a novel way to understand and promote intelligent development in the high-end equipment manufacturing industry and offers a new inspiration and framework for our research.

In conclusion, this study and existing literature have agreed on the importance of developing the high-end equipment manufacturing industry. However, current research on the development of the high-end equipment manufacturing industry mainly focuses on analyzing specific research topics, lacking a comprehensive and holistic perspective, which makes it difficult to obtain a comprehensive understanding and in-depth insights into the overall development trends of the high-end equipment manufacturing industry. This study takes a comprehensive perspective of the digital innovation ecosystem to explore the development mechanisms of the high-end equipment manufacturing industry, which distinguishes it from existing research. Furthermore, this study emphasizes the urgent need for the high-end equipment manufacturing industry to achieve innovation breakthroughs, intelligent transformation and upgrades through digitization. This viewpoint reveals research space and development value, providing a new perspective for the future development of the high-end equipment manufacturing industry.

2.2.3 Literature review of intelligent manufacturing. Although scholars at home and abroad have extensively studied the concept of intelligent manufacturing, opinions remain inconsistent. Foreign scholars tend to define intelligent manufacturing as using technological means for monitoring and management (Kusiak, 1989), while domestic scholars see it as a new production mode that runs through the entire production process of manufacturing enterprises (Zhang et al., 2019).

The scope of intelligent manufacturing encompasses the entire manufacturing industry. However, research on the intelligent transformation of manufacturing enterprises focuses mainly on technology innovation, enterprise development and production. There is relatively less research on upgrading high-end equipment manufacturing enterprises to intelligent manufacturing. The technical aspect is to explore the role of digital technology in manufacturing companies to promote the development of enterprise intelligent (Meng and Zhao, 2018). The research by Meng and Zhao (2018) demonstrates that the integration of digital technology and the transformation and development of the manufacturing industry has become a trend, providing important thinking directions for this study. The development aspect focuses on how people, machines and services can promote the high-quality intelligent transformation of enterprises (Ji et al., 2018), and the production aspect, the intelligent transformation of enterprises, is argued for by analyzing changes in intelligent production methods, in the manufacturing process (Tan et al., 2017). However, high-end equipment manufacturing enterprises are at the core of the industrial chain and are an important driving force for China’s manufacturing industry transformation and upgrading. The existing research has not yet explored the driving process of intelligent development in high-end equipment manufacturing enterprises, which is precisely the focus of this study.

In summary, this study and existing literature have agreed on manufacturing enterprises intelligent transforming and upgrading through applying digital technology for innovation development. However, existing literature predominantly adopts qualitative analysis and case studies to focus on exploring the role of digital technology applications in guiding the transformation and upgrading of the manufacturing industry. Currently, limited research empirically investigates how the digital innovation ecosystem influences the intelligent development of enterprises in the context of digital technology applications. Therefore, this study explores how the digital innovation ecosystem of high-end equipment manufacturing enterprises affects their intelligent development from an empirical analysis perspective.
3. Research framework

3.1 Research framework construction of digital innovation ecosystem

Not all innovation ecosystems share the same architectural model and internal framework (Su et al., 2018), highlighting the need for personalized analysis and targeted model frameworks. Examining the internal structure of innovation ecosystems can offer new insights for further exploring their sub-dimensions.

By reviewing the literature on existing innovation ecosystems, current research on the structural classification of innovation ecosystems often divides it based on the ecosystem’s lifecycle (birth, expansion, leadership and self-renewal) (Chen et al., 2014), the ecosystem level (macro-national level, mid-industry or regional level, micro-organizational level) perspective (Pombo et al., 2017) and the hierarchical structure (Su et al., 2018). Among them, the existing research based on the hierarchical structure mainly starts from the “core-periphery” and the “three-layer” structures (Su et al., 2018). The appendix contains the schematic diagrams of these two frameworks.

However, both frameworks have limitations, making it difficult to explain the problem fully. This study combines the two structures to overcome these limitations and constructs a “three-layer core-periphery” structural framework to systematically analyze the corporate innovation ecosystem. Under this framework, the core layer establishes various innovation platforms, connects peripheral participants and achieves system coordination and cooperation. This structure facilitates an in-depth study of the interactions and cooperation between innovation platforms.

This study employs a “three-layer core-periphery” structure to establish high-end equipment manufacturing enterprises’ digital innovation ecosystem framework. The core layer comprises high-end equipment manufacturing enterprises, recognized as key participants in the digital innovation ecosystem due to their rich digital technology capabilities, which play a critical role in ecosystem construction and management (Porter and Heppelmann, 2016). As an important area for realizing innovation-driven development, management transformation and digital upgrades in the industrial field, high-end equipment manufacturing reflects China’s highest level of science and technology, process level and quality requirements, with a high output value and broad supply chain. With the rapid development of new-generation network information technology as the core driving force, high-end equipment manufacturing enterprises rely on the mature application of digital technology to engage in relevant website and platform operations, breaking the physical limitations of time and space, enabling more scientific research cooperation to be directly realized through digital means, enhancing the universality of traditional scientific research cooperation and expanding the development space for business operations.

This article first analyzes the existing characteristics of the high-end equipment manufacturing industry. As a strategic and emerging industry with high-tech and knowledge-intensive characteristics (high-tech content and high knowledge), high-end equipment manufacturing is leading in innovation. Its strong industry association between the industrial and value chains, closely related to optimizing and upgrading some basic industries and technological innovation, contributes to its enormous potential for development and strong driving force. Therefore, we divide the platform layer into technology, innovation, relationship and financial platforms.

3.1.1 The technology platform. The technology platform is mainly manifested in technology R&D and patent licensing because technology R&D and patent licensing are the two most important aspects of the technology platform. Technology R&D elevates a company’s technological capabilities (Wang et al., 2020), while patent licensing assists in disseminating and applying technological achievements externally (Arora and Fosfuri, 2003). The construction of a technology platform requires the full utilization of internal and external technological resources within a company to facilitate resource sharing and collaborative
innovation. In this context, technology R&D and patent licensing are integrated into the planning and construction of the technology platform. This integration accelerates technological innovation and the conversion of achievements, thereby promoting industrial development and upgrading (Nepelski and De Prato, 2015). Therefore, within the framework of high-end equipment manufacturing, technology research and development and patent licensing are integral components of the technology platform.

3.1.2 The innovation platform. Under the current trend of intelligent development in manufacturing, the driving force of high-end manufacturing enterprises lies in advanced technological equipment and strong innovation capability, which facilitates the radiation and technology spillover to upstream and downstream enterprises, thus driving the entire industry chain’s technological innovation and competitiveness improvement. Innovative talents provide intellectual support to enterprises; specifically, innovative talents are a crucial part of the innovation platform. High-end manufacturing companies need to attract and cultivate professional talents with innovative spirit and practical experience to support their technology innovation and product development work (Tian and Liu, 2022); innovation ability, as the core competitiveness of enterprises, helps them to have a keen market insight and quick response ability to adapt to market changes and continuously meet customer needs (Liu and Atuahene-Gima, 2018); the construction of intelligent facilities provides digital infrastructure support for high-end manufacturing enterprises (Song et al., 2021). The synergistic effect of the three aspects can effectively promote technological innovation of high-end manufacturing enterprises and enhance the competitiveness of the entire industry chain. Therefore, innovative talents, innovation ability and intelligent facilities are important components of the innovation platform and are reflected in the corresponding peripheral layers.

3.1.3 The relationship platform. The relationship platform reflects the flow and interaction of relational resources in the digital innovation ecosystem of high-end equipment manufacturing enterprises; as an important social capital, relational resources significantly impact the development of digital innovation activities (Lin et al., 2017). Within this ecosystem, political connections are among the most important social capital (Zhang et al., 2022), as digital innovation activities often involve significant uncertainty and require government departments’ assistance in policy support, resource support and procurement activities. The current global economic integration has brought significant opportunities for enterprise development but has also intensified international competition. Simultaneously, the rapid development of science and technology has shifted focus towards high-tech and complexity; individual enterprises cannot meet the demands of today’s technological development by relying solely on their limited strength. In this context, high-end equipment companies tend to form strategic alliances with research institutions, other enterprises, etc. Within the same strategic alliance, each member is interconnected and can cooperate and share risks and benefits, effectively alleviating external pressure and risk and reducing the difficulty of achieving each other’s strategic goals (Marciukaityte et al., 2009). Therefore, the strategic alliance is also an indispensable key peripheral participant in the organizational platform of the high-end equipment manufacturing enterprise’s digital innovation ecosystem.

3.1.4 The financial platform. Financial support is crucial for the development and intelligent transformation of high-end equipment manufacturing enterprises. The technologies and equipment used in high-end manufacturing are relatively complex and require significant research, development and production investment. Furthermore, the market demand for high-end equipment manufacturing is limited, which leads to a longer time to realize profits and returns on investment. This small market demand challenges the enterprise’s cash flow, necessitating continuous financial allocation and optimization to ensure normal operations and steady growth (Zhang et al., 2019). The continuous development of digital, intelligent and automated technologies also demands significant
financial investment for high-end equipment manufacturing enterprises to keep upgrading and transforming their technologies (Kauffman et al., 2015). Through continuous financial investment, enterprises can improve their competitiveness, market position and economic benefits. As a financial platform for analyzing the funding arrangements of high-end equipment manufacturing enterprises, we have devised a comprehensive follow-up analysis plan divided into three outer layers: solvency, operational capability and growth ability. This plan enables us to better understand the enterprise’s financial situation and needs and provide more targeted financial support solutions.

In conclusion, Figure 1 shows the digital innovation ecosystem structure framework of high-end equipment manufacturing enterprises constructed in this paper.

3.2 Research sample
This article selects the high-end equipment manufacturing industry in the manufacturing sector as the scope of research. Compared to traditional equipment manufacturing, high-end equipment manufacturing, led by advanced technologies, occupies the high-value segments of the value chain and the core of the industrial chain. It is a strategic emerging industry that plays a decisive role in the overall competitiveness of the industry chain. Vigorously nurturing and developing the high-end equipment manufacturing sector contributes to expediting the economic development mode’s transformation and shifting from a manufacturing giant to a manufacturing powerhouse. Using it as a research sample has research value and meets practical needs.

Based on different application scenarios, the high-end equipment manufacturing industry can be divided into five sub-industries: aerospace equipment, marine engineering equipment, satellite manufacturing and application, rail transportation equipment and intelligent equipment. Figure 1 shows the digital innovation ecosystem structure framework of high-end equipment manufacturing enterprises constructed in this paper.

Figure 1. Structural framework of the digital innovation ecosystem for high-end equipment manufacturing enterprises

Source(s): Figure by authors
manufacturing equipment industry (Chen and Han, 2017). After defining the specific scope of coverage, this study compiled an initial list of companies from the publicly traded companies in relevant sub-industries published by the Shenwan Industry Classification and Tonghuashun Industry Classification, as well as the “High-End Equipment Manufacturing Industry Alliance” list. Then, referring to the Forward Industry Research Institute’s summary of the close association between listed companies in relevant industries and their industrial chains, we selected companies with a relevance degree of three stars or higher. To ensure the financial soundness of the selected companies, ST and *ST enterprises with two consecutive years of losses or the possibility of delisting, as well as those with many missing samples during the data collection process, were eliminated. Ultimately, we narrowed the list to 30 high-end equipment manufacturing enterprises with a high degree of industrial association in their respective sub-industries, sound financial conditions and active disclosure of relevant data. These characteristics give the selected companies excellent market competitiveness and potential for sustainable development, with a high-level trend of intelligent development, which helps us explore the mechanism of promoting high-level intelligent development of enterprises.

4. Methods

4.1 Fuzzy set qualitative comparative analysis (fsQCA)
This article mainly uses fsQCA based on the following considerations: Firstly, fsQCA enables a holistic analysis of multiple cases, thus ensuring the effectiveness of external promotion. Secondly, fsQCA's configurational perspective facilitates a comprehensive explanation of the intricate causal relationships among variables and systemic effects among multiple factors. Given the complexity of the intelligent development of high-end equipment manufacturing enterprises and the multifaceted implementation process involved, fsQCA identifies variable combinations and core conditions that promote enterprise intelligent development by analyzing the configuration of internal variables in the digital innovation ecosystem of high-end equipment manufacturing enterprises. It can provide a reference for high-end equipment manufacturing enterprises to improve their level of intelligence. In the subsequent empirical analysis, we will explain the coefficient threshold settings for each stage of the fsQCA analysis process.

4.2 Selection and measurement of variables
Following the “three-layer core-periphery” research framework of the digital innovation ecosystem established in this article, we measure and evaluate various indicators extended by each platform. When collecting relevant data within a span, we set the collection period for this article between January 1, 2018, and December 31, 2021.

4.2.1 The technology platform.

(1) Technology R&D
With the emergence of technologies such as artificial intelligence, cloud computing, blockchain, big data and so on, digital technology presents a strong trend of digital transformation and innovation while continuously achieving breakthroughs in innovation. To better understand the technological landscape, this study categorizes new digital technologies into five groups: artificial intelligence technology, blockchain technology, cloud computing technology, big data technology and the internet of things. By screening and counting the frequency of keywords in each technology category in each company’s annual reports, one calculates the comprehensive scores of the technology R&D level by weighing the scores using the entropy value method. In constructing the subdivided keyword
indicators, we drew on the materials in the “Research Database of Digital Transformation of Listed Companies in China”.

(2) Patent licensing

There are primarily three types of patents: invention, utility model and design. The high-end equipment manufacturing industry prioritizes the development of high-quality patents due to its high-tech transformation characteristics and the pressing demand to enhance technology innovation efficiency. Therefore, this article reflects the level of patent licensing of each high-end equipment manufacturing enterprise by calculating the score of the ratio of the number of effective invention patents to the number of authorized effective patents.

Among them, effective invention patents refer to inventions that have undergone examination and obtained patent rights. The number of effective invention patents is usually one of the important indicators of an enterprise’s achievements and contributions in innovation and technology fields. A higher number of effective invention patents usually means that the organization, enterprise or individual has stronger strength and competitiveness in the field of technology, has higher innovation and technology research and development capabilities, and can reflect an organization’s, enterprise’s or individual’s achievements and contributions in innovation and technology fields. The number of authorized effective patents refers to the number of patents that have been authorized and are still valid within a specific time frame obtained by an enterprise. We often use the number of authorized effective patents to measure the patent strength and effectiveness of an organization, enterprise or individual’s patent strategy (Tian and Liu, 2022). Organizations, enterprises or individuals with many authorized effective patents may indicate strong innovation, research and development capabilities and technological market competitiveness. At the same time, this is also an important indicator for evaluating the technological advantages and intellectual property reserves of an organization, enterprise or individual in a specific field. Each enterprise’s relevant invention patent data sources are from the CSMAR database, annual reports of enterprises and the QCC website (an Internet company based in China that provides enterprise information query and commercial data analysis services).

4.2.2 The innovation platform.

(1) Innovative talents

Innovation, as the soul of the digital innovation ecosystem, cannot be separated from developing a series of innovative activities that cannot ignore the role of talent team building. As the implementers of the enterprise’s technological innovation activities, talents can provide intellectual support for technological innovation and help achieve innovation activities (Tian and Liu, 2022). Innovative talents are the fundamental drivers of knowledge exchange, organizational activities, writing and digital technology applications. This paper reflects the innovative talent index of enterprises using the proportion of research and development personnel and the data sources from the annual reports of listed companies.

(2) Innovation ability

The ability of enterprise innovation permeates all business activities, such as research and development, production and marketing, and is closely associated with enhancing innovation (Li et al., 2022). This paper measures the innovation ability of enterprises by collecting indicators of three dimensions of innovation input, innovation output and innovation efficiency, performing the entropy weighting method to give a comprehensive score. We measure innovation input by the proportion of R&D investment to revenue; measure innovation output by taking the natural logarithm of the number of patent applications filed
by the enterprise in the current year; the formula for measuring innovation ability is $\text{Ln} \left( \frac{\text{number of patent applications by the enterprise in the current year}}{\text{R&D expenses over the past three years/total assets at the end of the period}} \right) + 1$, with specific data sources from the Guotai An database and the annual reports of listed enterprises.

(3) Intelligent facilities

As an essential aspect of the “new infrastructure” of intelligence, the enhancement of intelligent infrastructure construction is a critical driver for empowering the economy and society, providing a strong impetus for expanding the digital economy industry and accelerating enterprise intelligentization. The interview transcripts of enterprises responding to investor inquiries on the construction of enterprise infrastructure reflect the level of confidence that enterprise managers have in their intelligent infrastructure construction. This paper analyzes and mines the interview transcripts of enterprises answering investor questions, carries out a sentiment analysis on the subjective text of the points and answers given by enterprises and helps to clarify the views and attitudes of the management towards the current enterprise infrastructure construction, understand the emotional tendency of the management towards the construction of enterprise infrastructure and provide important intelligence support for evaluating the construction level of enterprise infrastructure and decision-making (Ming, 2012).

This study employs text sentiment analysis to measure each enterprise’s intelligent facilities construction level. Specifically, we preprocess, train and predict the interview text content using the snownlp algorithm to obtain sentiment scores. These scores can reflect the level of satisfaction and support that the enterprise management holds for the current infrastructure construction. A higher sentiment score implies a higher level of satisfaction and support, which indicates a higher level of intelligent infrastructure construction in the enterprise.

4.2.3 The relationship platform. The paper primarily characterizes organizational activity by analyzing the cooperation relationship between core enterprises and other entities (Yang et al., 2020). Listed companies often use the release of company news with the government, other companies, research institutions, etc., to expand their influence. Therefore, this paper collects news reports of cooperation events of sample companies and distinguishes the news content to identify the corresponding variable indicators.

(1) Political connection

In the digital innovation ecosystem, political connections are among the most important social capital and play an important role in innovation activities (Lin et al., 2017). There is inevitably resource interaction in the digital innovation ecosystem of enterprises, and the uncertainty brought by digital innovation based on emerging technologies also depends on a series of political connection activities such as government policy support, resource supply, product procurement and other political connections (Yang et al., 2020). Based on the above analysis, this paper constructs a set of keywords for retrieving political connection news for subsequent news retrieval.

(2) Strategic alliance

A strategic alliance is a long-term joint and cooperative agreement in any equity or non-equity form of shared risk and shared benefit between two or more economic entities (generally referred to as enterprises, but also applies if certain departments within a business reach an alliance agreement) to achieve specific strategic goals. Based on the understanding of the concept of strategic alliance, this paper constructs a keyword set for retrieving news about strategic alliance cooperation.
By retrieving the above two keyword sets, this paper uses Python to crawl relevant news data from domestic mainstream news websites and the news dynamic sections of each company’s official website from 2018 to 2021. It performs Boolean algebra operations on the headlines to filter out key news that meets the criteria. After the screening, we conduct a manual review to select relevant news that meets the criteria. Since news information is difficult to quantify completely, this paper measures the value of each respective variable using the number of relevant news events.

4.2.4 The financial platform. As a structural entity established to obtain funding to meet the financing needs of businesses for their development, the financial platform provides convenient support for their overall financial and investment needs. This paper subdivides the external layer variables under the financial platform into solvency, operational capacity and growth ability. Each dimension obtains the final ability index by setting specific variables and using entropy weighting to assign scores. The data source comes from the CSMAR database, annual reports of listed companies and the Wind database.

(1) Solvency
The strength or weakness of a company’s solvency directly affects its business performance. It will further magnify the company’s financial risks in a business environment where the company uses debt for operations, which in turn affects the development of the business. Therefore, the strength or weakness of a company’s debt-repaying ability is particularly important in the current complex and diverse market environment (Ji, 2021). This article takes cash, equity and interest coverage ratios as secondary indicators for calculating solvency and uses the entropy method to comprehensively score and obtain the evaluation index for solvency.

(2) Operational capability
Digitalization has shortened the time and spatial distance in the external environment and changed how elements are connected (Zhu et al., 2021). By reasonably designing the operation strategy of the digital innovation ecosystem and improving the operation capability, enterprises can gain competitive ecological advantages. This paper selects the accounts receivable turnover rate, total asset turnover rate and inventory turnover rate as the secondary indicators of enterprise operational capability, using the entropy value method to score the enterprise’s operational capability.

(3) Growth ability
Enterprise growth ability is essential for evaluating enterprises, as it reveals their development status. This paper selects earnings per share and operating profit growth rate as the peripheral variables for measuring growth ability, uses the entropy value method to weigh the scores and calculates a comprehensive index that measures the strength of the enterprise’s growth ability.

4.2.5 Intelligent maturity. With a focus on measuring the level of enterprise intelligence, the current research on the measurement of manufacturing intelligence is relatively scarce, lacking a comprehensive evaluation index system. Existing studies have analyzed the impact of intelligent manufacturing on technological innovation and productivity within a specific scope, using industrial robots as the representative variable (Acemoglu and Restrepo, 2020). Meanwhile, other studies aim to construct an indicator evaluation system for the intelligence of the manufacturing industry and conduct analysis and demonstration. In terms of constructing the indicator system, existing literature mainly combines industrial benefits with key technologies to measure indicators (Li, 2020), indicating that the current understanding of the level of manufacturing intelligence mainly focuses on the penetration
of key technologies and industrial benefits, suggests that intelligence is a technological and economic paradigm for achieving industrial development. Therefore, there is a need for a comprehensive and systematic evaluation index system to measure the level of enterprise intelligence in manufacturing.

Based on the literature review in the previous section, this article aims to construct an evaluation index table of enterprise intelligent maturity indicators to measure the intelligent maturity of the enterprises under study. Manufacturing intelligent refers to the development and advancement of intelligent manufacturing, relying on the current status of the development of intelligent manufacturing in the high-end equipment manufacturing industry (Ji, 2021); intelligent means the gradual realization of intelligent production methods in the entire industry. Improving the basic elements is the foundation for the transformation of intelligent manufacturing in the manufacturing industry. Applying related technologies is the key to promoting the intelligent upgrading of the manufacturing industry, and the ultimate goal of intelligent manufacturing is to improve enterprise efficiency (Li, 2020). Considering the characteristics and development trends reflected by enterprise intelligence, this article starts from the development status, technology level and performance output to construct the basic elements, technology development application and comprehensive performance output as the first-level indicators. Then, the second-level indicators and specific variable measurements are determined based on each first-level indicator’s coverage range and content.

Among them, the basic elements construction dimension includes the information degree in the current high-end equipment manufacturing industry, the current capital layout of enterprises and the education level of employees; the technology development application dimension includes the investment status of intelligent equipment, the level of informatization construction and the current intelligent construction projects of the enterprise; the comprehensive performance output dimension covers both economic performance and social performance. Table 1 shows the specific indicator descriptions.

5. Results
5.1 Calibration
Before conducting empirical analysis, this study employed the direct calibration method to transform multiple antecedent conditions and one outcome variable into fuzzy set membership scores. Specifically, we used the SPSS software to set fully non-membership,
crossover and full membership points based on each variable data’s 25%, 50% and 75% percentile; the raw variable data was then automatically transformed into fuzzy membership degree values ranging from 0 to 1 for fsQCA analysis. Table 2 describes the measurement indicators and anchor points for all conditioning variables.

5.2 Necessity analysis
In the fsQCA research method, consistency is the important criterion for testing the necessary conditions of variables. If the consistency of an antecedent condition is greater than 0.9, the antecedent condition is necessary for achieving a specific result and must be established when the result occurs. Table 3 shows the results of the fsQCA antecedent

<table>
<thead>
<tr>
<th>Antecedent variable</th>
<th>Fully-membership</th>
<th>Crossover</th>
<th>Fully non-membership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patent licensing</td>
<td>0.592</td>
<td>0.344</td>
<td>0.219</td>
</tr>
<tr>
<td>Technology R&amp;D</td>
<td>54.750</td>
<td>26.500</td>
<td>6.000</td>
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<tr>
<td>Innovative talents</td>
<td>0.401</td>
<td>0.277</td>
<td>0.186</td>
</tr>
<tr>
<td>Innovation ability</td>
<td>0.831</td>
<td>0.680</td>
<td>0.474</td>
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<tr>
<td>Intelligent facilities</td>
<td>4.496</td>
<td>2.916</td>
<td>1.438</td>
</tr>
<tr>
<td>Political connection</td>
<td>2.000</td>
<td>1.500</td>
<td>1.000</td>
</tr>
<tr>
<td>Strategic alliance</td>
<td>17.750</td>
<td>8.500</td>
<td>1.750</td>
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<tr>
<td>Solvency</td>
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<td>1.831</td>
</tr>
<tr>
<td>Operational capability</td>
<td>2.023</td>
<td>1.515</td>
<td>1.085</td>
</tr>
<tr>
<td>Growth ability</td>
<td>0.692</td>
<td>0.338</td>
<td>0.016</td>
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<td>3.208</td>
<td>1.979</td>
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Source(s): Table by authors

<table>
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<th>Antecedent condition</th>
<th>Consistency</th>
<th>Coverage</th>
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</thead>
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<td>0.708</td>
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<tr>
<td>Innovative talents</td>
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<td>0.446</td>
</tr>
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<td>~ Innovative talents</td>
<td>0.648</td>
<td>0.694</td>
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<tr>
<td>Innovation ability</td>
<td>0.581</td>
<td>0.615</td>
</tr>
<tr>
<td>~ Innovation ability</td>
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<td>0.545</td>
</tr>
<tr>
<td>Intelligent facilities</td>
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<td>0.494</td>
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<tr>
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<td>0.609</td>
<td>0.658</td>
</tr>
<tr>
<td>Political connection</td>
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<td>0.649</td>
</tr>
<tr>
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<td>0.701</td>
</tr>
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<td>0.614</td>
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<tr>
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<td>0.567</td>
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<td>Solvency</td>
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<td>0.531</td>
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<td>Operational capability</td>
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<tr>
<td>Growth ability</td>
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<td>0.561</td>
</tr>
<tr>
<td>~ Growth ability</td>
<td>0.578</td>
<td>0.629</td>
</tr>
</tbody>
</table>

Source(s): Table by authors

Table 2. Calibration of each antecedent condition

Table 3. fsQCA necessity analysis results of antecedent conditions
5.3 Conditional configuration path analysis

The key to configurational analysis is to reveal the sufficiency of different combinations of antecedent conditions forming different configurations to produce different results and to combine each condition into a causal configuration path (Man and Liu, 2022). The criterion for assessment is the level of consistency, and existing research proposes a consistency threshold of no less than 0.75 (Ragin, 2008). In line with previous research and the specific context of this study, a consistency threshold of 0.8, a frequency threshold of 1 and a PRI threshold of 0.75 were chosen during the truth table construction process. The criteria are reinforced by constructing the truth table and subsequent analysis, allowing for the identification of parsimonious, intermediate and complex solutions. This study primarily focuses on intermediate solutions while considering parsimonious solutions to identify core and marginal conditions.

Table 4 presents the results of the overall configuration analysis; it shows four configuration analysis paths for high-end equipment manufacturing enterprises to achieve intelligent development in their digital innovation ecosystem. In this paper, inspired by Ragin’s presentation of QCA results (Ragin, 2008), “●” is used to represent the condition variable as a core condition, “•” represents the condition variable as a marginal condition, “⊗” and “⊗” indicate that the condition variable does not exist and a blank space indicates that the condition variable is not important.

The results of Table 4 indicate four paths for high-end equipment manufacturing enterprises to improve their intelligent maturity. The overall consistency of the solutions is

<table>
<thead>
<tr>
<th>Antecedent condition</th>
<th>Path1</th>
<th>Path2</th>
<th>Path3</th>
<th>Path4</th>
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</thead>
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<tr>
<td>Patent licensing</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Technology R&amp;D</td>
<td>•</td>
<td>•</td>
<td>●</td>
<td>●</td>
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<td>Innovative talents</td>
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<td>•</td>
<td>•</td>
<td>•</td>
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<td>Intelligent facilities</td>
<td>●</td>
<td>●</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Innovation ability</td>
<td>●</td>
<td>●</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Political connection</td>
<td>●</td>
<td>●</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Strategic alliance</td>
<td>●</td>
<td>●</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Solvency</td>
<td>●</td>
<td>●</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Operational capability</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Growth ability</td>
<td>●</td>
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<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Consistency</td>
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<td>0.810</td>
<td>0.735</td>
<td>0.791</td>
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<td>Coverage</td>
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<td>0.111</td>
<td>0.086</td>
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<td>Unique coverage</td>
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<td>0.087</td>
<td>0.071</td>
<td>0.007</td>
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<tr>
<td>Solution consistency</td>
<td></td>
<td></td>
<td>0.804</td>
<td></td>
</tr>
<tr>
<td>Solution coverage</td>
<td></td>
<td></td>
<td>0.263</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Intelligent configuration path of high-end equipment manufacturing enterprises

Source(s): Table by authors
0.804, which is greater than 0.8, indicating that the solution paths have good explanatory power. Each combination has substantial explanatory power for the intelligence development of high-end equipment manufacturing enterprises; we will provide a detailed description of the configuration paths for each group.

Configuration path 1 is an innovation-oriented, relational type. Path 1 indicates that the more a company focuses on technology research and development of its technological platform, the larger the scale of its internal R&D personnel and the more active its communication and cooperation with the government and other members of strategic alliances, the more mature and complete the company’s level of intelligent maturity. Among them, the proportion of innovative talents is the core condition, and the level of technology R&D, political connections and strategic alliances are marginal conditions. This path can explain 11% of the intelligent development cases of high-end equipment manufacturing companies, with Guangdong Topstar Technology Co., Ltd. being a representative company.

Configuration path 2 is an innovation and relationship-oriented, balanced type. Path 2 indicates that enterprises actively engage in the research and development of digital technology applications, improve their innovation level in terms of personnel, infrastructure construction and capability, and enterprises with high political relevance, close cooperation between political alliances, high debt repayment and operational capability, have a higher level of intelligent maturity. The proportion of innovative talents, solvency and operational capability are core conditions, while the rest are peripheral. This path can explain 11.1% of the intelligent development cases of high-end equipment manufacturing enterprises, with representative enterprises being Zoomlion Heavy Industry Science & Technology Co., Ltd. and Shanghai Huace Navigation Technology Ltd.

Configuration path 3 is a financial support type. Path 3 indicates that close cooperation with government departments, strong political affiliations and outstanding operational capabilities of companies will contribute to developing and applying the company’s intelligent maturity. Operational capability is the core condition, and the political connection is the marginal condition. This path can explain 8.6% of the intelligent development cases of high-end equipment manufacturing enterprises, of which the representative enterprise is China Fangda Group Co., Ltd.

Configuration path 4 is a relationship-driven, balanced type. Path 4 indicates that enterprises with a high proportion of technical personnel actively participating in technology research and development with a certain level of innovation capability, close political relationships, close cooperation with political alliances and good operational capability can often achieve a leapfrog development of intelligent. Innovative talents and operational capability are core conditions, while the others are marginal. This path can explain 5.4% of the intelligent development cases of high-end equipment manufacturing enterprises, with representative enterprises such as Beijing UniStrong Science & Technology Co., Ltd.

6. Discussion
This article investigates how to make high-end equipment manufacturing companies more intelligent in the context of rapid digital technology development and the rise of emerging industries. By considering the unique structural characteristics of high-end equipment manufacturing companies, this paper establishes a “three-tier core-periphery” framework for operating a digital innovation ecosystem to explore how the various elements within the ecosystem can collaboratively influence a company’s level of intelligence. The research findings indicate that these elements interact, collaborate and collectively impact the intelligence level of companies, resulting in four representative pathways for the intelligence development of high-end equipment manufacturing enterprises.
The key combinations of these pathways differ due to factors such as a company’s business positioning and operational strategies, which are influenced by companies’ relatively high level of autonomy in China’s market-oriented economic system. Additionally, factors like technology R&D, political connections, strategic alliances and operational capabilities play pivotal roles in most of these pathways, aligning with China’s high-end equipment manufacturing industry conditions. Government support for the high-end equipment manufacturing sector, technological collaborations and China’s leading position in various fields encourage companies to seek breakthroughs in their journey toward intelligence transformation. Simultaneously, the widespread application of digital technologies accelerates the process of intelligence enhancement for these companies.

In conclusion, the empirical findings of this study align with the actual situation in China’s high-end equipment manufacturing industry, further emphasizing the research value of this paper. Although these conclusions are drawn from the Chinese context, we believe that the theoretical model of this framework and pathways holds universal applicability and can offer valuable insights for high-end equipment manufacturing companies in other countries and industries. The development of digital technology and emerging industries is a global trend, requiring adjustments and optimizations based on local policies, market conditions and corporate strategies.

7. Theoretical contribution
Firstly, this article closely follows the current practical issues in the manufacturing industry that urgently need to realize intelligent transformation and development and focuses on how each component element in the digital innovation ecosystem of high-end equipment manufacturing enterprises can improve the effectiveness of enterprise intelligent development. Most existing research involves the overall analysis of the intelligent manufacturing industry, focusing on the impact of single elements, such as technological innovation and intelligent technology, on the overall intelligent transformation of the manufacturing industry. This article conducts a more targeted empirical analysis based on the high-end equipment manufacturing industry, which is more targeted and accurate than previous theoretical studies and systematic analyses.

Secondly, this article is innovative in collecting and obtaining research data. Since obtaining data related to digital innovation ecosystems from mainstream databases is difficult, existing research is mostly limited to theoretical analysis and discussion. This article collects relevant data from public documents of listed companies by crawling and uses text sentiment analysis to filter and process the data to achieve indicator quantification. To a certain extent, it has overcome the dilemma of being limited to theoretical analysis due to difficulties obtaining data in related research fields.

Moreover, our research constructs a “three-tier core-periphery” digital innovation ecosystem framework for high-end equipment manufacturing enterprises. This framework helps to deeply understand the operating mechanism of the digital innovation ecosystem and the cooperation of internal factors. It provides high-end equipment manufacturing enterprises to improve their intelligence and provide new solutions. Referring to the research of Kindermann et al. (2021), the innovation of our study is that we incorporate platform elements such as technology, innovation, relationship and financial into the framework and explore how these elements work together in the digital innovation ecosystem, to drive the intelligent development of enterprises. This achievement enriches the theoretical research on enterprise transformation and development in the digital context. It has important academic and application value for understanding and shaping the practice of intelligent enterprises, further promoting academic development in related fields.
Finally, this article used the configurational analysis fsQCA research method instead of traditional empirical analysis. The traditional empirical analysis mainly explores the one-to-one causal relationship between variables, while in reality, many variable factors affect each other and play a joint role. fsQCA method analyzes the concurrent causal relationship of multiple antecedent conditions from a qualitative perspective, breaking through the limitations of traditional empirical methods.

8. Practical implications

With the rapid development of China’s high-end equipment manufacturing industry, the digital innovation ecosystem and intelligent development have become important trends leading the industry development. Our study provides a way for enterprises to understand the digital innovation ecosystem and emphasizes the importance of synergistic interactions among internal elements for the intelligent development of enterprises.

The research findings of this paper provide new insights and approaches for promoting the intelligent development of high-end equipment manufacturing enterprises, which are of significant guidance. The research conclusions offer practical implications for local governments and enterprise managers, especially those actively promoting infrastructure construction, facilitating the intelligent transformation and upgrading of local manufacturing industries and striving for the intelligent development of enterprises.

Our research findings indicate that factors such as government support and investment, as well as cooperation among enterprises, significantly impact the intelligent development of firms. It highlights the need for policymakers to consider optimizing these factors when formulating relevant policies to promote enterprises’ intelligent development better. Additionally, policymakers should also play a leading and supportive role in developing the application capabilities of enterprises, which will help improve the overall competitiveness of the country and the industry.

For enterprise managers, our research findings reveal the necessary conditions for the intelligent development of enterprises, including aspects such as technological research and development and infrastructure construction. It provides managers with a new approach to understanding and harnessing digital technology to drive the intelligent development of their enterprises, helping them formulate and implement relevant strategies and policies more effectively. Furthermore, by understanding and applying our research findings, businesses can allocate resources more efficiently and improve the success rate of digital transformation.

References


Appendix

![Diagram of core-periphery model](source)

**Figure A1.** Structural framework of the "core-periphery" model

**Source(s):** Figure courtesy of Zhao and Zeng (2014)
References (Appendix)


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